CIRCULAR IMPACTS

Phosphorus Recycling from Manure

A Case Study on the Circular Economy

Funded by the European Union

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Abstract

In this case study paper, phosphorus recycling from manure is discussed, with a special focus on the recycling process developed by the BioEcoSIM consortium. We analysed phosphorus flows globally, at a European level and on a national level, with a focus on the Netherlands. In the Netherlands, as in some other regions in Western Europe, there is excess supply of manure due to intensive livestock production. The oversupply, combined with legislation, generates a negative manure price. This negative manure price creates the business case for BioEcoSIM and other manure processing techniques. The BioEcoSIM technique processes manure into phosphorus and nitrogen fertilizer as well as an organic soil improver or biochar. By extracting from manure the useful components, transport costs are reduced. Furthermore, greenhouse gas emissions and particulate matter formation are decreased. However, since manure is already almost completely recycled on arable and pasture land, the effect on phosphorus flows is limited. The EU phosphorus flows show that the main losses of phosphorus in the food sector are through sewage sludge, other waste water and food waste, and not through manure. Nonetheless, losses of phosphate from manure do have a high environmental impact, since it causes eutrophication. This paper shows also what the macroeconomic consequences of phosphorus recycling from manure will be.

Table of Contents

Executive Summary

In the project CIRCULAR IMPACTS, the macroeconomic and societal impacts of the circular economy are investigated. The context for this analysis is the European Semester, a governance framework of the European Commission to coordinate policies among the European countries. In order to get a better grasp on the mechanisms at stake, four case studies are investigated more in-depth. The case study discussed in this paper is on phosphorus recycling from manure, with a special focus on the technique developed in the EC-funded project BioEcoSIM. Because the case study must be relevant in the context of the European Semester, a national and macroeconomic focus is chosen.

The element phosphorus (P) is essential for life and is used to make phosphate fertilizer, one of the three main mineral fertilizers. It is an irreplaceable part of modern agriculture. Phosphate rock is on the EU list of critical raw materials. In order to get a grasp on the use of phosphorus and current recycling and losses of phosphorus in agriculture and food, we analyse phosphorus flows globally, at a European level and on a national level, aimed in particular at the Netherlands. The EU phosphorus flows show that the main losses of phosphorus in the food sector are through sewage sludge, other waste water and food waste. Phosphorus in manure is almost completely recycled on arable and pasture land. Losses from the fields or from stables are relatively minor, although they have a high environmental impact.

However, In the Netherlands and some other regions in Western Europe, the use of manure of intensive livestock resulted in accumulation of phosphorus in the soil, generating environmental problems. This resulted in national and European legislation to avoid overuse of manure, implying that less manure could be used for soil fertilization within the region. This impied excess supply of manure in the Netherlands and some other regions in Western Europe that has to be exported to other regions. The high transport costs imply that the livestock farmer has to pay to get rid of the manure, i.e. a negative manure price emerged. This negative manure price creates the business case for BioEcoSIM and other manure processing techniques that are only profitable with a negative manure price. BioEcoSIM processes manure into phosphorus and nitrogen fertilizer as well as an organic soil improver or biochar. By splitting manure in useful components, transport costs as well as greenhouse gas emissions and particulate matter formation as a consequence of storage and transport of manure are reduced compared with long distance manure of transport and to a lesser extent manure separation and drying. In summary, environmental policies are the forces behind long distance transport of the minerals and create business opportunities for BioEcoSIM as well as other techniques that reduce transport costs like manure separation and manure drying.

When thinking about different scenarios, the most obvious one is to extend the business model of BioEcoSIM to process all excess manure in the Netherlands according to this process (we focus on one country because of the national focus of the European Semester) and compare this with current processing and transport of manure. Because efficient use of manure recycling is already required by law, business opportunities in technologies to split manure in different fertilizers (like BioEcoSIM) will have no or minor consequences for the demand for mineral phosphorus in the EU.

In the impact assessment, mainstreaming BioEcoSIM for all excess manure is compared with the current situation. This results in a small increase in GDP of 15 million euro

because of the lower costs (assuming that the calculations by the BioEcoSIM consortium are right). As far as the new technologies reduce particulate matter formation in relatively densely populated areas in the Netherlands, the new technologies may have benefits with respect to health and therefore less absence at work due to sickness. This implies an increase in effective employment (not a reduction in the unemployment rate), and therefore also an increase in GDP. This is not calculated.

Furthermore, we have calculated the increase in welfare based on the benefits with respect to the environment, all based on the LCA made by the BioEcoSIM consortium. Mainstreaming BioEcoSIM reduces greenhouse gas emissions by 1.4 MT CO_2-eq, resulting with a price of 60 euro per ton CO_2eq in a benefit of 8.7 mln euro. It results also in a benefit of 1.5 KT PM10 equivalent particulate matter formation, which can be valued based on a price of 45 euro per kg PM10 on 67 mln euro. So, the total welfare benefits of mainstreaming the BioEcoSIM process for all manure exports of the Netherlands are about 91 million euro.

The calculations above show the methodology that can be used to calculate Gross Domestic Products (GDP) and welfare effects. However, one must be aware that it crucially depends on the correctness of the LCA en cost calculations made on a micro scale, and that it also depends on prices used for valuation of environmental costs as well as the costs of the new process.

The consequence of the roll out of the BioEcoSIM concept for the current account will be small for the EU as a whole, where it is not clear to what extent this has consequences for the real exchange rate and the interest rate because at least in the short term the technique will require extra investment that may compensate the balance of payment effect of the change in net phosphorus imports.

As far as new technologies reduce cost to process and export manure, the livestock sector may grow further in regions with excess manure supply, given this is allowed for by legislation.

The analysis in chapter 2 shows that recycling of phosphorus from sewage sludge, waste water, food waste and slaughter waste may reduce losses in the phosphorus circular flow significantly and therefore reduce the demand for mineral phosphorus. For example a simulation exercise shows that if over-application of phosphorus in the soil, losses from sewage sludge and losses from slaughter waste in the EU would be reduced by 90%, then European phosphorus fertilizer use would be reduced by 94% compared with that in 2015, while the Netherlands would have net exports of phosphorus fertilizers that are 12 times the amount of phosphorus fertilizer net imports in 2015.

The legislation that requires recycling of manure may also be an example for the legislation for other phosphorus waste flows. An obligation to recycle phosphorus in other flows will, as was the case with manure recycling, increase cost and therefore reduce GDP. The use of secondary phosphorus may have consequences for the environment and will have consequences for the import of phosphorus. This reduces dependency for the EU on an unstable market. Furthermore, the recycling of phosphorus reduces the speed with which phosphorus will become scarcer and therefore may reduce cost and uncertainty in the long term.

A next level of scenario analysis would be to have a more integrated policy analysis, such as the introduction of taxes for externalities and policies for climate. We perform a small calculation exercise to analyse the effect of the introduction of a price of 60 euro per tonne CO_2 emissions and a price of 45 euro per kg PM10 formation for the profitability of BioEcoSIM, consistent with the current insights on external costs. In that case the benefits of processing manure by BioEcoSIM would be increased by 25 euros per tonne of processed manure compared with the current situation. One must be aware that all depends on the validity of the cost price calculations and the LCA results in such a situation as well as the correctness of the prices for the externalities used. Finally, one must be aware that the benefits of a specific business case like BioEcoSIM depends not only on price developments, but also on other developments like the size of the livestock sector in different regions compared with available land and the amount of secondary phosphorus produced from other waste flows. When for example for climate policy in the context of the Paris agreement reduction of the livestock sector is required, a business case like BioEcoSIM may not be profitable anymore.

1 :: Introduction

In the project CIRCULAR IMPACTS, the macroeconomic and societal impacts of the circular economy are investigated. In order to get a better grasp on the underlying mechanisms, four case studies are conducted. This case study paper discusses phosphorus recycling from manure with a special focus on one technique, i.e. the technique developed in the EC-funded BioEcoSIM project.

The element phosphorus (P) is essential for life and is used to make phosphate fertilizer, one of the three main mineral fertilizers. It is an irreplaceable part of modern agriculture (EC 2013) Phosphate rock is on the EU list of critical raw materials (EC, 2014). Phosphorus cannot be substituted or made in an artificial manner. But phosphorus can be recycled, mainly from wastewater (e.g. sewage water), manure and organic waste (e.g. wasted food). In this case study we focus on phosphorus recycling from manure.

The case of phosphorus presents an excellent opportunity to show how a more or less closed circular flow in nature has been replaced by a linear flow by mining phosphate rock for mainly fertilizer production, reducing the need to recycle the phosphorus from human and animal excretion. In order to reintroduce recycling of phosphate, phosphate fertilizers may be produced from sewage sludge or manure. This will decrease the dependence on phosphate rock and diminish environmental damage. The focus of our case study is BioEcoSIM, a concept to transfer pig manure into phosphate and nitrate fertilizers and a product to improve the soil (biochar), arguing that it is circular because phosphorus from manure is transferred back into a product comparable with fossil fertilizers.

In this report we follow the stepwise case methodology as developed in Deliverable 4.1 of the CIRCULAR IMPACTS project (Smits & Woltjer 2017). By following this process during the case study analysis, the developed methodology can be tested and further refined.

This methodology distinguishes the following steps:

Step 1: Defining the baseline

Step 2: Defining the new business case

Step 3: Changes in the key sector

Step 4: Expected effects on other parts of the economy

Step 5: The impact on society

Step 6: Are alternatives available?

Step 7: Policy options

Step 8: Overall conclusions

It has to be emphasized that going from one step to another, we switch from a global to an EU and a national level, and back. In the baseline we describe the flow of phosphorus on a global, European and national (Dutch) level. The business case, i.e. BioEcoSIM, is valorising pig manure which is relevant for regions with oversupply of manure. From the pig manure, among others, phosphorus is extracted which may be sold regionally, but can also be sold on a global market.

In general, we start from a global perspective and zoom in on a specific business case with regional significance, and next we analyse the overall, i.e. macroeconomic, consequences of this business case. It is important to realise that the business case, i.e. BioEcoSIM, is primarily focussed on pig manure valorising.

There are several EU-funded projects that relate to this case study. The publication 'Resource Efficiency in Practice - Closing Mineral Cycles' is based on a project on behalf of DG Environment (EC 2016). The project had a focus on the inefficient use of fertilisers, which on the one hand causes environmental problems in regions with over application, and on the other hand causes a disturbance of natural mineral cycles leading to a shortage of minerals in certain parts of the world. Especially the case study on the province North-Brabant, the Netherlands, is supplementary to the one presented here.

Systemic is an ongoing project (2017-2021) funded under the EU Horizon 2020 programme. Its goal is to recover and recycle mineral nutrients like phosphorus (P), nitrogen (N) and potassium (K), along with the production of biogas, from manure, biowaste, sewage sludge and food and feed waste. In this way, dependency from non-renewable phosphorus rock can be diminished, and furthermore a reduction of greenhouse gas emissions, from the production of nitrogen fertilizer, can be achieved. Here is a clear link with the BioEcoSIM project, though Systemic has a broader scope than only manure.

The Run4Life project is also an ongoing project (2017-2021) which receives funding from the EU Horizon 2020 programme. The objective is to recover nutrients from wastewater. The project both implies the development of nutrient recovery technologies, and advocates the institutional, legal and social acceptance of these technologies. The case study described here has a focus on nutrient recovery from manure, but we also pay some attention to nutrient recovery from sewage sludge. To this extent, there is a link with the Run4Life project.

In the context of this case study a workshop has been organized, of which the results are taken into account in this report. The agenda and list of participants are included as an annex to this report.

2 :: Step 1: Defining the Baseline

2.1 Phosphorus as a limited resource

Phosphorus rock is on the list of critical raw materials of the EU (European Commission 2014). Phosphate rock is mainly used for fertiliser production, where demand for phosphate fertilizers is expected to increase because of global population and welfare growth and depending on policies also increases in biofuel demand. There are no alternatives for phosphate in agriculture. The (European Commission 2014) sees phosphate rock as having a high supply risk because production is concentrated in a limited number of countries and imports of the EU depend on even a more limited number of countries.

In the short term the limited amount of reserves of phosphorus rock is not a problem. Morocco has most of the phosphorus rock reserves, but also in other regions there is sufficient for the coming decades or centuries (Ridder et al. 2012; Cordell & White 2014; Koppelaar & Weikard 2013). Phosphorus rock reserves are about 60 GT (gigatonne), equivalent with 8 GT phosphor, while production is in the order of magnitude of 22.8 MT (megatonne) phosphor per year, i.e. 0.3% of the reserves (Koppelaar & Weikard 2013).[1] If you include expected growth in demand because of population growth, change of diets towards livestock products and increase in biofuel production current reserves are sufficient for somewhere between 100 and 200 years, while it is very plausible that in between economic useful reserves will increase because of new explorations and because of technological change. The cost of mining may increase because first the most easy reserves with the smallest amount of pollution with for example cadmium and radioactive uranium may be mined (Cordell & White 2015; Cordell & White 2014), but technology will also improve, reducing the cost of mining. Koppelaar & Weikard (2013) suggest that phosphate rock mining cost for current and potential reserves are between 100 and 300 dollars per tonne phosphate rock (with current price around 200 dollars per tonne), where sufficient phosphate rock seems to be available till 2120 or later. This may put an upper limit to long term phosphate fertilizer prices.

The EU depends for 90% on import of phosphate rocks (European Commission 2017). Within the EU only Finland has some phosphate rocks. The list of supplying countries (Morocco/Western Sahara, Russia, Syria, Algeria, Israel, Jordan and Egypt, are the most important ones) shows that it remains a small number of countries with relatively high geopolitical risks that supply phosphate rock to the EU (European Commission 2017). The price spike of phosphate rock in 2008 showed the instability of the phosphate rock market, but even this large shock had limited consequences for the sector, because the share in total cost of food production in the EU is very small and because large accumulated stocks of phosphorus in soil have been build up over time, implying that for large parts of agricultural land a severe reduction of phosphorus use is possible without reducing crop yields (European Commission 2017). This is fundamentally different for regions like sub-Saharan Africa, where soil is poor in phosphate (Cordell & White 2014).

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[1] This number was much lower till 2009 because estimates for phosphate rock in Morocco have been updated from 5.6 GT towards 51 GT based on a literature study (Cordell & White 2014).

More than 70% of the present known global reserves of phosphate rock are located in Morocco, of which 10% in the contested part called Western Sahara (Chaudhary & Kastner 2016; Kasprak 2016; Cordell & White 2014). Thirty-five percent of phosphorus rock imports by the EU comes from Morocco (European Commission 2017). Morocco controls (the main part of) Western Sahara that was till 1975 Spanish territory, but this is strongly contested especially by the separatist movement The Polisario Front (Kasprak 2016; Ridder et al. 2012, p. 48). At the moment production is not consistent with the availability of reserves: China is at this moment the main producer with 44% market share but only 5% of reserves, while Morocco has only a market share of 13% with 73% of global reserves (European Commission 2017). Therefore, when other country's domestic reserves of phosphate become more costly to extract in the coming decades, Morocco may get a phosphate rock monopoly more than OPEC, the Organization of the Petroleum Exporting Countries, has over oil (Kasprak 2016; Shelly 2004). Furthermore, the tendency to vertical integration of phosphorus rock and fertilizer production, the large role of state owned phosphorus rock producers, as well the tendency towards further concentration of the phosphorus fertilizer industry may pose further risks to phosphorus supply to the EU (Ridder et al. 2012).

The main short term problem with respect to phosphorus seems not phosphorus scarcity, but leakage into the environment (Buckwell & Nadeu 2016) and geopolitical uncertainty of supply (Ridder et al. 2012). When phosphorus is recycled, more resources become available for the fertilizer business and this will improve resilience. As formulated by the European Commission: "Aside from price issues, the major economic advantage of using recycled phosphorus is in terms of resilience – consistent flows, sourced locally, and without the price volatility of phosphate rock." (EC, 2013, p. 13)

2.2 Phosphorus prices and price elasticity

In 2008, the price of phosphorus rock increased with 700%, while in 2009 it returned to a price that was about double the price before 2008 (Mew 2016). Insights about the fundamental cause of the 2008 price spike differ. Ridder et al. (2012, p. 38) see the increase in wheat prices as the main cause. EC (2013, p. 8) refer to China imposing an export duty on phosphate rock. However, Chinese exports were already a small part of total phosphate exports before. Khabarov & Obersteiner (2017) see the doubling of phosphorus fertilizer imports by India (as the consequence of a production problem in India) as the main cause of the price spike in 2008. The price shock was magnified by protective trade measures, and the Indian fertilizer subsidy scheme that compensate price fluctuations on the international market making demand completely inelastic (Khabarov & Obersteiner 2017).

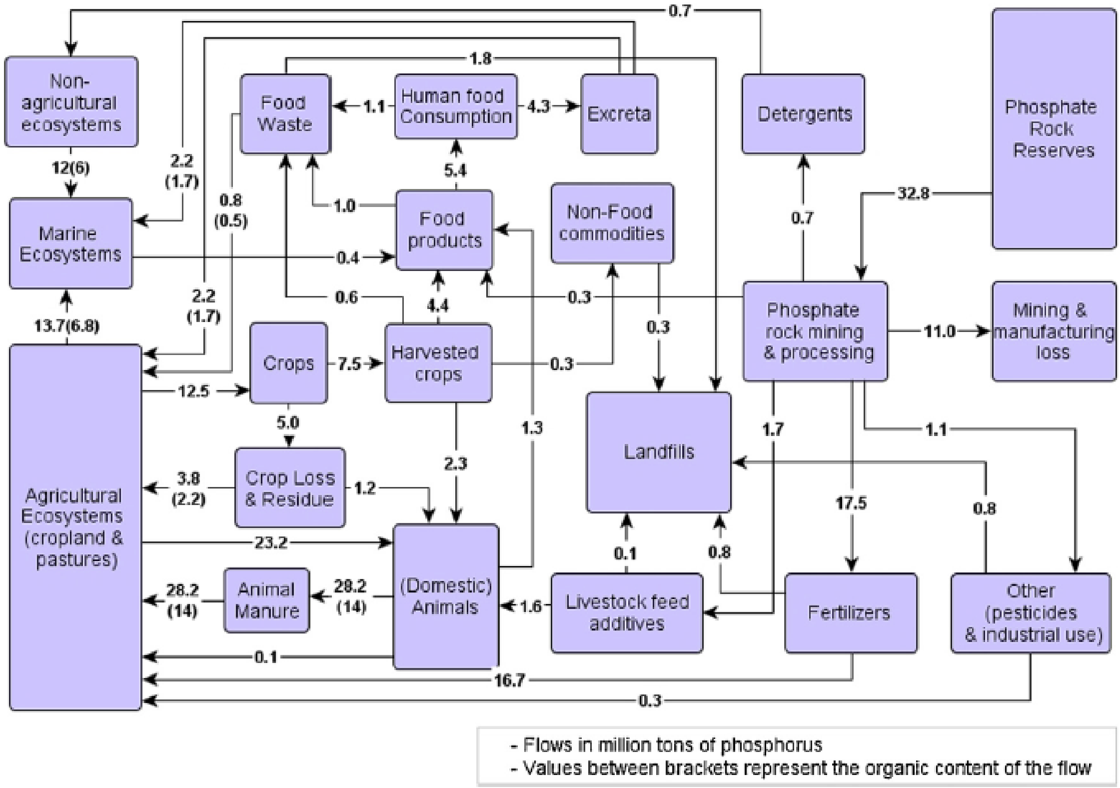
Koppelaar & Weikard (2013, p. 1461) suggest that the high prices of 2008 did influence only a small share of phosphate fertilizer producers because 70% of them are vertically integrated with the mining industry. Excess of phosphorus fertilizer accumulates mainly in the soil and can be used by plants in succeeding years. Therefore, the price elasticity of demand is relatively large for regions with accumulated phosphorus in the soil like Western Europe.

In summary, it is not very plausible that long term equilibrium prices will rise significantly in the coming decades. However, the low supply elasticity of phosphate rock combined with inelastic demand for some regions in the world, especially with political instability in supplying regions, may increase the risk of large price fluctuations of phosphorus fertilizers in the short term.

2.3 Global phosphorus flows

In order to get an insight into the possibilities for phosphorus recycling phosphorus flow charts can be very useful. Figure 1 below gives an insight into the phosphorus flows on a global level for 2009.

Figure 1: Global Phosphorus flows in 2009 (Source: Koppelaar & Weikard 2013).



Of all mined and processed phosphate rock in 2009 (32.8 million tons of phosphorus) more than a third is lost during the mining and manufacturing process (11.0 MT), more than half is turned into fertilizers (17.5 MT), and some phosphate rock is used for additives in livestock feed (1.7 MT) and food (0.3 MT). In total 19.5 MT of phosphorus per year goes into the agricultural system.

Almost all fertilizer goes into cropland and pastures (16.7 MT). There is a circular flow of phosphorus between agricultural ecosystems (cropland and pastures), and (domestic) animals and animal manure, but more phosphorus goes from animals to agricultural land (crops and pastures, 28.2) than the other way round (23.2). Because of oversupply of manure and fertilizers on crop- and pastureland quite some phosphorus goes into marine ecosystems (13.7), where it is lost. 15.2 MT[2] is stored in agricultural land, while 12.5 + 23.2= 35.7 MT goes into crops and animals. Please note that also 12 Mt of phosphorus flows from non-agricultural ecosystems into marine ecosystems.

An important leakage is landfills, which in this figure adds up to 3.8 million tonnes in 2009. However, within the EU, the Landfill Directive (1999) requires that from 2016

[2] Calculated from all inflows and outflows of agricultural land

onwards the use of municipal biodegradable waste for landfill is reduced gradually to a maximum of 35% of such waste produced in 1996.[3]

Leakages of phosphorus are more and more avoided. With respect to sewage sludge 42% is returned to the soil after stabilization, but application is in most cases not consistent with plant requirements. The problems involved are transport costs, insufficient knowledge on nutrient composition and concerns about pathogenic contents (Buckwell & Nadeu 2016, p. 10). Current techniques used to recover phosphorus from sewage sludge are in most cases only in an experimental phase, and as far as operational have a low phosphor recovery rate of about 30% (maximum 40%) in the form of struvite or sludge dewatering, where struvite is mainly produced to prevent problems with the pipe system, not phosphorus recovery. New techniques with recovery rates of 70-95% are available, but require mono-incineration (i.e. incineration of sludge without other waste) and further investment in the techniques is needed to make them operational (Buckwell & Nadeu 2016, p. 10). Ruijter et al. (2015) analyse the current flows in the municipal waste treatment sector, where recovery rates vary between 0 and 100%. However, in the whole waste water treatment sector only 0.2 Mt P from the 13.1 is recovered, and the rest is going to landfill and cement (80%) and water (20%).

2.4 EU phosphorus flows

Van Dijk et al. (2016) analyse phosphorus flows for the EU27 in 2005. Agricultural land is fertilized with 1389 KT (kilotonne per year) of phosphorus, 1749 KT phosphorus from manure, and 157 KT phosphorus from other recycling. Of this input of 3295 KT phosphorus 842 KT goes into food processing, 1460 KT into animal feed (of which 1023 KT roughage), and 924 KT is stored in the soil. 84 KT is lost, half by leaching and drainage, half by runoff and erosion. So, loss on agricultural soil was only 2.5% of total phosphorus input, in 2005.

Accumulation has a negative impact on the environment in regions with excess supply of manure. Stricter fertilizer and manure regulation has been implemented to reduce the problems of phosphorus accumulation in the soil. As a consequence, the gross nutrient balance for the EU has been halved from 700 KT to 325 KT between 2005 and 2013 (Eurostat), by reducing mineral fertilizer use with 300 KT (mainly in the EU15) and reducing phosphorus in manure with 105 KT between 2005 and 2013 (Eurostat), while nutrient use by harvested crops has increased with about 50 KT (but the last is not significant because the conclusion changes with different pairs of years).

For animal production, total phosphorus input is 2370 KT, of which 1048 KT roughages, 437 from feed crops, 438 KT is imported through animal feed, 481 KT comes from food processing (mainly compound feed), and 250 KT from feed additives, while 553 KT is supplied to the food processing sector.

The EU is a net importer of phosphorus in animal products (15 KT). With respect to crops (excluding animal feed) the balance is about 8 KT Phosphorus net imports.

Losses from stables equal about 60 KT, which is small compared to the losses from food processing (339 KT, of which 293 KT slaughter waste and the rest solid waste), while losses from the consumption sector are 655 KT, including 227 KT sewage sludge, 130 KT waste water and 160 KT food waste.

[3] Council Directive 1999/31/EC on the landfill of waste

If we have a different look at the flows, one may see that 1389 KT is coming in the EU as fertilizer, 249 KT as feed additives, 189 KT as plant-based animal feed and 27 KT as inorganic food additives. One must conclude that in the EU the net phosphorus import is mainly translated into losses after consumption (655 KT), slaughter waste and solid waste in food processing (325 KT). Losses from stables and loss from agricultural land are relatively minor (in total about 105 KT), although they may have large environmental consequences. Accumulation in the soil was 924 KT in 2005, but has halved since, with a better spread over the regions with low phosphorus stock than before, of which 260 KT through less use of inorganic fertilizers (Eurostat).

2.5 Dutch phosphorus flows

Because the Netherlands has a severe manure problem, and therefore phosphorus oversupply, it may be interesting to have a special look at the Dutch phosphorus flows, again for 2005 based on van Dijk et al. (2016). Twenty-two KT is imported as fertilizer, 23 KT as animal feed (net imports), 7 KT as mineral feed additives and 3 KT as inorganic food additives.

Seventy-four KT of phosphorus in manure is recycled from animal production to crop production, and 3 KT of phosphorus is recycled from food processing and consumption into crop production. Fourty KT of phosphorus goes from food processing and consumption to the animal sector (of which 38 KT compound feed: see Smit et al. (2015)).

Through net imports of crop-based products the Netherlands imports 45 KT phosphorus, and through net exports of animal based products exports 4 KT phosphorus plus 6 KT of manure. Accumulation in soil was about 30 KT in 2005, but was reduced to 2 KT in 2014 (Eurostat), partly by reducing mineral fertilizers from 20 KT to 4 KT and partly by reducing phosphorus in manure applied in the Netherlands from 66 KT in 2005 to 55 KT in 2015 (partly through increasing phosphorus in manure export from 6 to 14 KT) (CBS, Statline).[4]

With respect to phosphorus losses, 20 KT of phosphorus is lost by food processing and 21 KT after consumption, plus 12 KT through pet excreta. The losses from crop and animal production of 3 KT phosphorus are relatively small compared to this, although these losses are important from an environmental perspective.

The Dutch reduction in excess phosphorus use is solved because of legislation, and this legislation generates a negative manure price. This negative manure price generates the business case for more advanced recycling methods of phosphorus in manure as discussed later in this report.

2.6 The Dutch manure problem

Our main theme is phosphorus recycling, since the environmental part of manure over-application is to a large extent solved by European legislation like the Nitrate Directive and the Water Framework Directive. For regions with intensive livestock industry the legislation implies an oversupply of manure: manure production is larger than what can be applied on land. In the section below we describe in short the history of manure oversupply, with a focus on the Netherlands (based on; van Loon (2017), PBL (2016) and Hees et al. (2012)).

[4] For 2005 average of 2004-2006 used, consistent with Van Dijk.

Since the 1970s manure is seen as waste instead of a useful resource, as it was until this period. Until the 1960s the focus of regulation was on safety of use of fertilizers. In 1962 the European agricultural policy focused on protection against cheap import of cereals and in the context of the GATT a compromise was made to have no import tariffs for fodder crops. This stimulated between 1962 and 1990 the import of animal feed through the harbour of Rotterdam allowing expansion of especially pig farming in Southern and Eastern parts of the Netherlands.

Already in 1972 it was mentioned that the manure from intensive farming resulted in soil and water pollution. However, optimism about technological progress from the farmers side prevented further policy intervention. An investment subsidy paid from 1978 onwards stimulated further investments in intensive farming.

In 1984 a proposal for a law limiting further expansion of pig and poultry farming was introduced. However, this law became active in 1987, which allowed farmers to anticipate the law and expand extra in the years before.

In the 1990s mineral accounts to calculate excess manure production and regulatory taxes were introduced next to production restrictions for pig and poultry farming, while a maximum number of cows was set by the European milk quota policy.

In 1991 the EU implemented a Nitrate directive that required preventive policies for nitrate. The Dutch policy did not have explicit norms for animal manure, and therefore policy had to be adapted. User norms for animal manure were introduced, where the Netherlands (and some other countries and regions) got an exception (derogation) for the use of manure on high productive grassland. Over time regulation became more specific but also more complex. The more complicated regulation became, the higher administration cost and opportunities for fraud.

The European Water Framework Directive focuses, among others, on phosphate. Because of these stricter norms a phosphate surplus emerged after 2010. This was not the consequence of more manure production, because this was less than at the end of the 1990s, but because of a stricter policy with respect to phosphate fertilization.

Although legislation is based on average use per hectare and includes also restrictions for the country as a whole, it is sufficiently effective that in the Netherlands almost all phosphorus applied on land is nowadays used for crop growth.

The consequence of the manure policy in the EU is that in several regions a surplus of manure was generated. This implied that a negative manure price emerged, i.e. livestock farmers had to pay to get rid of their manure. As long as local crop farmers can use the manure produced, they have a benefit as long as the price is below the cost price of fertilizer. Solutions to reduce transport cost are sought for, because transport of manure is costly.

In summary, the expansion of the livestock sector is partly determined by the cheap imports of animal feed because of GATT trade agreements. Although problems with pollution as a consequence of manure were already recognized in 1972 and mineral accounts with regulatory tariffs were already introduced in the 1990s, EU legislation restricted the use of manure further and as a consequence several regions saw an excess supply of manure. The manure and fertilizer regulation is a compromise between precision with respect to plant needs and administrative problems because of complexity and risk of fraud.

2.7 Conclusion

Phosphorus is essential to life, and phosphorus fertilizer production from phosphorus rock is important to increase agricultural yields. The surplus of phosphorus used accumulates in soils or is spilled in water. Accumulation in nature and water has negative consequences for the environment. Phosphorus rock production (i.e. mining) has also significant negative environmental effects and requires a lot of water, so reducing these environmental problems may also be a reason to reduce phosphorus fertilizer use.

Phosphorus rock supply in a baseline development is sufficient for the coming centuries, but the concentration of reserves and the almost complete dependence on imports of the EU and other regions in the world create geopolitical supply risks.

The EU phosphorus flows show that the main losses of phosphorus in the food sector are through sewage and other waste water and food waste. To reduce the inflow of phosphorus in the EU (1389 KT fertilizer, 249 KT feed additives, 189 KT plant-based animal feed and 27 KT inorganic food additives) these waste flows have to be recycled. Phosphorus in manure is almost completely recycled, while losses from the fields or from stables are relatively minor, but with a relatively high negative environmental impact. The policies implemented to prevent over-fertilization from manure, show how policies influence recycling of phosphorus from manure, which may be an example for recycling of other parts of the phosphorus flows. EU environmental policies that generated clear environmental benefits, was the background of excess supply of manure in the Netherlands and other regions in the world. This created the business case that will be discussed in the next section.

3 :: Step 2: Defining the New Business Case

3.1 Introduction

We have chosen BioEcoSIM as a case study to investigate the macro-economic and societal consequences of an innovative approach. The BioEcoSIM project, a project consortium with 14 partners from 5 countries, aimed to develop a concept to process pig manure into mineral fertilizers and biochar and to demonstrate its economic, technological, environmental, and social feasibility.[5] The BioEcoSIM case is an interesting case study since it includes an extensive integrated economic, environmental and social impact assessment. The case is also useful from the perspective of the European Commission because the project is funded by EU research funds, and therefore is part of the EU research policy.

3.2 The BioEcoSIM process

In the EU-funded project BioEcoSIM "research and industry developed a technology to convert livestock manure into organic soil improvers and mineral fertilisers", where according to the project coordinator Dr. Jennifer Bilbao the "overall process uses energy-efficient technologies and works on the principle of circular economy."[6] The explicit target of the project is to "valorise pig manure into high value products that can be easily handled, transported, and applied back in the agriculture."[7] The application of the technique reduces energy-intensive ammonia production for nitrogen fertilizer by producing a substitute, reduces EU dependency on phosphate fertilizers, increases water efficiency and reduces the cost of manure disposal for farmers.[8] By recycling mineral and organic components in an efficient manner and by increasing the efficient use of resources (see box 1 of Deliverable 2.1) the project contributes to the circular economy.

The BioEcoSIM process consists of four steps:[9]

- Pre-treatment of raw manure by adding sulphuric acid (H_2SO_4) and separation of the solid and liquid fraction of pig manure
- From the liquid fraction struvite and calcium phosphate (CaP) are produced through phosphorous precipitation
- From the rest of the liquid fraction nitrogen is recovered as ammonium sulphate through absorption and crystallisation
- The solid fraction is dried with superheated steam after which biochar is made via pyrolysis, where the gas fraction is burned to produce electricity and heat for the process.

The last step may also be skipped, implying that the solid fraction is used as a soil improver with a small phosphorus and nitrogen content.

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[5] Fraunhofer, 2016, sheet 7

[6] The EU-funded project BioEcoSIM is led by Fraunhofer IGB, 14 partners (https://www.bioecosim.eu/).

[7] Fraunhofer, 2016, sheet 7

[8] Smeets et al. 2016, p. 7 and Fraunhofer, 2016, sheet 7.

[9] BioEcoSIM, 2015, sheet 6; Fraunhofer, 2016, sheet 8

Based on field experiments the consortium claims that the phosphor product from processed manure is better than fossil phosphor fertilizer, but that at this moment it cannot be easily traded because it is still seen as an animal fertilizer in legislation.[10] Other important outputs are nitrogen fertilizer (ammonia) and either a soil improver or biochar. The split of manure in fertilizers and soil improver has as an advantage that the fertilizers can be exported, while the soil improver can be used locally to keep the soil in good shape. If the soil improver is processed into biochar and synthetic gas then the process may have advantages from a climate perspective because biochar binds carbon for a long period of time than the soil improver.

As inputs in the process pig manure, sulphuric acid (H_2SO_4), potassium hydroxide (KOH) and sodium hydroxide (NaOH) are required (Fraunhofer, 2016, sheet 20, 34). The BioEcoSIM process generates a rest product of water that contains a relatively large amount of potassium which must be cleaned before supplying clean water.

In summary, pig manure can be processed into biochar or soil improver dehydrated ammonium sulphate, struvite and calcium phosphate, where phosphorus recovery from the liquid fraction is more than 90%.

3.3 What process is replaced?

The BioEcoSIM process is not replacing a linear system, because manure is used on land and the European Nitrates Directive (EC, 1991) sets a maximum on the amount of nitrate in manure used per hectare per year. However, timing and the amount of nutrients for the plants has to be adjusted to the needs of the plants instead of the need to get rid of the manure. The fact that farmers on manure producing farms apply more manure on their farms than other farmers suggests already that the application of manure is not optimal from the perspective of plant requirements (Smeets et al. 2016, p. 7). The consequence is inefficient use of the nutrients and over-fertilization in some regions. Furthermore, direct use of manure requires storage of manure which generates ammonia, methane and nitrous oxide emissions. Finally, the composition of manure does not allow for precision agriculture, and therefore fossil fertilizer is still used additionally to manure, even in regions with excess supply of manure.[11]

The BioEcoSIM consortium compares the new business case with three other existing state-of-the-art manure management techniques, i.e. long distance transport, manure separation and manure drying. The BioEcoSIM process is primarily developed to solve problems in regions with excess supply of the nutrients nitrogen and phosphorus. In those regions legislation requires that the manure is used in agriculture or processed to other useful products while limits are set for excessive use of manure on land. Therefore, the BioEcoSIM process is compared with three state of the art substitute techniques selected by the consortium, which are Long Distance transport of raw manure (LD), Manure Drying (MD) and Manure Separation (MS).[12]

In summary, because manure processing is already required in the case of BioEcoSIM it has been chosen to compare this new technique with three existing 'state-of-the-art' techniques for manure management.

[10] Currently the EU is revising legislation.

[11] BioEcoSIM, 2015, sheet 6; Fraunhofer, 2016, sheet 8

[12] Fraunhofer, 2016, sheet 48

3.4 Expected future developments

The process is designed for processing at farm level or a few pig farms in each other's proximity. This minimizes storage and transport cost of the manure and related emissions. Through technological change the process and economies of scale in building the processing units cost may be reduced over time, but it is not clear by how much. The consortium also suggests that economies of scale can be realized by using larger processing units, but that probably the benefits of production efficiency will not compensate for the increased transport and storage costs (Smeets et al., 2016, p. 39).

3.5 Environmental evaluation of the business case

The BioEcoSIM consortium carried out an extensive life cycle analysis[13] of the BioEcoSIM system with biochar production and with soil improver production compared to three state-of-the-art manure management systems. The LCA analyses are based on pig manure with a 6% dry matter, which is roughly the EU average, but perform also a sensitivity analysis for pig manure with 3% and with 9% dry matter. The scope of the LCA includes the environmental impacts of storage, transport and processing of manure and the application of nutrient rich products on agricultural land, including the avoidance of production of synthetic fertilizers.

The LCA evaluation is based on a number of intermediate indicators and three endpoint indicators: human health, biodiversity and depletion of mineral and fossil resources which are integrated in one overall indicator (Smeets et al., 2016, p. 18). In the environmental evaluation no potential rebound effects are included (Smeets et al., 2016, p. 22).

The main environmental effects of manure processing identified in the LCA are the human health and ecosystem effects of climate change, the impact of particle matter formation on human health and depletion of mineral and fossil resources. The BioEcoSIM method has lower particulate matter emissions because it avoids most of the emissions related with storage and transport of manure and products of manure processing. The BioEcoSIM process also reduces the emissions of greenhouse gases, because of lower emissions from manure storage and transport. The emissions decrease further in case of the production of biochar, because of the carbon sequestered in the biochar.

The use of electricity, natural gas and chemicals in BioEcoSIM leads to slightly higher depletion effects compared to the other three systems. All manure processing systems have comparable environmental benefits from substitution of mineral fertilizers by the nutrient containing products of manure processing.

Some of the interviewees were a little bit more optimistic on the possibility to reduce fossil fertilizer use than accomplished in the LCA: The BioEcoSIM process may create the possibility to fine tune the supply of the nutrient and so give an opportunity for precision agriculture and by this avoid over-use of mineral fertilizers. This seems to be consistent with some field experiments where the phosphorus salt produced by BioEcoSIM performs better for plant growth than mineral fertilizers.

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[13] Externally reviewed and approved based on criteria of the International Standard Organisation (ISO) for Life Cycle Analyses (ISO standards 14040, 14044 and 14071 (Smeets et al., 2016, p. 18).

Other insights gathered from the interviews are that compared with less precise methods of manure processing, the project may prevent over-fertilization in the direct environment of pig farms while the organic component of manure can still be used to improve the land. There is some disagreement on how much potassium in the rest product can be used locally. By making fertilization more adjusted to requirements of the plants total fossil fertilizer use can be reduced thereby preventing some mining activities, while odours will be less than with the alternative processes and transport cost is reduced.[14]

Another element not included in the analysis is the pollution of ecosystems by heavy metals and other pollutants from the application of the products of manure processing. This may be more with less processed manure, and also fossil fertilizers have pollution with for example cadmium synthetic fertilizers.

The analysis is based on the current methods of energy production systems used in the EU. If energy would be produced sustainably then the disadvantage of fossil fuel depletion of minerals and fossil resources would be smaller and the advantage of having less greenhouse gas emissions because of storage larger.

In summary, the environmental performance of BioEcoSIM is better compared to other state-of-the-art manure processing systems, because of lower particulate matter formation and greenhouse gas emissions from manure storage and transport of manure, although the mineral and fossil resources depletion effects are slightly higher. If biochar is produced instead of a soil improver than the climate change mitigation benefits are higher. The favourable environmental impacts also exist in case of manure with a 3% and 9% dry matter content is processed, but the relative benefits of BioEcoSIM are the highest in case of manure with a 9% dry matter content.

3.6 Economics of the business case

According to the consortium analysis net costs per ton of manure are 5-10 euro per ton lower than long distance transport, manure drying and manure separation, where the difference is larger when pig manure has a larger fraction of dry matter. With 6% dry matter investment cost would be 1.1 million euro per 20,000 ton manure, with 120,000 euro capital costs, and 67,000 euro costs for acids and bases used in the process. Energy use is 300 MWh, where a price of 130 euro/MWh is assumed. Maintenance cost is assumed to be 3%, where transport costs are not mentioned. Cost of disposing the liquid fraction is set at 5 euro per tonne, where the liquid fraction is 83% of the original weight.

The revenues are from phosphorus salts, ammonium sulphate and organic soil improver, where prices are 142, 185 and 70 euro per tonne respectively, based on market prices of mineral fertilizers and granulates. Under these conditions the process becomes profitable when the alternative disposal cost is more than about 15 euro per ton pig manure, while the current disposal cost in the Netherlands is about 25 euro per ton pig manure, implying that the BioEcoSIM process is profitable compared with current techniques used to get rid of the pig manure.

One must be aware that other researchers reach other conclusions. For example (Wagenberg et al. 2018) calculate a higher cost for manure processing through BioEcoSIM than the manure drying technique. This is partly because they assume that investments for manure storage already have been made and therefore savings on storage facilities

[14] See video https://youtu.be/bxUxcHK_9F0 at the end, and presentation.

are not relevant and because they use different prices. Furthermore in practice many seemingly profitable business opportunities turn out in bankruptcy after implementation.[15]

It is mentioned that at a price of 35 euro/ton extra revenue of 1.8 euro/ton manure for biochar can be generated[16], because biochar will get then a premium price for its role in carbon sequestration.

In conclusion, an important aspect of the profitability of the business case is the negative price for pig manure, i.e. the business case is based on an over-supply of pig manure in certain regions. As far as the current pig manure management techniques are more expensive than the BioEcoSIM process, the process may be economically viable under current circumstances.

3.7 Social effects of the business case

It is expected that employment will not change much, because the technique is not labour intensive. There are changes in transportation needs, but longer transport distances of the nutrient products are counterbalanced by less voluminous transport (marketable products from manure are 4% of its volume). Furthermore, there may be less odour regionally because of less manure use for fertilization and because less manure has to be stored and transported.

Phosphate rocks contain contaminants such as cadmium and uranium which may cause health problems (EC, 2013). This may be prevented by using recycled phosphorus, although also recycled phosphorus may contain some toxic elements.[17]

Less mining is needed due to reduced fossil fertilizer use, preventing pollution and illness in other regions. Furthermore, less fossil fertilizer use reduces imports of phosphorus fertilizer in the EU and therefore reduces the import of phosphate rock. This may reduce geopolitical conflicts about primary resources. However, as discussed before, most experts and stakeholders expect no change in mineral fertilizer use as a consequence of the introduction of the BioEcoSIM process because manure processing is already required by law.

3.8 Enabling and restricting factors, as well as policies

The main enabling factor for the BioEcoSIM concept to become commercially a success is the negative price for pig manure in several regions. This negative price is the result of concentration of animal production in certain regions, combined with legislation, which limits the maximum use of manure on crop land and pasture and requires that the manure is used productively. The (negative) price for pig manure varies however during the season and depends on transport costs. Pig manure contains a lot of water, which increases transport costs. Therefore, often the manure is dried before transport. For export of manure one has to fulfil hygiene conditions.

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[15] Interviews Kees Kroes and Harry Luesink

[16] Smeets et al., 2016, p. 32

[17] Fraunhofer (2016), sheet 21.

Current legislation on fertilizers is a restriction to the BioEcoSIM business concept, because at the moment the fertilizer made from biodegradable pig manure waste is not accepted as a fertilizer. In other words, it is not equal to fossil fertilizer and is counted as part of the manure application to land. The revision of the Fertilizer Regulation in 2013 put an emphasis on harmonising the access to the EU market for biodegradable waste as an input for fertilizers and soil improvers. In 2016 a proposal from the EC was published[18] which aims to further update rules concerning the approval of fertilizers, and especially allowing fertilizers on the market made of secondary resources such as manure.

The BioEcoSIM process solves some externalities with respect to eutrophication as a consequence of over-supply of manure and greenhouse gas emissions. If these externalities would be priced, then the process would become more profitable because fossil fertilizers would increase in price, the biochar would sell at a higher price and pollution by over-fertilization would have a price.

3.9 Conclusion

The discussion on the BioEcoSIM business case shows that the environmental, economic and social benefits are not easy to evaluate and that the business case depends on current circumstances, i.e. the negative manure price, which is mainly a consequence of the requirement to use manure productively, and the regulations derived from the Nitrate and Water Framework directives that set limits to the amount of manure that may be applied per hectare of land. The analysis by the consortium suggests that the BioEcoSIM process is a cheaper manner to manage excess pig manure than the best alternative methods, and therefore it is already beneficial from an economic point of view. From an environmental point of view the BioEcoSIM seems to generate less greenhouse gas emissions and reduces particulate matter formation, mainly because of the smaller effects from storage and transport. However, BioEcoSIM leads to higher mineral and fossil resources depletion because it requires more energy and chemicals, of which the effects are not compensated by lower fossil fuel use for transport.

[18] https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-157-EN-F1-1.PDF

4 :: Step 3: Changes in the Key Sector

4.1 What is the key sector?

In order to be able to analyse the BioEcoSIM case, it is important to identify the key sector. Because the starting point of the choice of the case study was the phosphate oversupply in certain regions, an obvious choice as the key sector would be the phosphate sector. However, the BioEcoSIM consortium focuses on the valorisation of manure, and therefore the key sector would be the manure processing sector or maybe even the livestock sector. In this analysis we chose the first option because our focus is on the phosphate problem, while we postpone the analysis of the manure sector to the section on consequences for other sectors.

4.2 Scenarios

The aim of the CIRCULAR IMPACTS is to compare a circular scenario with a baseline scenario. Therefore, it is important to define suitable scenarios. However, definition of a suitable scenario is not easy. Already a projection of baseline developments till 2030 is very uncertain. Therefore, the design of alternative scenarios creates many difficulties. We suggest below three ways to approach the problem of scenario design. We emphasise that this exercise to upscale the business case in order to analyse the consequences is not part of the objectives of BioEcoSIM, but is only an exercise within this case study.

Scenario 1: the baseline

> The situation in 2017. Over-supply of manure in several European regions with intensive livestock production, especially pigs. The manure surplus is transported to regions with less livestock and more crop production. Because of costs transport distances are minimized (i.e. within the legislative framework). As far as legislation is effective, phosphorus fertilization is more or less balanced, which implies no increase of the stock of phosphorus in soil but also no significant decrease. Current increases in phosphorus stock in the soil is because of fraud which may be solved in the short term.

Scenario 2: new business case

> One approach could be to calculate the effects if the BioEcoSIM concept or a comparable approach to manure processing would be scaled up to all excess pig manure regions in the EU and where the nutrients produced are transported to regions where it substitutes for mineral fertilizer use. So, one has to calculate how much oversupply of manure is processed, how much nutrients and biochar may be extracted from it, and how much fossil fertilizer may be replaced by it. However, only limited effects are expected with respect to total phosphorus fertilizer use, because secondary phosphorus fertilizer will replace manure products, and in both cases the total phosphorus amount is the same. Only when the secondary phosphorus fertilizer is used more efficient than manure products, there will be an effect. Therefore, the economic consequences will be relatively small for the phosphorus fertilizer market.

Scenario 3. Processing most phosphorus flows into secondary fertilizer.

> In section 2 it has been shown that phosphorus imports are required mainly because of losses in phosphorus cycle. If a large share of these phosphorus losses

would be recycled, the import needs of phosphorus into the EU would be reduced significantly. This means recycling phosphorus not only from manure, but also from sewage sludge, slaughter waste, etc. Therefore, such a scenario may be useful to investigate changes in the macro-economic dependence of the EU on phosphorus import flows.

Scenario 4. Pricing of externalities

Another approach could be to analyse the consequences of pricing external costs in the economy, i.e. a policy focused on the fundamental causes of the pollution and excess resource depletion. If all greenhouse gas emissions would be taxed consistent with external cost, as well as water and air pollution and land degradation, then the cost-revenue balances would change fundamentally, probably implying that fossil phosphate and nitrogen fertilizers become more expensive. Not only manure, but also other forms of secondary nutrients, e.g. from sewage or animal bones, would become more profitable. For this to happen, regulation has to be adopted that all types of fertilizer are handled on the same foot.

However, although such a scenario would be optimal in case of a deep analysis of a really optimal form of circular economy scenario, it goes beyond the current case study. Basically everything may change, including the conditions for the case study. For example, if all externalities would be priced (and all perverse subsidies abandoned) it is certainly possible that livestock production in regions with excess manure supply would be relocated towards regions where the manure can be used fruitfully, taking out the business case of the BioEcoSIM. Therefore, such a scenario analysis is not accomplished in the context of this case study. However, we calculate an economic valuation of the envrionmental effects of the BioEcoSIM process, and this gives an indication how the benefits of the process change if the environmental costs would be priced.

In summary, we did some calculations on the scenarios instead of a model exercise. We focused on scenario 2 and partly on scenario 3, i.e. scenario 2 where BioEcoSIM is rolled out for all excess pig manure regions and scenario 3 where P is recycled not only from manure but also from sewage sludge and other bio waste. In those sections where macroeconomic impacts are relevant, we included scenario 3, because most effects will occur when phosphorus is recycled from more sources than manure alone. In those sections where macroeconomic impact is not at stake, we focused on scenario 2 only. The calculations on scenario 4 can be found in a box in chapter 6 and in paragraph 8.2.1.

4.3 Technological change and economies of scale

If phosphorus recycling from pig manure is scaled up, this will have an effect on costs and prices.

There will be economies of scale when the factory for recycling phosphorus is scaled up. However, this means that a factory is built on a central place, with as a consequence that transport and storage cost from the farm to the factory will increase. In case the facility is positioned on the farm, transport costs of 2 till 4 euro per tonne are saved. Altogether, economies of scale may be counterbalanced by transport costs, where environmental and social benefits will be reduced in case of transport of the manure.

Scaling up the recycling process may change the negative price of manure. Since the BioEcoSIM process becomes profitable above a price of about 15 euro per ton of pig manure this will become the new equilibrium price for removal of pig manure in regions with excess manure supply.

The technology to recycle phosphorus from other sources is still in development. According to ICL (a fertilizer company) secondary "phosphate is readily available from multiple sources, the main ones being manure & litter, phosphate rich ashes (wood, SSA, meat and bone meal) and Struvite (Magnesium Ammonium Phosphate). Typically, the phosphate content ranges between 10-25%. For all these sources to be used as feedstock for fertilizer production the nutrient availability to plants must be considered and, in most cases, improved. Wishing to contribute to closing the phosphorous cycle, ICL seeks cost effective technologies to integrate these high availability secondary phosphates into its fertilizers production." (ICL 2018) Note that the BioEcoSIM technique produces high quality, ready to use phosphate fertilizer.

4.4 Changes in the phosphorus sector

The average price for phosphate in Europe will not change much when manure is recycled, since phosphorus in manure, recycled phosphorus or fossil phosphorus in fertilizer all have the same nutritional value on the fields (except when the recycled phosphorus is sold outside Europe). Only as far as excessive use is prevented in the excess supply regions (which some experts doubt because of strict regulation but others suspect because of fraud) or when phosphorus from BioEcoSIM can be used more efficiently by the plants (e.g. by using precision agricultural techniques) demand for mineral phosphorus fertilizer may decrease a bit. This may have a small effect on the imported fossil fertilizer price and the net imports of phosphorus in the EU.

In the case of a scenario where not only the BioEcoSIM process is implemented, but also sewage sludge, food waste, slaughter waste and other biomass is recycled, the influence on the price of phosphorus fertilizer and the net imports of phosphorus by the EU will be much larger. For example a simulation exercise shows that if storage of phosphorus in the soil, losses from sewage sludge and losses from slaughter waste in the EU would be reduced by 90%, then European phosphorus fertilizer use would be by 94%, while the Netherlands would have net exports of fertilizers that are 12 times the amount of phosphorus fertilizer imports in 2015. All assuming that agricultural production would remain the same.

With respect to the possibilities for recycling of non-manure phosphorus the following may be relevant. Changes in the phosphorus sector are already taking place. In 2011 ICL and the Dutch Authorities agreed on a covenant to replace 15% rock by 2015 and up to 100% in 2025 (Langeveld 2016). This means that in 2025 the entire phosphorus rock feedstock, amounting for 0.5 Tg/year, should be replaced with secondary phosphorus, initially from human wastewater (Metson et al. 2015; Paul J.A. Withers et al. 2015). However, this requires further processing of struvite into more useful fertilizers products, or mono-incineration of phosphorus sludge.

When we summarize some of the main consequences of an increase in secondary phosphorus fertilizer production, then the following effects may happen:

- Use of recycled phosphorus for the production of fertilizer and other products instead of use of phosphorus-rock;
- Less phosphorus rocks and fossil fertilizers are imported into the EU;
- Investment in plants for phosphorus recycling, increasing total investment;

- It may be that value added and employment in fossil fertilizer producing firms will be reduced, but as ICL shows, as far as the recycled phosphorus is not in the right condition it may also be that these companies will just upgrade secondary phosphorus. So, as far as the fossil fertilizer companies are upgrading phosphorus for secondary resources, fossil fertilizer producers may even benefit;
- When more recycled phosphorus becomes available, more transport of phosphorus from Western Europe to Eastern Europe and other parts of the world will occur;
- The price of phosphorus fertilizer may decline, although this does not happen automatically because of the monopoly power of phosphorus rock producers.

Please note that the effects on the market by BioEcoSIM are significantly less far-reaching than recycling from unused waste streams like sewage, because the BioEcoSIM concept replaces direct manure application, which is already a form of nutrient recycling while recycling from waste flows generates new sources of supply of secondary phosphorus.

4.5 Conclusion

The BioEcoSIM concept and other manure processing concepts may change the phosphorus sector. In designing scenarios one has the possibility to focus only on upscaling the BioEcoSIM process, to focus on recycling phosphorus from several resources, or to focus on a scenario where the whole economy changes into an optimal circular economy through optimal green taxation, regulation and other policies.

Although some technological improvement may be expected in the BioEcoSIM process, it is probably limited, while economies of scale in production are probably not worthwhile because they production cost advantages will be more or less compensated by increases in transport and storage cost.

Although a broad introduction of BioEcoSIM may reduce the negative manure price, it will probably have only limited effects on the phosphorus balances because the process replaces other management options of manure. Only as far as efficiency of nutrient application improves through the higher quality and better transportability of the produced fertilizers, demand for fossil fertilizer may be reduced a little through the implementation of the BioEcoSIM process.

The effect of recycling of other waste streams that contain phosphorus will have more effect on the EU phosphorus flows and may reduce the net import of fossil fertilizer and phosphorus feed and feed additives significantly.

5 :: Step 4: Expected Effects on Other Sectors

5.1 Changes in the manure market

Recycling of manure will change, of course, the manure market. Concerning the manure market we have to distinguish poultry, cattle, pig and sheep manure. Manure contains valuable ingredients, especially nutrients and organic matter. But it also contains unwanted components, such as water, pathogens and smell. Compared with the other types of manure pig manure contains a lot of water.

The (negative) price of manure depends on the regional (im)balance between demand (crop and pasture land) and supply (livestock production).

Change from direct manure use to recycling phosphorus from manure with the BioEcoSIM concept results in:

- More choices for the livestock producers: sell the manure to a crop farmer or sell it to a recycling plant;
- Less transport of manure (the manure is processed at a short distance from the farm);
- Decrease of the negative price of manure in certain regions (as far as the BioEcoSIM technique is cheaper than the alternatives).

Furthermore, the manure market is highly influenced by government regulation, both on the supply and demand side and also concerning conditions for trade of manure. To organize manure processing, this legislation must be adjusted.

5.2 Crop production

Greenhouse and field experiments with the fertilizers produced by the BioEcoSIM process show that the produced phosphorus salt generated in some cases even higher yields than mineral fertilizers, and that the ammonium sulphate had comparable yield effects. This implies that the fertilizers produced by BioEcoSIM have a quality that is at least comparable with mineral fertilizers (Ehmann et al. 2017). Furthermore, the fertilizers can be used with machines that are already available for spreading mineral fertilizers. Because spreading fertilizers requires less heavy machines than spreading manure, crop producers may prefer the use of secondary fertilizers over direct manure application. This would imply that it may be preferred when the price is comparable with mineral fertilizers and that from the perspective of crop producers the main change would be a wider range of fertilizers to choose from.

As far as BioEcoSIM would reduce the negative manure price, the implicit subsidy to the crop sector through this negative price would be reduced. However, the effect on the crop sector is small. In the EU27 about 0.4% of total crop production cost is on phosphorus fertilizer (globally 1%), and 1.6% on all fertilizers together (including horticulture; if excluding it, it is 0.5% respectively 2.1%)[19]. Furthermore, farmers are able to reduce phosphorus fertilizer application when prices are high, because in large parts

[19] Based on MAGNET data of 2007.

of the EU the soil contains a lot of phosphorus. As a result, the global market price of phosphorus fertilizer will not be a fundamental issue for crop farm profitability, at least not in Europe. This implies that even if price spikes like in 2008 occur, the negative effects on the sector will be limited.

5.3 The livestock sector

At the moment, the growth of the livestock sector is restricted by regulations around manure production in regions with excess supply of manure. When manure is recycled and exported, this may change the view on manure and thereby may change legislation. In that case it is conceivable that the concentration of the livestock sector increases, depending on legislation. Furthermore, because of a little bit lower negative manure price the cost of livestock production will decrease a bit with a small increase in livestock production as a consequence (rebound effect), given this is not prevented by legislation.

5.4 Transport sector

In case only BioEcoSIM is implemented, the consequence will be mainly that international transport of secondary fertilizers is increased, while long- and short-distance transport of manure is reduced. As far as nutrient use with secondary fertilizers is better than their substitute, transport of imported fossil fertilizers may be reduced marginally.

When all phosphorus of waste flows is recycled, the changes for the transport sector will be more fundamental. Phosphorus rock and mineral fertilizer imports through the European harbours will be reduced, while the export of secondary fertilizer will be increased.

6 :: Step 5: The Impact on Society

6.1 Introduction

The macro-economic impacts of the new technologies are difficult to assess, especially because there is a lot of uncertainty even on the impacts on profits at business scale. In this chapter we evaluate the economic impacts of mainstreaming BioEcoSIM using the results of the (confidential) impact assessment by the BioEcoSIM consortium (Smeets et al. 2016). In order to make explicit how such an analysis depends on assumptions of the future development of the economy, we discuss in a separate section some effects of changes in those assumptions.

6.2 Impact of mainstreaming BioEcoSIM

As a thought exercise we create a scenario where BioEcoSIM is mainstreamed for all phosphorus in pig manure that is exported from the Netherlands in 2015, where in the baseline 40% is exported by means of long distance transport and 60% through manure separation. Because analysing the effects for 2030 would involve too much speculation on a baseline development and the mechanisms involved are the same, we use the current situation for the analysis instead of a baseline situation in 2030.

Figure 2 (with references and base data used in Annex 1) shows an overview of the main environmental and economic effects of mainstreaming BioEcoSIM for all pig manure that is exported in 2015. This exercise is a hypothetical scenario exercise where the processing of all pig manure from which the phosphorus is exported (about 3 million tonnes) with BioEcoSIM, is compared to the export of all excess pig manure with long distance transport and manure separation, roughly consistent with the current situation.

A crucial step for aggregating the results is the validity of the estimate of cost reduction in the case study, in this case a saving of 5 euro per tonne pig manure. Please note that this figure comes with a lot of uncertainty. For example, if we follow Wagenberg et al. (2018), the benefits will be less because they assume that in the case of BioEcoSIM investments for storage of manure already have been made and therefore are sunk costs that doen't change when BioEcoSIM processing would be introduced, while they also consider uncertainties with respect to prices of the different products made from manure. Wagenberg et al. (2018)'s conclusion is that manure drying is in general more cost efficient than the BioEcoSIM process. However, it should be noted that the BioEcoSIM process will become more beneficial when trade distances increase.

When we assume that the estimated benefits per tonne of manure are correct, these benefits can be directly translated into GDP benefits by multiplying the benefit per tonne of processed manure by the amount of manure of which the phosphorus is exported. Such a calculation does not include effects of changes in the size of the crop and livestock sectors as a consequence of the cost changes.

GDP effects are only a small part of the total welfare effects. According to the Life Cycle Analysis (LCA) of BioEcoSIM, the main environmental benefits of BioEcoSIM compared with long distance transport and manure separation are reductions in greenhouse gas emissions and particulate matter formation. When these benefits are multiplied by their values used in cost-benefit analyses for the Netherlands (CE Delft 2017) the welfare effects of the environmental benefits can be calculated (being more than 90 million euros compared with the GDP benefit of 15 million euros).

Figure 2: Economic and environmental effects of mainstreaming BioEcoSIM compared with the current situation for 3 million tons of Dutch manure processed for phosphorus exports

	Environmental	Economic	Unit
GDP		15.00	mln euro
GHG emissions	-144600		ton CO2eq
		8.68	mln euro
Particulate matter formation	-1488000		kg PM10eq
		66.96	mln euro
Total welfare benefit		90.64	mln euro
Fossil fuel depletion	31800		tonne oil equivalents
Current account net imports		0.26	mln euro
Depreciation (replacement investment)		4.50	mln euro
Employment		small	
Transport sector sales		-24.90	mln euro
Livestock sector income		55.00	mln euro
Crop sector income		-40.00	mln euro

Because the BioEcoSIM process probably does not increase the efficiency of use of the nutrients compared with other ways of acquiring the phosphorus from manure[20], there is no effect on fossil fertilizer imports from that side. The only direct effect of the introduction of the BioEcoSIM process on the current account is through its higher use of fossil fuels. Based on the figures on differences in fossil fuel depletion from the BioEcoSIM LCA and a crude oil price of 60 euro per barrel, the net imports of fossil fuels can be calculated (increase of 0.26 million Euros), representing only a very small amount, but illustrative for the calculation method.

A next economic indicator is the amount of investment needed. Depreciation and therefore replacement investment will be about 4.5 million Euros per year, while BioEcoSIM will require an additional investment of about 45 million Euros compared to the alternative processes.

The employment effects of BioEcoSIM will be small. The processes are automated to a large extent and therefore will not generate much employment. The investment may generate some temporary employment, while the reduction in transport cost implies a shift in employment in other sectors.

The transformation towards BioEcoSIM would generate changes in sector income. Based on the change in transport cost for manure, the loss of income for the transport sector will be about 25 mln Euros, whereas other sectors will sell more. With respect to the livestock sector, the equilibrium price of manure will be reduced with the same amount, generating a benefit for all traded manure for the livestock sector of 55 million Euros, because the opportunity cost export of phosphorus from manure decreases with 5 euro. Forty million euros is the change in value of the manure sales to the crop and extensive livestock sector, which is just a transfer of income from the crop sector to the livestock

[20] Personal communication with Harry Luesink

sector. The difference, 15 million euro, is the cost reduction for the export of manure, and equals the increase in GDP. Everything is summarized in Figure 2.

6.3 Dependence on other developments

The benefits of the BioEcoSIM case depend on the assumption that the current situation is the correct starting point. If for example the Netherlands has to reduce its livestock sector in order to reduce greenhouse gas emissions because of the Paris Agreement, less manure will be produced in the Netherlands and therefore no manure has to be exported anymore. The business case of BioEcoSIM will, in that case, no longer be profitable.

If a general price of 60 euro per ton CO_2eq on greenhouse gas emissions would be set, or more or less plausible greenhouse gas price (CE Delft 2017), the performance of the BioEcoSIM case would improve with about 3 euro per tonne of processed manure, not an extremely large effect compared with the total cost per tonne of processed manure. If also a price for particulate matter formation would be set, this would have large consequences for the profitability of the BioEcoSIM process; at a price of 45 euro per kg PM10 (CE Delft 2017), the benefit would be 22 euro per tonne processed manure, making the BioEcoSIM process even profitable at a slightly positive manure price. If both particulate matter and greenhouse gasses would be priced, the benefits of processing manure by BioEcoSIM would be increased by 25 euros per tonne of processed manure compared with the current situation. Again, all depends on the correctness of the estimate of the benefits and the prices that have been chosen.

One may also argue that mineral fertilizer prices should be increased in order to include a social valuation of the risk of phosphorus scarcity in the far future or the consequences of import dependency for a region like the EU. For example, if the price of phosphorus mineral fertilizer would be doubled, the revenues of business cases dealing with phosphorus recycling, for example through sewage sludge processing, would improve significantly. For the BioEcoSIM case, a doubling of the price of secondary fertilizers would increase revenues with about 4 euro per ton processed manure (Smeets et al. 2016, p. 39, table 3.5). However, an increase of fertilizer prices will also increase the value of manure and this may compensate the benefits of BioEcoSIM. Thus, it is likely that the effect of an increase in mineral fertilizers prices on the profitability of BioEcoSIM will be negligible.

If current manure importing countries would become stricter with respect to environmental requirements and therefore less manure can be sold nearby, this would imply an increase in distances for transport and therefore an improvement of the business case of manure processing compared with manure export.

Finally, the calculations are based on the current energy system. If the energy system would become greener, then transport will generate less greenhouse gas emissions, and therefore the greenhouse gas benefit of BioEcoSIM will be reduced.

Although not included in the impact analysis, the fertilizers produced by BioEcoSIM may have a higher productivity compared to direct manure application, as suggested by Ehmann et al. (2017). This may imply that by using the fertilizers produced by BioEcoSIM fewer nutrients are needed for the same productivity effect, indicating that substituting manure by secondary fertilizers demand for mineral fertilizers is reduced. This would imply a small improvement in relation to the depletion of resources, i.e. phosphorus rocks, and combined with that less negative effects on the environment through mining in phosphorus rock-producing countries. However, it should be noted that experts do not agree on the relative efficiency of fertilizer compared with manure, and that the relative benefits may depend on soil, climate and other production conditions. Therefore, such an analysis is too complicated for a case study as small as the one discussed in this report.

6.4 Conclusion

The calculations of the economic consequences of mainstreaming BioEcoSIM show how the results of an impact assessment at the scale of a case study can be scaled up to come to effects on GDP, welfare, trade balance and investment. The case study also shows that the outcomes are highly uncertain and dependant on many developments.

7 :: Step 6: Are Alternatives Available?

A fundamental question when developing new techniques is to what extent better alternatives are available. Here we focus again on the BioEcoSIM concept. Whether these alternatives are realistic depends on future policies and price developments.

7.1 More efficient use of phosphorus

As far as the purpose of phosphorus recycling is a reduction in fossil fertilizer use (which is not the case for BioEcoSIM which is mainly focused on valorisation of manure), the alternative is to increase resource use efficiency of phosphorus. There are several possibilities to reduce fossil fertilizer use (Schoumans et al., 2015 and Withers et al., 2015), not only through precision farming for crops and grassland, but also for example by reducing phosphorus in feed additives. The amount of phosphorus in feed can be adapted to the need of the animals in different life stages (phase feeding). Furthermore, the phytase enzyme can be added to feed which makes the animals process phosphorus in a more efficient way. This results in less phosphorus needed in feed additives, and less phosphorus in manure (EC, 2013, p. 16), and therefore a smaller excess supply of phosphorus in manure at a given livestock production.

7.2 Less livestock production

If less meat would be consumed, livestock production would be reduced, as well as phosphorus use. Furthermore, manure production would go down, reducing the need for advanced manure processing techniques. According to WHO, people in the EU eat 70% more meat and dairy products than is known to be good for their health, thereby generating diseases. From this perspective, a reduction in livestock production through decreased consumer demand for meat and dairy products would positively influence health and related costs, greenhouse gas emissions and the pressure on nutrient resources.

The Paris Agreement may have important consequences for the livestock sector, and therefore for a business case such as BioEcoSIM. For example, in the Netherlands greenhouse gas emissions by the livestock sector have to be reduced significantly to reach the Pairs climate goals, even for 2030. Therefore, it seems plausible that the livestock sector in this region has to be reduced in the near future. This may solve the excess manure problem, and therefore make business cases dealing with phosphorus recycling more difficult, because they depend on the existence of a negative manure price.

What would the consequences be for Dutch GDP if the pig farming sector would be reduced? The average income per labour year for unpaid labour in the pig farming sector over 2001-2017 is 28,000 euro[21], i.e. far below the modal income of 37,000 euro in the Netherlands, where one should note that pig farmers not only supply labour, but also capital to the farm. Therefore, it seems plausible that people currently working in the pig farming sector can earn a higher income if they would take another job and would use their capital for other investments, although one must be aware that as far as pig farmers

[21] See Agrimatie: https://www.agrimatie.nl/binternet.aspx?ID=4&bedrijfstype=5

stay in the sector, they seem to prefer this above the alternatives. Furthermore, when some pig farmers stop their business, other pig farmers save on cost for manure processing and therefore their income will increase.

Because the Netherlands is both a net exporter of manure and pig meat, the reduction of the pig farming sector will have consequences for the net trade balance.

7.3 Relocation of livestock production

Even if global livestock production would remain the same, having a better regional tuning between livestock and crop production could be an alternative. Then all manure produced in a region could be used within the region on cropland and grassland, while manure would be valued for its nutritional value. In reallocating production, one must be aware that animal wealth, ammonia emissions and antibiotic use are at this moment relatively good in the Netherlands compared with other parts of the world, which can be a short term benefit for having animal production concentrated in the Netherlands.

7.4 Use manure for feed production

Experiments to combine intensive livestock production with animal feed production are in process. Over-supply of phosphorus and other nutrients in waterbodies results in eutrophication, which leads to the growth of aquatic plants such as algae and duckweed. However, dried algae and duckweed can be used as feed. This makes it possible to compose a circle of nutrients: nutrients from manure are used to grow algae and duckweed, algae and duckweed are used as feed (together with other feed sources), with livestock products as an outcome of this process.

Ecoferm is an example of a farm which used this circle of nutrients. More specifically, Ecoferm produced veal in combination with duckweed (feed), biogas, electricity, and clean water. The basin with duckweed was located on top of the stable in an attic, which is an example of vertical agriculture. Compared with BioEcoSIM, in this process more residual flows are re-used, namely P and N, but also CO_2, water and residual heat.

The case of Ecoferm is interesting because residual flows are re-used within one firm, including residual flows which are difficult (or expensive) to store and trade, e.g. CO_2 and heat. Furthermore, less transport is needed. This is an advantage from a circular point of view, as reusing within one firm is more efficient compared to recycling and transporting.

In this option the livestock farms itself become more circular by using manure directly for feed production. Ecoferm got subsidies from the EU, but also from the national and regional authorities. Unfortunately, the Ecoferm concept is not profitable yet (de Wilt et al., 2016).

8 :: Step 7: Policy Options

Buckwell and Nadeu (2016, p. 11) conclude that "even with the favourable assistance currently underway through regulatory reform, research and information provision, NRR[22] activity will not spontaneously, swiftly and significantly increase in scale." Therefore, further collective action is justified. It should start with an appraisal of suitability of the current legislative landscape to test if it is most appropriate to stimulate the next stage of development of NRR. Then it should examine in detail the benefits and costs of each of the ways that could be undertaken to provide this stimulus.

Buckwell and Nadeu (2016, p. 11) distinguish eight possible collective actions, five of them creating enabling conditions:

- Obligations
- Targets
- Investment grants
- Subsidies
- Fiscal reliefs

And three reducing external costs:

- Fertiliser tax
- Land fill and incineration fees or restrictions
- A nutrient surplus tax

8.1 Creating enabling factors

What are the enabling factors for a successful introduction of the BioEcoSIM or a similar concept?

8.1.1 Targets and obligations

The current approach of stimulating nutrient recycling and manure management is to set voluntary targets through green deals or otherwise. These approaches will only work out in case of win-win situations. The targets may stimulate the search for win-win solutions and may help to communicate about barriers towards implementation of nutrient recycling techniques. So, given current and perhaps in the future more stringent legislation on manure management and fertilization, such policies may help to implement technologies like BioEcoSIM if the developed technology is already profitable in current circumstances.

An example of a voluntary agreement comes from the Netherlands. In a platform with a wide range of stakeholders in the phosphate value chain, targets were set towards a percentage of recycled phosphorus in the manufacturing processes for fertilizer. Also the European Phosphorus Platform has a role to exchange information on technological possibilities.

However, if the current situation generates no profitable business opportunities although the opportunities are beneficial from the perspective of the whole society, stricter regulation is needed. The case of BioEcoSIM shows how important it is that processing of manure is obligatory, because the process is only profitable at negative manure prices

[22] NRR is an acronym for Nutrient Recovery and Reuse

that are the consequence of regulation. Blending targets for fertilizers and requirements to recycle also sewage sludge and bone meal may be examples of regulations that could be implemented to make recycling more profitable than in the past. Currently, such regulations are already partially implemented.

One may consider setting a minimum blending rate for recycled and fossil fertilizers as another way to set targets for recycling. The fertilizer producer ICL is doing so at the moment on a voluntary base.

Another option is to set import quota for fossil fertilizers and phosphate rock. However, this type of regulation will not be accepted by the WTO.

8.1.2 Investment grants

One approach, easy to accomplish, is financing R&D, including demonstration plants and first investments on a large scale. The EC is doing this through FP7 and Horizon2020 projects and also investment, startup and innovation grants. Examples of innovation policy are the subsidies for BioEcoSIM and Ecoferm.

8.1.3 Subsidies and fiscal reliefs

Next to regulation one may also give subsidies, fiscal reliefs or investment subsidies. For example, a subsidy per unit of recycled nutrient, i.e. a feed-in tariff may stimulate the spread of nutrient recycling technologies.

8.2 Solving barriers

What are the barriers for a successful introduction of the BioEcoSIM concept and how can these be reduced? First, we focus on reducing external costs, in line with Buckwell and Nadeu. Next, we add other examples of solving barriers.

8.2.1 Reducing external costs

Because the fundamental cause of externalities related to nutrient use and manure production is that no prices exist for these externalities. One may try to internalize these through taxation. This implies that the waste flows or the inputs or outputs generating the externalities get a price. For example, in Denmark a tax on fertilizer has been introduced. However, this was not effective (Hees et al. 2012) because the tariff was low (and for households, not for agriculture). If a tax on mineral fertilizers would be high enough, this would stimulate the use of recycled fertilizers.

Another way to price the externalities could be landfill taxes and incineration fees. However, such a tax may also generate perverse effects, where people dump the organic wastes, or recycle also polluted types of waste (Verrips et al. 2017).

As a thought experiment we may investigate what the consequence would be of a greenhouse gas price of 60 euro per ton CO_2. The climate benefit of biochar production would according to the LCA (Smeets et al. 2016, annex I; Ehmann et al. 2017) be 51 kg CO_2 per ton of manure, i.e. a benefit of 3.10 euro for biochar processing. The BioEcoSIM process with soil improver compared with long distance transport has in that case a benefit of 110 kg CO_2 per ton of manure, generating an extra profit of 6 Euros per tonne of manure.

8.2.2 Current regulation

First, existing regulation has a major impact on the use of phosphate. Phosphate use per hectare in the EU has been reduced significantly between 1980 and 2016 by stricter EU and national fertilizer, manure and detergent regulation. The sector is highly regulated. Regulation concerning fertilizer industry, farms, food, the water treatment sector and more are in place, both at European, national, regional and local level. According to Buckwell & Nadeu (2016, p 11) it is important that the consistency of these regulations is carefully analysed and made consistent with recycling.

An important argument for public involvement is externalities of greenhouse gases and pollution. Another is that the recycling industry for nutrients will probably be very dispersed and inexperienced, making it difficult to compete with the centralized fossil fertilizer companies. Also social attitudes have to change, and therefore investment in the new facilities may be risky (Buckwell & Nadeu 2016, p. 73).

Because a large number of externalities are involved, corrections of market failures seem to be needed. As far as external costs are involved, taxation and restrictions on non-recovered nutrients seem to be an obvious instrument, although it may not always be easy to operationalize this because of the high transaction costs (Buckwell & Nadeu, 2016, p 71). Cross compliance, i.e. refusing subsidies if regulations are not abided, is an attempt to solve the problem of forcing farmers to follow the regulations.

8.2.3 Certification

Buckwell & Nadeu (2016, p 11) suggest that the quality of recycled fertilizer is not necessarily the same as that of mineral fertilizers. A good quality certification system is important, especially because in contrast with the mineral fertilizer sector the recycling sector is dispersed and because consumers, traders and farmers may have doubts about the quality and safety of using the recycled nutrients. Food scandals like BSE from recycled animals as animal feed created fear for using recycled products. Therefore, certification that guarantees the quality of the product, and that may for example recognize the perhaps better quality of the phosphate fertilizer produced by BioEcoSIM, is essential to valorise recycled fertilizers on the market.

8.2.4 Creating policy stability, i.e. a stable investment climate

Stability and predictability of legislation is an essential condition to reduce investment risk. For example, if it is not certain that large scale livestock in the areas with currently excess manure supply will continue to exist for some time, the investment in projects like BioEcoSIM may be too risky. For investors it is important that they know what to expect in the long term. So, creating policy stability concerning phosphate and manure use may improve the investment climate.

9 :: Step 8: Overall Conclusions

9.1 On BioEcoSIM

On the one hand, a business case like BioEcoSIM is mainly a technology that reduces transport cost and therefore saves money for the intensive livestock farmers. On the other hand, however, BioEcoSIM has benefits with respect to greenhouse gas and particulate matter emissions and it may be that it makes more precise and therefore more efficient nutrient application possible, potentially reducing phosphate accumulation in the soil and eutrophication of water. However, since manure is already recycled in the baseline (i.e. used on arable and grass land), the BioEcoSIM concept has limited effects on the phosphorus rock mining.

The supposedly better high quality fertilizers that are produced from manure, however, must be accepted as substitutse for fossil fertilizers, and must be certified to have equal or even better characteristics to receive the price it is worth.

The project BioEcoSIM generates a bundle of new technologies. The BioEcoSIM consortium already recognizes that it may be useful to use the separate technologies and combine them with other technologies. The main benefit from the investment by the EC in such a project is that new technologies become available and it showns to what extent they are successful.

A requirement for profitability of BioEcoSIM is a negative manure price, i.e. the existence in certain regions of large scale intensive animal production. Another solution to the excess of manure supply could be a situation where arable and animal farming are more in equilibrium.

The main issue to be solved with the BioEcoSIM concept is valorisation of pig manure. Therefore, the BioEcoSIM concept is compared with three state-of-the-art alternatives, which are all techniques implying transport of phosphorus from manure.

9.2 On manure and phosphorus recycling

Phosphorus depletion is not a significant problem in the coming decades, but because stocks, production and exports are concentrated in a small number of regions and the EU depends almost completely on imports, geo-political uncertainties are an important argument to reduce dependency on primary phosphorus sources. Also the environmental consequences of phosphorus rock mining may be a reason to reduce demand for phosphorus rock. Furthermore, because of the crucial importance of phosphorus for food production, there are also good arguments to focus on preventing problems with phosphorus supply in the far future.

As mentioned, the effect of BioEcoSIM on preventing phosphorus depletion is limited. However, if other types of biomass, like sewage sludge, are recycled, the effect on phosphorus depletion will be significant.

The case on phosphorus recycling from manure shows that legislation restricting manure application on land combined with requirements to process excess manure resulted in less phosphorus application on land in Western Europe, with as a consequence less phosphorus accumulation in the soil. The legislation created a negative price for manure and therefore business opportunities for manure processing. Because legislation is so important, a long term vision on and clarity about legislation is very important. Investors need to be sure that legislation does not change drastically in the short term.

9.3 Economic, environmental and social impacts

As far as the BioEcoSIM business case reduces the cost of manure management, the negative price of manure in several regions of Western-Europe will be reduced. This implies lower cost for intensive livestock farmers and lower benefits from negatively priced manure for the crop farmers in the neighbourhood of intensive livestock farmers.

If all losses in the EU phosphorus flow would be recycled, i.e. if also phosphorus from sewage sludge, slaughter waste etc. is recycled, then phosphorus imports will be reduced significantly. This will reduce dependence on other parts of the world, which will have consequences for phosphorus rock producing countries like Morocco. With respect to the transport sector there will be changes: less import of phosphorus rock and more export of phosphorus products for the harbours.

Stricter regulation on fertilization and manure application resulted in negative manure prices, which is beneficial for crop farmers and costly for livestock farmers. As far as excess manure has to be exported, transport and processing costs increase, reducing direct profitability of livestock farms. So, legislation protects the environment at an economic cost. However, if one also includes the benefits from the improved environment, manure legislation is beneficial from the perspective of a social cost-benefit analysis (PBL 2017).

With respect to the purchasing power effect, the purchasing power will not change significantly as long as recycled phosphorus is not much cheaper than phosphorus made from phosphorus rocks.

With respect to the environment, BioEcoSIM has a (restricted) positive impact on reduction of GHG emissions and particulate matter formation. This is because of benefits generated through nitrogen processing and the use of biochar, and not because of extra benefits from the recycling of phosphorus. However, the benefits for reducing phosphorus pollution may be higher if one includes that current legislation results in fraud with very negative environmental implications.

With respect to social impacts one must be aware that the new technique is not labour intensive. It is not expected that there will be a significant change of employment, although the technique may increase value added at farm level a little bit. For the reputation of livestock farmers, especially pig farmers, this new technique may be positive since the use of manure causes odour and manure transport causes annoyance. As far as there are less dangerous materials like cadmium in secondary fertilizers than in fossil fertilizers this may have positive consequences for health and the ecosystems.

9.4 Some further observations

The example of phosphorus recycling from manure shows how regulation may generate new business opportunities, and how some of these business opportunities may be blocked by outdated regulation.

The business case that emerges from the manure sector, where the fundamental problem of pollution was a signal of waste and related lack of circularity, can be a source of inspiration for other sectors, where the urgency is less pressing and where solutions are based on reducing pollution without a focus on improving circularity. A processing requirement like in the manure sector could be an example. It can also be an argument for even farther reaching regulation where obligatory phosphorus mining of phosphorus in the ground may further improve the environment and reduce phosphorus demand for agriculture.

The business case shows dependency on manure and fertilizer regulation, which makes it vulnerable to changes in legislation. Also regulation focused on reducing the number of animals in livestock intensive regions may reduce excess manure supply and therefore take out part of the business case of BioEcoSIM and comparable businesses.

Current manure exports of for example the Netherlands partially depend on exports to Germany. When legislation becomes more strict in Germany or when Germany finds some hygienic problems with Dutch manure it may be more difficult to sell excess manure to Germany. In that sense, a process like BioEcoSIM is more flexible because the manure products can be more easily exported to other regions in the world and don't have hygienic problems.

9.5 Policy recommendations

Standardisation and certification are crucial with regard to the markets for secondary fertilizers, and regulatory barriers have to be solved.

Another issue is innovation policy. As shown, innovation policy for manure processing mainly reduces transport cost and potentially increases opportunities for better fertilizer efficiency. Also for other waste streams that contain phosphorus, innovation policy may help to develop better and cheaper technologies. Targets and feed-in tariffs may also help.

Finally, as far as pollution is still widespread, pricing of externalities by taxes and subsidies may be the most important policy. If eutrophication and greenhouse gas emissions and other externalities would be taxed according to external cost, relative advantages of different technologies wsould change. However, from an environmental perspective, it may be better to relocate and reduce livestock production, which to some degree will happen automatically if prices of pollution have to be paid by the beneficiaries. Regulation for obligatory processing of waste flows with phosphorus is a very effective instrument for further reaching phosphorus recycling.

Annex 1: Technical Annex: Calculation of the Environmental and Economic Impacts

The table below shows the sources and calculations made to create Figure 2 in the main text.

Tonnes pig manure export 2015	3000000					
	Unit		Source	Environmental	Economic	Unit
GDP	5	euro per tonne manure	BioEcoSIM, p. 40		15.00	mln euro
GHG emissions	-0.0482	ton CO2eq per tonne manure	BioEcoSIM, p. 27	-144600		ton CO2eq
GHG emissions	60	euro per ton CO2eq	(CE Delft 2017);		8.68	mln euro
Particulate matter formation	-0.496	kg PM10eq per tonne manure	BioEcoSIM, p. 26	-1488000		kg PM10eq
Particulate matter formation	45	euro per kg PM10	(CE Delft 2017);		66.96	mln euro
Welfare benefit					90.64	mln euro
Fossil fuel depletion	0.0106	tonne oil equivalents per tonne manure	BioEcoSIM, p. 28	31800		tonne oil equivalents
Current account net imports	8.16	crude oil price assumed 60 euro per barrel			0.26	mln euro
Depreciation (replacement investment)	1.5	euro per tonne manure	BioEcoSIM, p. 37		4.50	mln euro
Employment					small	
Transport sector sales	-8.3	euro	BioEcoSIM, p. 40		-24.90	mln euro
Livestock sector income		11 mln ton manure 5 euro benefit per tonne	Koeijer et al 2017, p. 24		55.00	mln euro
Crop sector income		11-3 mln ton manure (also 5 euro)			-40.00	mln euro

Annex 2: Expert Workshop

Workshop Agenda: Phosphorus recycling – Progress towards a circular economy

13:00 – 14:00 Registration & light lunch

14:00 – 15:00 Session 1: to what extent does phosphorus recycling from manure contribute to the transition to a circular economy?

14:00 – 14:05 Welcome by **Volkert Beekman** (chair of the workshop), Wageningen Economic Research.

14:05 – 14:20 A case study on phosphorus recycling as part of the Circular Impacts project by **Marie-Jose Smits**, Wageningen Economic Research.

14:20 – 14:35 Advantages and disadvantages of manure processing, with BioEcoSIM as an example by **Edward Smeets**, Wageningen Economic Research.

14:35 – 15:00 Open discussion

15:00 – 16:00 Session 2: manure processing and environmental impact

15.00 – 15:05 Introduction to the session by **Volkert Beekman**

15:05 – 15:15 Phosphorus recycling from manure, and its contribution to phosphorus recycling in general by **Jan van Bergen**, Dutch Ministry of Infrastructure and Water management.

15:15 – 15:25 The environmental impact of manure processing by **Theun Vellinga**, Wageningen Animal Science Group.

15:25 – 15:45 Open discussion

15:45 – 16:00 Coffee break

16:00 – 17:00 Session 3: economic and societal consequences of phosphorus recycling

16:00 – 16:10 Introduction to the issue by **Geert Woltjer**, Wageningen Economic Research

16:10 – 16:55 Panel and open discussion

- **Geert Woltjer**, Wageningen Economic Research
- **Rob de Ruiter**, EcoPhos
- **Rob Dellink**, OECD
- **Roelof Jan Donner**, Ministry of Economic Affairs and Climate

16:55 – 17:00 Concluding comments by **Aaron Best**, Ecologic Institute

17:00 End of meeting

List of participants of the workshop Phosphorus recycling – Progress towards a circular economy, The Hague, 27 February 2018

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