P-REX

Sustainable sewage sludge management fostering phosphorus recovery and energy efficiency

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Report on market for phosphorus recycling products

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Table of Content

Table of Content I

Glossary V

Figures VI

Tables VIII

1 Introduction 11

1.1 Background 11

1.2 Objectives and Method 11

1.3 Market value chain and segments 12

1.3.1 Importer 12

1.3.2 Phosphorus compound producer 12

1.3.3 Fertilizer compounder 12

1.3.4 Fertilizer blender 13

1.3.5 Wholesaler 13

1.3.6 Retailer 13

1.3.7 Farmers coop 13

1.3.8 Farmer 13

2 Overall results and discussion 14

2.1 Market description 14

2.1.1 Overview of the fertilizer value chain and recycling in the studied regions 14

2.1.1.1 Bulgaria 14

2.1.1.2 Czech Republic 14

2.1.1.3 Germany 15

2.1.1.4 Spain 15

2.1.1.5 Switzerland 16

2.1.2 European phosphorous demand 16

2.1.2.1 Fertilizer market 16

2.1.2.2 Other markets 19

2.1.3 European value chains to satisfy fertilizer demand 21

2.1.3.1 Processing of mineral phosphorous 21

2.1.3.2 Import and logistics 22

2.1.3.3 Wholesalers and retailers 22

2.1.4 Prices along the value chain 22

2.1.5 Information in the value chain 23

2.1.6	Packaging and delivery to the farm	23
2.2	Possibilities for entry in the agricultural value chain	24
2.3	Conclusion	26
3	Processing map	29
3.1	Scope	29
3.2	Method	29
3.3	European phosphorus flows	29
3.4	Fertilizer production	31
3.4.1	Processes	31
3.4.2	Results	34
3.5	Outlook	38
4	Bulgaria	39
4.1	Introduction	39
4.2	Import of phosphate fertilizers	39
4.3	Export of the phosphate fertilizers	40
4.4	Summary	42
4.5	Agriculture Stakeholders	43
4.6	Role of individual participants of the market	43
4.6.1	Farmer cooperations, farmers	44
4.7	Other Markets (except of agriculture)	46
4.8	New market created for recycling?	46
4.9	Conclusions	46
5	Czech Republic	47
5.1	Introduction	47
5.2	Import of the P-rich materials and products	47
5.2.1	Raw phosphorus materials import	48
5.2.2	Phosphate fertilizers import	48
5.3	Export of the P-rich materials and products	50
5.3.1	Raw phosphorus export	50
5.3.2	Phosphate fertilizers export	50
5.4	Summary	51
5.5	Agriculture – Stakeholders	53
5.5.1	Importer	53

5.5.2	Phosphorus compounder	53
5.5.3	Wholesaler	54
5.5.4	Retailer	55
5.5.5	Farmer coops, farmers	55
5.6	Fertilizer companies in Czech Republic	57
5.7	Other Markets (except agriculture)	57
5.8	Conclusions	58
6	Germany	59
6.1	Fertiliser Producers in Germany	59
6.1.1	Phosphate fertiliser Producers	59
6.1.2	Nitrogen Fertiliser Producers	61
6.1.3	Potash and Magnesium Fertiliser Producers	65
6.2	Fertiliser Distribution – Wholesalers and Retailers	67
6.2.1	Agricultural cooperatives	67
6.2.2	Fertilizers for ecological farming	69
6.2.3	Summary Fertiliser Distribution	70
6.3	German phosphate fertilisers	70
6.3.1	Phosphate fertiliser types and their market penetration	70
6.3.2	Chemical characteristics of popular phosphate fertilizers	71
6.3.3	Mineral phosphate fertiliser flows to and from Germany	72
6.4	Total phosphate supply to German cropland	73
6.5	Regional market aspects	74
6.6	Fertiliser market value and prices	78
6.7	Conclusion	79
7	Spain	80
7.1	Agriculture in Spain	80
7.2	General Description of the fertilizers market in Spain	81
7.3	Fertilizers consumption	81
7.4	Actors in the value chain	83
7.5	Importers	86
7.6	Producers	87
7.7	Wholesalers and retailers	88
7.8	Farms and Farmers cooperatives	89

7.9 Conclusions 89
8 Switzerland 91
8.1 Overview 91
8.2 Agriculture 92
8.3 Other Markets 95
8.3.1 Horticultural, gardening and landscaping 95
8.3.2 Ecological Farming 96
8.3.3 Other 96
8.4 Fertilizer Stakeholders in Switzerland 96
8.5 Discussion of Swiss Market Structure and Conclusions 96
9 References 97
Annex 102
Annex A : Processing Map 102
Annex B : Bulgaria 108
Annex C : Data tables Czech Republic 114
Annex D : Czech Republic 118
Annex E : Germany 128
Annex F : Germany - Additional Information 137
Annex G : Spain 144
Annex H : Switzerland 162

Glossary

Struvite	Magnesiumammoniumphosphate (MAP)
Arable land	Arable land is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow ("FAOSTAT - Concepts & definitions - Glossary (list)". FAO. Retrieved 2 November 2013)
Agricultural area	The sum of areas under arable land, permanent crops and permanent meadows and pastures ("FAOSTAT - Concepts & definitions - Glossary (list)". FAO. Retrieved 2 November 2013)
Land	Land can be divided into agricultural land, forest and other land. ("FAOSTAT - Concepts & definitions - Glossary (list)". FAO. Retrieved 2 November 2013)
ESU	1 European size unit or ESU is defined as a holding generating an income of less than 1200 €/a.
WWTP	Wastewater treatment plant
Organic fertilizer	Fertilizer containing organic materials

Figures

Figure 1: Diagram of results and reports foreseen in the DoW of P-REX 12

Figure 2: Schematic view of the fertilizer value chain 12

Figure 3: Mineral phosphorous application in European countries (Eurostat, 2010), P-REX study regions with bold border (from west to east: Spain, Switzerland, Germany, Czech Republic and Bulgaria). UAA-Utilised Agricultural Area. 18

Figure 4: Processes for mineral fertilizer production and marketing. On the one hand from waste and on the other hand in the fertilizer industry from phosphorus rock. Arrows indicate possible entry points in the fertilizer production value chain. Optional processes marked with*. PA denotes Phosphoric Acid. 25

Figure 5: (a) Phosphorus imports into EU (b) further processing of phosphoric acid (Richards & Dawson, 2008) (The Essential Chemical Industy online, 2013) 29

Figure 6: Phosphorus flows in EU-27 (2005) [in 1000 t] Source: Van Dijk (2013) 30

Figure 7: Phosphorus use in EU-27 in tons per year (Eurostat, 2013). 31

Figure 8: Process scheme for producing different types of fertilizer (International Plant Nutrition Institute , 2010) 32

Figure 9: Overview of the production of NPK fertilisers from phosphate rock or SSP/TSP (European Commission, 2007) 33

Figure 10: Process scheme of the Dihydrate process (European Commission, 2007) 34

Figure 11: Sites processing fertilizer containing phosphorus in EU-27. Sites marked with a red circle produce TSP/SSP (European Commission, 2007) (Public Sources , 2014) 35

Figure 12: Sites marked with the P-Rex symbol are interested in using recycled phosphorus products, companies marked with a green triangle are interested but not at the current status (P-Rex, 2013). 37

Figure 13: Companies interested in using secondary phosphorus-containing materials are marked with the P-Rex symbol and sites which already recycle phosphorus are marked red (P-Rex, 2013). 38

Figure 14: Fertilizers import into Bulgaria in t/a (Bulgarian Statistical Institute, 2011) 40

Figure 15: Fertilizers export from Bulgaria in t/a (Bulgarian Statistical Institute, 2011) 41

Figure 16: TSP price paid by actors along the value chain in the Bulgarian fertilizer market (Bulgarian Statistical Institute, 2011)(Interviews, 2013) 44

Figure 17: Overview of the different parts in the value chain in the Bulgarian fertilizer market 45

Figure 18: Import of various phopshorus rich material into the Czech Republic (Czech Statistical Institute, 2012) 48

Figure 19: Import into the Czech Republic (fertilizers – left, raw material containing P – right) in overview (Czech Statistical Institute, 2012) 50

Figure 20: Overview of stakeholders on Czech fertilizer market (based on data from questionnaires, 2012)56

Figure 21: P flow in Czech fertilizer market (Czech Statistical Institute, 2012)(questionnaires, 2012) – amount expressed as P2O5 volumes 56

Figure 22: Sector map of the phosphorus in the Czech fertilizer market. 57

Figure 23: TSP price paid by stakeholders along the value chain in the Czech Republic (Czech Statistical Institute, 2012) (Individual stakeholders) 58

Figure 24: N and P fertiliser production in Germany locations and capacities 59

Figure 25: Structure of the German “Raiffeisen” co-operations 69

Figure 26: Average prices of mineral fertilisers in € per ton of nutrient (Statistisches Bundesamt, 2012) 79

Figure 27: Spanish Fertilizer Overview (ANFE, 2009) 82

Figure 28. Fertilizer Sales in Spain (million t) (ACEFER, 2012) 82

Figure 29: Seasonal Evolution of the Phosphorus Fertilizer Prices in Spain (COAG; IFA, 2012) 83

Figure 30: Number of actors in the fertilizers value chain 85

Figure 31: Fertilizer import ports (ACEFER, 2011) 87

Figure 32. Main Fertilizer Production Plants in Spain 88

Figure 33: Mass fraction of phosphorus present in different forms in the Swiss fertilizer imports (Eidgenössische Zollverwaltung, 2012) 92

Figure 34: TSP price paid by actors along the value chain in the Swiss fertilizer market (from company interviews; values from 2 actors) 93

Figure 35: P-flow based in the Swiss fertilizer market (Eidgenössische Zollverwaltung, 2012) (Raaflaub & Genoni, 2005) (company interviews) 94

Figure 36: Sector map of the phosphorus sales in the Swiss fertilizer market (Eidgenössische Zollverwaltung, 2012) (Raaflaub & Genoni, 2005) (company interviews) 95

Figure 37: Production of most popular crops in 20 years (Statistisches Bundesamt, 2012) 139

Figure 38: Total crop yield 2012 in million tonnes per Federal State and comparison to 2011 (Statistisches Bundesamt, 2012) 140

Figure 39: Average crop yield in dt/ha per Federal State, preliminary result for 2012. (Statistisches Bundesamt, 2012) 140

Figure 40: Recent development of fertiliser sales in million tonnes of nutrients in Germany (Industrieverband Agrar, 2012) 142

Figure 41: National sales of fertilisers per nutrient type in Germany (Statistisches Bundesamt, 2012) 143

Tables

Table 1: Agricultural land, number of holdings and major crops in selected countries and the EU ((Eurostat, 2007) (Eurostat, 2010) (CIA, 2011) 17

Table 2: Absolute and specific mineral phosphorous application use in selected countries and the EU (Eurostat, 2010) 18

Table 3: Product mix of fertilizer sold in Germany 19

Table 4: Market volumes of phosphorus raw material for mineral product groups in Europe 20

Table 5: Quality requirements and associated decontamination processes for mineral phosphorus product groups 21

Table 6: Processing companies per country 22

Table 7: TSP price paid by actors along the value chain in the studied countries. In general data from 2012. The variations between different price quotes for the same year and between different years for the same quote are typically ±30%. 23

Table 8: Information provided by different actors in the value chain (data from company interviews) Groups providing similar information (e.g. importer and producer) were grouped for better readability. 23

Table 9: Fraction of different packaging in selected European countries (IFA; UNEP, 2000) 24

Table 10: Comparison waste and product with regards to price and cost factors. 24

Table 11: Strength and weaknesses of different possibilities for entry on the fertilizer market 26

Table 12: Common abbreviations of products containing phosphorus 32

Table 13: Sites using or interested in using recycled phosphorus materials (P-Rex, 2013) 36

Table 14: Amount of fertilizers imported into Bulgaria annually (t/a) (Bulgarian Statistical Institute, 2011) 40

Table 15: Amount of fertilizers exported from Bulgaria annually (t/a) (Bulgarian Statistical Institute, 2011). 41

Table 16:Development of annual P consumption in kg/ha in the Republic of Bulgaria in the last 10 years (Eurostat, 2013) 42

Table 17: Phosphate fertilizers import and export Republic of Bulgaria (Bulgarian Statistical Institute, 2011). 42

Table 18: List of contacted companies in Bulgaria 43

Table 19: Sector map of the phosphorus in the Bulgarian fertilizer market 45

Table 20: Information flow in value chain (data from company interviews) 45

Table 21: Amount of fertilizers imported into the Czech Republic annually overview (Czech Statistical Institute, 2012) 49

Table 22: Relative amount of fertilizers exported into the Czech Republic annually overview (Czech Statistical Institute, 2012) 51

Table 23: Phosphorus materials import and export Czech Republic (Czech Statistical Institute, 2012) 51

Table 24: Phosphate fertilizers import and export Czech Republic (Czech Statistical Institute, 2012) 52

Table 25: Development of annual phosphorus consumption in kg/ha of arable land in the Czech Republic in the last 10 years (Ministry of Agriculture, Czech Republic, 2012) 52

Table 26: List of contacted companies in the Czech Republic 54

Table 27: Information flow in value chain (data from company interviews) 57

Table 28: Phosphate fertiliser companies and capacities in Germany 60

Table 29: Nitrogen fertiliser companies and capacities in Germany (Industrieverband Agrar, 2012) modified 62

Table 30: Potash and magnesium fertiliser capacities in Germany (Industrieverband Agrar, 2012) 66

Table 31: Potash and magnesium fertiliser product range (Industrieverband Agrar, 2012) 67

Table 32: Supply of phosphate-containing fertilisers to agriculture (t P_2O_5) (Statistisches Bundesamt, 2012) 71

Table 33: Nutrient forms and declarable solubilities of major phosphate containing fertilizer types (Industrieverband Agrar, 2012) 72

Table 34: Deliveries to agriculture and imports of phosphate fertilisers in 1.000 t P_2O_5 (Statistisches Bundesamt, 2012) 73

Table 35: Phosphate-fertiliser imports in 1.000 t P_2O_5 (Statistisches Bundesamt, 2012)(modified) 73

Table 36: Foreign trade: phosphate fertilisers 1.000 t P_2O_5 (Statistisches Bundesamt, 2012) 73

Table 37: Supply of nitrogen, phosphate, potash and lime fertilisers to agriculture (Statistisches Bundesamt, 2012). 73

Table 38: Mineral fertiliser application in kg nutrient per ha agriculturally used land (including fallow land) (Statistisches Bundesamt, 2012). 74

Table 39: Domestic sales of phosphate fertilisers by Federal State and type, 2010/2011 in t P_2O_5 (Statistisches Bundesamt, 2012) 75

Table 40: Share of Federal States in total sales by type of phosphate fertiliser in P_2O_5, 2011/2012 in percent (Statistisches Bundesamt, 2012) 76

Table 41: Share of phosphate fertiliser types in P-fertiliser sales by Federal State, 2011/2012 in percent 77

Table 42: Farmers' expenditures for commercial fertilisers [1)] (Bundesministerium für Ernährung und Landwirtschaft, 2009) 78

Table 43:Spanish Fertilizer Market - Domestic Consumption (million t) (ACEFER, 2011) 81

Table 44: Companies covering different parts of the value chain 84

Table 45: Production, Consumption, Imports and Exports of fertilizers into the Spanish Market (ANFFE, 2013) 86

Table 46. Spanish Fertilizer Market - Imports (Million t) (ACEFER, 2012) 86

Table 47: Spanish fertilizer producers 87

Table 48: Spanish Fertilizer Market, Production (Million t) 88

Table 49: Wholesalers and retailers distribution into the Spanish market. 89

Table 50: Companies covering different parts of the value chain (Data from company interviews) 92

Table 51: Information flow in value chain (data from company interviews) 95

Table 52: German farms and their acreages (Statistisches Bundesamt, 2013a). 137

Table 53: German farm sizes in hectare (ha), 2012 (Statistisches Bundesamt, 2013a). 137

Table 54: Farms in Federal States 2012 (Statistisches Bundesamt, 2013b). 138

Table 55: Crop production in Germany in terms of acreage and yield per crop type (Statistisches Bundesamt, 2012) 141

1 Introduction

1.1 Background

The survey of market structure focuses on mineral products (mineral fertilizer, various other phosphorus chemicals for industrial and consumer markets). Worldwide, some 90% of the phosphorus ore is used for mineral fertilizer production (Kongshaug, et al., 2012). Mineral fertiliser is a complement to organic fertilizers such as farm yard manure (FYM) and soil conditioner which supply the main part of the plant's nutrient needs. Therefore mineral fertilizer will be the first to be replaced by mineral phosphorus recycled from wastewater. This is possible since the secondary phosphorus has processing, storage and application properties similar to mineral fertilizer. Organic fertilizers (as opposed to mineral) are sometimes mentioned to give an overall perspective, but the organic fertilizer market is not covered in this report. Neither is local reuse of recovered phosphorus-containing materials or the phosphorus which is reused with a status of "waste" rather than with a status of fertiliser.

1.2 Objectives and Method

The objective of the market study is to provide a guideline to corporations intending to place a new recycling product on the market. The study is based on stakeholder interviews and literature and covers five countries: Bulgaria, Czech Republic, Germany, Spain and Switzerland.

The preliminary results of the market and also legal studies (see D11.2 of P-REX) both studies were presented and discussed with a group of 55 selected experts in a workshop in Podebrady, Czech Republic. The discussions took place in parallel groups at seven tables and the participants were very active. The discussions yielded an analysis of different themes and many ideas for solutions and approaches. These were useful as context for the present report but mostly they will be a starting point for the coming report D11.3 (Figure 1) where past business cases will be analyzed and future possible business models developed and described. These models will together with the present study of legal and societal factors be the basis for suggestions for the most promising and urgent modifications of policy.

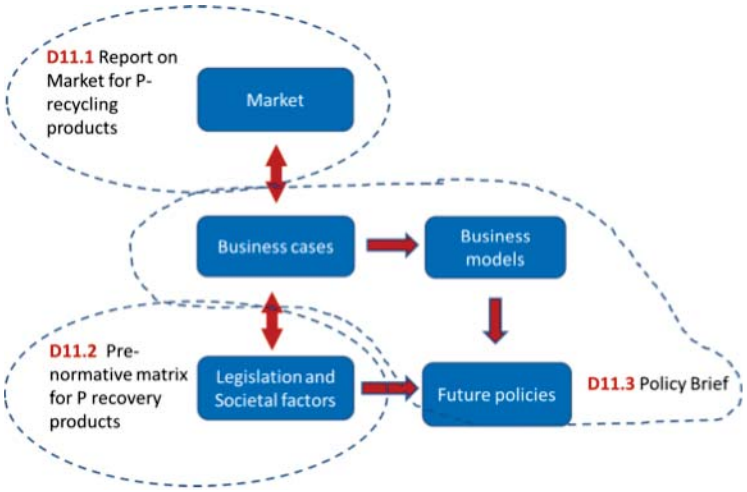

Figure 1: Diagram of results and reports foreseen in the DoW of P-REX

1.3 Market value chain and segments

The market study maps the fertilizer value chain (Figure 2). Below a short description of the acitvities and motivations of the actors in the fertilizer value chain is given.

Figure 2: Schematic view of the fertilizer value chain

1.3.1 Importer

The importer imports rock, phosphoric acid or finished fertilizers from abroad. European phosphorus reserves are insignificant, less than 0.1% of global reserves (Jasinski, 2013), so all imports come, directly or indirectly, from outside Europe. The importers expect a certain quality and certain physical characteristics from the phosphorus producers such as specified phosphorus content.

1.3.2 Phosphorus compound producer

The phosphorus compound producer chemically transforms raw materials to a form which can be used for fertilizers. Typically raw phosphate is acidulated or transformed into phosphoric acid which in turn can be further transformedFigure 9: Overview of the production of NPK fertilisers from phosphate rock or SSP/TSP(Figure 9). Compound producing factories are often integrated producing also finished fertilizer granules.

1.3.3 Fertilizer compounder

The fertilizer compounder produces fertilizer granules out of powdery or liquid materials. The producers have to be aware that the end-user requires a certain quality (particle size distribution, dust fraction

and solubility) which is also often part of legislation. Fertilizer can be divided into compound (multi-nutrient, e.g. NPK) and single nutrient fertilizers (IFA; UNEP, 2000).

1.3.4 Fertilizer blender

Compound fertilizers can be produced as complex (multi-nutrient) granules or as a blend of granules with different nutrients. The fertilizer blender blends different granules to fit the desired nutrient specification. Many actors perform several functions and can be at the same time compound producer, fertilizer compounders and blenders. The finished products are then sold to the wholesaler.

1.3.5 Wholesaler

The wholesaler sells fertilizers to the retailer. Some wholesalers are also retailers, thus supplying both other retailers and directly the end-user. Wholesalers are generally interested in field trials and feedback from end-users for quality assurance. They also have to make sure that they have enough fertilizers in stock.

1.3.6 Retailer

The retailer sells the fertilizers to the end-user. The retailer depends on the products obtained from the wholesaler and has to make sure that he gets a good quality product .

1.3.7 Farmers coop

The farmers coop is a retail organisation owned and controlled by the farmers in the same region. They thus source farm equipment and supplies for members. Some coops' activities also involve sale of member's products and common cultivation and harvest of products. Being farmer-owned, coops can react more quickly to their wishes than an ordinary retailer. Through a coop the farmer has a better negotiating position with his suppliers.

1.3.8 Farmer

The farmers buy the fertilizers from a retailer. As an end-user their demand should be guiding the actions of the other actors in the value chain.

2 Overall results and discussion

In this chapter an overview important results from the five studied countries; Bulgaria, Czech Republic, Germany, Spain and Switzerland; are highlighted. Characteristics of the European phosphorus market is briefly described and discussed. Possibilities for market entry of recycled phosphorous are summarized.

2.1 Market description

2.1.1 Overview of the fertilizer value chain and recycling in the studied regions

2.1.1.1 Bulgaria

Bulgaria, as all countries in Europe except Finland, has no own resources of rock phosphates and thus depends on imports. Some 240’000 tons of fertilizers were imported in 2011, of which 10 % constitute of NPK, 60 % NP and 1 % PK. etc. The Bulgarian fertilizer market is dominated by two producers (Neochim PLC and Agropolychim JSC) who also act as the main wholesalers and distributors to farmers. Apart from these two companies, four other main wholesalers and many smaller ones exist.

In the Bulgarian market no company is using recycled phosphorus materials and they did not show interest in phosphorus recycling during interviews conducted within the P-REX project.

No industrially recycled phosphorous from sewage is currently used in Bulgaria. However, direct application of sewage sludge is allowed and practiced in Bulgaria. Farmers currently are not open to the idea to use recycled phosphorous in other forms in the near future since they have poor knowledge about the risks and are afraid to products recycled from waste.

2.1.1.2 Czech Republic

In the Czech Republic 205 national and 235 international fertilizer producers are registered. Of nineteen companies surveyed in the Czech Republic, three are involved in phosphate fertilizer production (Lovochemie, Fosfa and Silvamix). While Lovochemie had dominated the phosphate fertilizer production for 44 years, it stopped production in 2012 due to an interruption of phosphorous supply from Russia. Since then the import of phosphate fertilizers dominates the market. An important holding in the agricultural sector is Agrofert, which includes fertilizer wholesalers and the fertilizer producer Lovochemie. In the Czech Republic many wholesalers also act as retailers and sell directly to the end-user. The three most important wholesalers are Navos, ZZN Polabi and ZZN Pelhřimov.

The fertilizer producer Lovochemie is interested in recycled materials in large volumes (>5000 t), much larger than what could be produced by struvite precipitation in major plants. They prefer struvite to phosphorus rock and would also consider ash with phosphorus content of about 17%. The phosphorus specialties producer FOSFA is interested not only in the recycled product but also in recycling technologies. They could use for example struvite, but currently the price is too high. Currently no recycled mineral phosphorus materials are used in the Czech Republic and few stakeholders except the fertilizer producers are interested in phosphorus recycling. The reason of low interest in phosphorus recycling is probably the lack of information, social barriers and the lack of pressure to use recovered phosphorus.

In the Czech Republic direct application of sewage sludge is possible and practiced. However, farmers are not open to use of other recycled phosphorus products for fear of recycling contaminants (see also chapter 5 and Annex D).

2.1.1.3 Germany

There is one phosphate fertilizer producer, ICL, and seven companies producing Nitrogen-fertilizer in Germany. Only one of those, Yara, has some limited primary phosphate resources in Finland. The fertilizer distribution is dominated by the Raiffeisen farmers' cooperatives of which almost all farmers are members. The coops provide a full range of production material, e.g. seeds, fertilizers, feed-stuffs, agricultural engineering and the offer a large range of services to their members. The coops are organized in a national matrix organization with divisions for different products and for different regions. There is little competition between them.

The phosphate producer ICL is participating in most of the European phosphate recycling initiatives and would accept and test mineral, preferably ash-based, secondary phosphate products at their production site in Ludwigshafen. The ICL Negev mines have an estimated remaining lifetime of a few decades, so to keep the European manufacturing plants operational, secondary resources should replace rock phosphate. Two of the Nitrogen-fertilizer producing companies ALZCHEM, DOMO and SKW Piesteritz consider extending their product range and cooperating with P-recyclers. DOMO and SKW have already allocated some funds to further investigate the potential of producing a NP fertilizer including secondary phosphates. Concerning the German distribution step, the fertilizer distributors do neither favor, nor refuse selling recycled phosphates. Wholesalers mainly care for financial and logistical issues – quality discussions are mainly reserved to the retailer level.

The fraction of sewage sludge directly used in agriculture is decreasing due to the more and more stringent regulation implemented by the federal states. The fraction used directly is currently 30% (RPA Milieu Ltd and WRc , 2008). Recent political discussion even promotes the ban of direct sludge application (see also chapter 6 and Annex E).

2.1.1.4 Spain

Five major fertilizer importers with a total fertilizer import of 2.1 Million t/a operate in the Spanish fertilizer market. Approximately 46 % of the phosphorous traded on the Spanish market is imported and the rest is produced from imported feedstock. Spain produced some 321'000 t phosphorous fertilizer in 2010. There are eleven fertilizer producers in Spain of which Fertiberia dominates the market. 13 fertilizer exporters in Spain who exported some 38'000 t of Phosphates in 2010 are known. While independent retailers still account for a large proportion of the fertilizer market in Spain, retailer chains have become more and more important and now dominate the fertilizer market. Five associations represent farmers' interests in Spain

According to actors in the value chain, the challenge for recyclers on the Spanish market would be to be to offer secondary phosphorus at a comparable price. A higher price would considerably decrease the interest of the Spanish actors in this kind of product. Most of the interviewed actors agree in the importance of the phosphorus recycling in the future, but from their point of view the first step for introducing recycled phosphorus on the market would be to adapt the Spanish legislation accordingly.

Only then can recyclers reach competitive production cost and sale prices necessary in order to trigger demand for secondary phosphorus (see also chapter 7 and Annex G)..

2.1.1.5 Switzerland

Switzerland phosphorus fertilizers are supplied by imports of raw materials and finished products. The country has three fertilizer compounding and two blending plants refining and mixing for the agricultural market and also for niche markets. The Swiss phosphorus fertilizer market is dominated by the farmers coops (Landi) and their holding company Fenaco. Fenaco controls 55% of the production/import step through Landor, 75% of the wholesale step through Landor and Agroline and even 85% of the retail step through the Landi stores and Agroline.

All Swiss producers and importers would be able to use recycled phosphorus as a new phosphorus-source. They would pay a price which is the same as the standard phosphorus or lower. Furthermore, most of the companies need the recycling product to in granulated form as a ready to use fertilizer. In Switzerland direct application of sludge on arable land is prohibited since 2006. 100% of the sludge is incinerated, about half of it in mono-incineration plants (see also chapter 8 and Annex H).

2.1.2 European phosphorous demand

2.1.2.1 Fertilizer market

In the EU as a whole agricultural land represents 40% of total land (arable land 24%, grassland 13.5% and permanent crops 2.5%).The average holding larger than 1 ESU, in the EU has 24 ha of land(Table 1). The studied countries average farms sizes varying from 19 ha in Switzerland to the 133 ha in Czech Republic, which has farms more than five times larger than the EU average. The studied countries are located in northern, middle or southern Europe and consequently have different climatic conditions. Spain for example is facing drought and irrigation issues, which has led to a high level of fertigation in Spain (10% of the fertilizer). The crops also vary from northern crops like sugar beets and potato to southern crops like olives and citrus fruits (Table 1).

Table 1: Agricultural land, number of holdings and major crops in selected countries and the EU ((Eurostat, 2007) (Eurostat, 2010) (CIA, 2011)

	Agricultural land (1000 ha)	**Number of holdings over 1 ESU**	**Agricultural land (ha/ holding)**	**Major crops**
Bulgaria	3’500	118'000	30	vegetables, fruits, tobacco, wine, wheat, barley, sunflowers, sugar beets
Czech Republic	3’500	26'000	133	wheat, potatoes, sugar beets, hops, fruit
Germany	16’000	348'000	47	potatoes, wheat, barley, sugar beets, fruit, cabbages
Spain	18’000	939'000	19	grain, vegetables, olives, wine grapes, sugar beets, citrus
Switzerland	900	62'000	15	grains, fruits, vegetables
EU	150’000	7'311'000	24	

[1] (Eurostat 2010)

[2] (Eurostat 2007). The holdings smaller than 1 ESU (generating an income of less than 1200 €/a) is discarded in the EU statistics. They represent a large fraction of the number of holdings (46%), but a small fraction of the surface (7%). Over 70% of them consume more than 50% of the farm produce themselves.

[3] (CIA , 2011)

The studied countries have varying specific mineral phosphorus fertilizer use varying from 3.9 kg P/(ha agricultural land*a) in Bulgaria to 8.1 kg P/(ha agricultural land*a) in Spain, the EU-average being in between (6.0; Table 2). The ranking varies over time since the use of phosphorus increased by 60% (BG) or decreased (CR, DE, ES, CH) by up to 50% over the last five years in the different countries. One of the reasons, as observed in the Spanish study, is that farmers tend to cut down on phosphorus when prices are high and funds are scarce. The crop can use the phosphorus in the soil, and cutting phosphorus fertilization has often no direct effect on yield for many years (Römer, 2013). Also the type of crops can co-determine the specific phosphorus fertilizer use. Vegetable cultivation which is common in Spain is more intense and fertilizer-consuming than for example grain production.

Table 2: Absolute and specific mineral phosphorous application use in selected countries and the EU (Eurostat, 2010)

	Mineral phosphorus application	
	(t P/year)	(kg P/(ha agricultural land*a))
Bulgaria	17'000	4.8
Czech Republic	13'500	3.9
Germany	102’000	6.2
Spain	147'000	8.1
Switzerland	4'500	5.0
EU27, Eurostat estimation	1'032'000	6.0

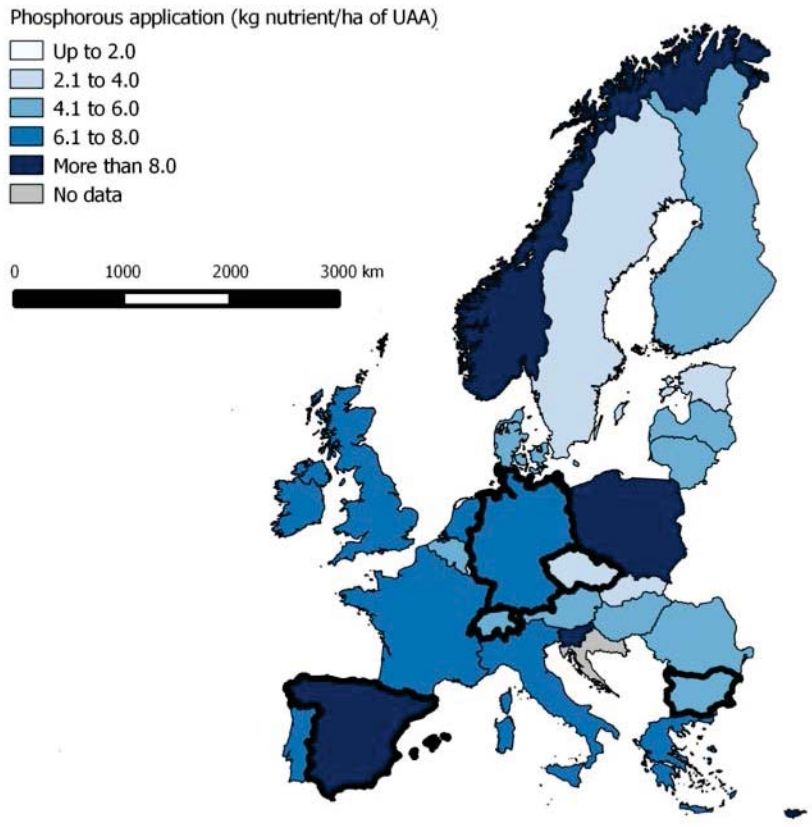

Figure 3: Mineral phosphorous application in European countries (Eurostat, 2010), P-REX study regions with bold border (from west to east: Spain, Switzerland, Germany, Czech Republic and Bulgaria). UAA-Utilised Agricultural Area.

The product mix of sold fertilizer is only known for Germany (Table 3), but comparing with Swiss and Czech imports we can safely say that pure phosphorus fertilizers have only a small part of the European market. Thus a combination of recycled phosphorus with other nutrients to compound fertilizers makes it possible to sell much larger volumes.

Table 3: Product mix of fertilizer sold in Germany

	Fraction of total phosphorus (%)
NPK	19
NP	65
PK	8
P	8

In the end-user step two sectors with similar products and retailers can be distinguished:

- agriculture and horticulture (large market volume)
- gardening and landscaping (small market volume)

The gardening and landscaping products are in general more diversified and sold in smaller packages with higher margins. However, often the raw materials used are the same as in agriculture and horticulture. The higher margins are motivated the diversity of products, the smaller packages and by known brands built on long experience and market presence. According to results from the studied regions this sector makes up some 3-5% per weight of the phosphorus market (CH 5%, CR 3-5%. DE 5%, BG 3%).

Ecological farming is a distinct fertilizer market practiced on 4.7% of EU agricultural land. Ecological farms rely mostly on organic materials like farm yard manure and soil conditioner for nutrient input. Soft phosphate rock is the only available and allowed mineral source for supplying additional phosphorus when it is lacking. In principle, water insoluble phosphates such as struvite, phosphate slags or calcined phosphates may be in compliance with the rules of ecological farming. However, none of the recycled fertilizer types is approved for ecological farming in compliance with Regulations (EC) 834/2007 and (EC) 889/2008.

2.1.2.2 Other markets

It is useful to put the phosphorus fertilizer market into the context of the total mineral products market in Europe. The fertilizer market of EU-27 currently (2010) uses some 65% of the mineral phosphorus raw materials (Table 4). The amount of fertilizer fluctuated by up to 40% in the last years (Figure 7) influencing market share. The market share will also change as phosphorus in detergents for household use are phased out and also if animal byproducts currently banned can again be processed to feed phosphate. The raw materials of for other products are more expensive than those for the fertilizer. Therefore the fertilizer raw materials market value fraction is smaller than its volume fraction.

Table 4: Market volumes of phosphorus raw material for mineral product groups in Europe

	Amount (10^3 t P/a)[1]	**Fraction (%)**
Fertilizers	1000[2]	65
Feed	250[3]	16
Detergents and soaps	200	13
Food and beverages	33	2.1
Water treatment	21	1.4
Toothpaste	3	0.2
Other uses: Ceramics, leather, anticaking, setting retarders, flame retardants, paper, anticorrosion pigments, textiles, rubber manufacture, activated carbon, fermentation, antifreeze	42	2.7
Total	1550	100

1 Non-agricultural products in (Schrödter, Betterman, Staffel, & Wahl, 2012). Data from 2006.

2 Eurostat 2010/2012

3 (IFP, 2009)

The quality requirements for raw materials for other markets are also higher (Table 5). In general Fe, Mg, Al and Ca need to be lower than 5000 mg/kg P (Schipper, 2013). To reach those limits requires intensive processing when starting from a typical sludge ash. It has a content of Fe >300’000 mg /kg P and Al >400’000 mg /kg P (Adam, 2012). On the other hand, the current feed stock rock phosphate and also bone-meal ashes are rich in calcium, which is also considered a contaminant in non-feed, non-fertilizer in other market sectors. Therefore sewage sludge could also be a suitable raw material to be processed to meet stronger purity requirements. The feed market might be interesting for recyclers since the main compounds used for feed are calcium phosphates that can be produced directly by precipitation from wastewater or leachates of ash and sludge.

Table 5: Quality requirements and associated decontamination processes for mineral phosphorus product groups

	Main quality requirements (mg/kg P)	**Decontamination of phosphate rock**
Fertilizers	Some contaminants limits	Usually not required
Other non-food, uses[1]	Fe, Mg, Ca, Al: 100 to 5000	Digestion to phosphoric acid and filtration. Usually solvent extraction; crystallisation process in one European plant. Sometimes phosphoric acid from the thermal route is used.
Feed[2]	As<40 F< 8000 (also Cd, Hg, Pb and dioxins)	Digestion to phosphoric acid and filtration. Elimination of As and F. Crystallization as DCP or MCP.
Food and beverages[3]	Volatile acids<30 Chlorides<600 NO_3<10 SO_4<3400 F<30 As, Cd, Pb, Hg<3	Digestion to phosphoric acid and filtration. Solvent extraction and additional purification. Sometimes phosphoric acid from the thermal route is used.

[1] Schipper 2013

[2] 2003/100/EC, legal limits recalculated assuming MCP and DCP

[3] EC/231/2012, legal limits recalculated for phosphoric acid

The amount of phosphorus in mineral fertilizer is smaller than in the organic materials. Farm yard manure accounts for a supply 2000 kt/a of phosphorus and sewage sludge in agriculture 160 kt/a of phosphorus (Figure 6).

2.1.3 European value chains to satisfy fertilizer demand

2.1.3.1 Processing of mineral phosphorous

There are only few (0-3) companies that are able to chemically transform mineral phosphorus raw materials (e.g. acidification of phosphorus rock) in each of the studied countries. (Table 6).

Table 6: Processing companies per country

	Chemical transformation of phosphoric raw materials	**Granulation**	**Blending**
Bulgaria	2	2	6
Czech Republic	0	3	3
Germany	1	8	>50
Spain	3	>10	>100
Switzerland	0	3	2

2.1.3.2 Import and logistics

Logistics is of great importance for international fertilizer trade. An additional road transport of only 100 km represents 15% of the total price, which is high enough to determine which supplier will be chosen[1]. As pointed out in the German study, transports on inland waterways and by rail is much cheaper, but only if entire trains or barges can be filled, starting from 800 tons per shipment. Consequently the national fertilizer market is supplied by finished products in barge/train in large quantities with corresponding warehouses. Or raw materials are shipped in large quantities to fertilizer plants which produce the products demanded in the region.

2.1.3.3 Wholesalers and retailers

The studied countries have a varying market structure in the wholesaler and retailer step. In Germany and Switzerland those steps are dominated by farmer's cooperatives. In Bulgaria and Spain there is one larger company controlling 40% and 75% respectively of the wholesaler step. In the Czech Republic the wholesale and retail steps are diversified.

2.1.4 Prices along the value chain

The Triplesuperphosphate (TSP) price in the studied countries was calculated with data from company interviews (Table 7). Although the prices are vary a lot between actors and over time they give an indication of prices paid by actors along the fertilizer value chain in agriculture and horticulture. Prices and margins in the specialized gardening and landscaping markets are considerably higher. The import prices vary between 370 €/t and 500 €/t. Following packaging and transport and the margins required for handling and storage end-user prices vary between 500 €/t and 970 €/t. The recycler can judge if the higher prices in the end-user step are worth the additional work of branding, packaging, transport and even retail.

[1] Road transport costs around 5 €/t +0.1 €/(t*km) (Glas, et al., 2008). A purified sewage sludge ash contains around 10% phosphorus. Transporting such a material 100 km would cost 150 €/t phosphorus. Phosphorus costs the end-user 1000 €/t (German study).

Table 7: TSP price paid by actors along the value chain in the studied countries. In general data from 2012. The variations between different price quotes for the same year and between different years for the same quote are typically ±30%.

	Import/production bulk (€/t)	**Retailer bag delivered (€/t)**	**Farmer bag delivered (€/t)**
Bulgaria	360	510	970
Czech Republic	500	530	650
Germany	-	-	500
Spain	-	-	-
Switzerland	370	420	600

2.1.5 Information in the value chain

The information provided by stakeholders was systematically collected in Switzerland and the Czech Republic and less detailed in the other countries (Table 8). The important factors for successful transactions include price, quality (physical characteristics, P-content) and service (delivery speed). In the German market wholesalers mainly care for financial and logistical issues quality discussions are generally reserved to the retailer level.

Table 8: Information provided by different actors in the value chain (data from company interviews) Groups providing similar information (e.g. importer and producer) were grouped for better readability.

Importer **Producer**	**Wholesaler** **Retailer**	**Farmer** **Coop**
Price P_2O_5-content (e.g. TSP 42-46 %) Cadmium-content Physical characteristics (dust content, granulation) Quality Verified supplier Package size Delivery speed	Price Availability Packaging (bigbags, bags) Delivery speed Quality Verified supplier	Local access to the farm (possible with truck?) How the want delivery (home delivery, pick up, store) Physical characteristics What kind of fertilizer distributer they use Packaging (big bags, bags) Creditworthiness Feedback

2.1.6 Packaging and delivery to the farm

Packaging varies strongly between countries as shown for selected countries in an UNEP study on environmental impact of fertilizer transport (IFA; UNEP, 2000). The delivery to the farm is mostly in bulk in Denmark, Germany and the Netherlands. Loose bags dominate in Spain, indicating a rather labour- intensive type of agriculture whereas palleted bags are preferred in Norway and on Ireland. Intermediate bulk containers (IBC), finally, dominate in the UK. Liquid fertilizer is always a minor delivery form being the most popular in France (16% of total) among the studied countries.

This illustrates to the recycler, again, the diversity of the European national markets. It also shows that the fraction of blended material is low (compare bulk and bulk blend), although also many bagged fertilizers are blended (Table 9).

Table 9: Fraction of different packaging in selected European countries (IFA; UNEP, 2000)

	Denmark	Germany	Nether-lands	Norway	Spain	France	UK	Ireland
To the farm								
Bulk	83	80	83	1	20	34		8
Bulk blends	9	4	7	0	8	9	10	
Loose bags	0	0	0	0	58	2	0	
Palleted bags	7	3	10	51	10	21	16	71
IBCs	0	0	0	48	0	18	65	21
Fluids	1	13	1	0	3	16	9	

2.2 Possibilities for entry in the agricultural value chain

If the recycler chooses to sell the recycled material under waste regulation the market price will be low, in the range of phosphorus in manure. This might still be an interesting solution since the fix costs for investment in technology and REACH registration can be avoided or kept low as well as variable costs. Quality control will be less stringent and less costly. Because of the lower fixed costs this solution is favorable for smaller recyclers. Their limited output will favor regional solutions which in turn will benefit from lower transport costs (Table 10).

Table 10: Comparison waste and product with regards to price and cost factors.

	Waste	**Product**
Price	Lower	Higher
Fixed cost	Lower	Higher
Technology	Lower	Higher
REACH registration	No	Yes
Variable cost	Lower	Higher
Quality control	Lower	Higher
Transport cost	Lower	Higher

Larger recyclers might be better off offering their material under the legislation as products. They can use economies of scale to face the fix costs of investment in development and construction of more advanced technological solutions. Also the quality control involved in such a strategy will have economies of scale.

The recycler who chooses to enter the production of products can either put products of their own onto the market or choose to cooperate with fertilizer producers. They may enter the fertilizer production value chain at different stages (Figure 4):

- sell feedstock for phosphoric acid or superphosphate production (PA)
- sell feedstock for granulation (GR)
- sell granules for blended fertilizers (BL)
- sell a finished product for wholesalers or retailers (WR)
- sell a finished product directly to the customer (CU)

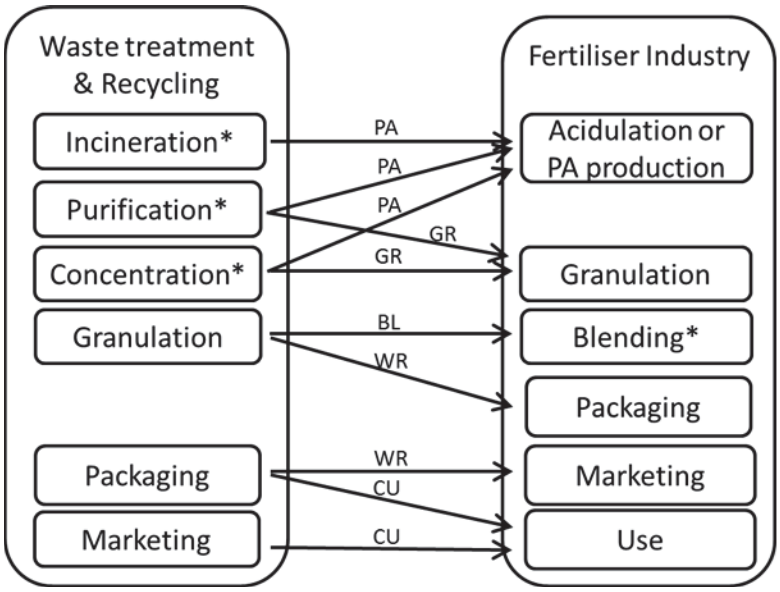

Figure 4: Processes for mineral fertilizer production and marketing. On the one hand from waste and on the other hand in the fertilizer industry from phosphorus rock. Arrows indicate possible entry points in the fertilizer production value chain. Optional processes marked with*. PA denotes Phosphoric Acid.

The choice will be dependent on the individual recycler and they all have strengths and weaknesses (Table 11). The fertilizer industry has huge experience and capacity in all steps from acidulation to marketing. Thus, if a reasonable price can be negotiated, it seems efficient for a recycler to specialize on the production of feedstock for acidulation or for granulation. However, if granulation expertise can be found, a position on the market for blended fertilizers might be interesting. This market is usually less focused on brands and specialties and more on price and reasonable quality, which can be suitable for a recycler entering a saturated market. To introduce their products at the fertilizer distribution level recyclers would need qualified personnel to talk to wholesalers and retailers.

Table 11: Strength and weaknesses of different possibilities for entry on the fertilizer market

		Partner (*optional)	Strength	Weakness
PA	Feedstock for acidulation or phosphoric acid production	Producer	Strong partner for fertilizer production and marketing, specialization on recyclate production.	Price negotiation with one large company.
GR	Feedstock for granulation	Producer	Several SME-size partners to choose from for fertilizer production and marketing. Specialization on recyclate production.	
BL	Product for Blending	Granulator*, Logistics company*, Blender	Access to market of blended materials. Several SME-size partners to choose from.	Several partners necessary.
WR	Product for wholesale and/or retail	Granulator*, Wholesaler/ Retailer	Recycling brand with higher margins possible. Many (smaller) partners possible.	Formulation and granulation capacity as well as feedstock with other nutrients must be secured by the recycler or by partner.
CU	Product for customer	Granulator*, Logistics company*	Recycling brand including own sales organization with higher margins possible. No partners necessary.	Many functions in addition to the recycling core competence must be secured by recyclers or by partners.

The recycler might consider entering collaboration with smaller fertilizer producers serving certain regions or niches such as the gardening and landscaping sector. These actors are often in the range of 100-10’000 t phosphorus/a in which recycling plants operate. Similar interests may promote a partnership.

2.3 Conclusion

In order to provide a guideline to corporations intending to place a new recycling product on the market the fertilizer market in Europe has been studied through literature and stakeholder interviews.

This is by far the most thorough study of the European (phosphorus) fertilizer markets. Commercially available surveys cover individual market stakeholders and market volumes. In addition, this survey includes aspects such as market structure, price structure and information exchange along the value chain. Furthermore, this study targets the recycler’s needs making it particularly interesting for this group.

The study comprises five different countries in south, middle and Eastern Europe and represents countries of small to large size. It thus provides insight in different cases and then tries to analyze the simi-

larities and differences encountered. All dimensions and the whole range of conditions that can be encountered in Europe are not covered, but a considerable part.

The method used and the quality of results differ between countries because of the experience of the four project partners performing the survey and the because of reactions and the willingness of the stakeholders to contribute to the survey.

There are still points left to be studied to provide more info relevant for recyclers. Further studies of the less deeply covered countries would be worthwhile. Although the group of countries studied is diverse, further countries such as the Nordic countries with their large distances and cold climate would surely also add new insights.

In the present study the fertilizer demand is described in terms of volumes and mineral fertilizer product types. The role of organic based fertilizer, which represents a larger amount of phosphorus than the mineral fertilizer, is not described. Neither are the instances of mixed organo-mineral fertilizer. Also the possible motivation for this kind of phosphorus supply (i.e. the mix organic/mineral) was not questioned. Such an analysis would certainly also give valuable insights. It would help the recycler to find an innovative market strategy and product design. A step in this direction will be made in the P-REX project: the project partner IASP will analyze how crops can best be supplied with phosphorus from different fertilizer products, whether organic or inorganic, whether recycled or fossil.

The research question was: how can a phosphorus recycler sell the recycled material? This question could be answered by providing a description of different aspect of five regional markets pointing out common and differing aspects, deriving options of entry in the value chain and evaluating their respective strengths. The main conclusions are:

Technical aspects

- Fertilizer production plants are much larger (2’000-200’000 t phosphorus/a) than the struvite recovery plants (200 t phosphorus/a) currently implemented. The upcoming ash based recycling plants will be similar in size to the smaller fertilizer production plants.
- Feedstock logistics is a challenge for ash based plants; metropolitan regions will be favourable for implementation.
- The fertiliser market is large enough for absorbing the phosphate from the wastewater stream at market prices.
- The market is currently served with highly soluble (water soluble), reasonably effective phosphates. At best recycled products will be as effective as conventional fertilisers.
- Recycled fertilisers must be sold with similar characteristics as conventional fertilisers in terms of price, plant availability, granule and other physical properties.
- Market aspects
- The studied countries usually have one or two dominant producers/importers, e.g. Fertiberia (ES), Agrofert (CR), Landor (CH), Neochim and Agropolychim (BG).
- Fertiliser distribution is dominated by large agricultural cooperatives and their retailer networks on several of the studied countries (DE, ES, CH)

- Most of the interviewed companies expressed the willingness to incorporate recycled phosphorus fertilizers or feedstock into their portfolio. Despite market integration and logistical hurdles, there are several alternative partners in each region with whom recyclers can enter the fertilizer value chain.
- Customers and actors are expected to be suspicious as in the case of every newly implemented technology and good marketing with successful case studies will be a key factor to for market penetration with recycled feedstock.
- Successful entrance of recycled products into the market is tightly connected with legislation.

The rationale behind phosphate recycling is a societal, future oriented concern. Real life benefits must be offered to actors to make market success of recycled materials possible.

3 Processing map

3.1 Scope

The present chapter contains a map of major locations for further processing of phosphorus- rich materials in Europe.

3.2 Method

Different methods were applied to gain information. Next to the evaluation of literature and open source information, questionnaire-based interviews were performed to find out to what extent fertilizer companies are using or would be prepared to use phosphorus from renewable feedstock (Annex A). In total over 104 processing sites were contacted. The names of the companies were obtained from Fertilizer Europe, Fertilizers Producers' Directory and a market study provided by Ceresana Research.

3.3 European phosphorus flows

EU-27 imports about 2'500 - 2'700 kt of phosphorus per year (Richards & Dawson, 2008) (van Dijk, et al., 2013).The largest fraction is imported in the form of rock phosphate (49%) followed by already processed fertilizer (23%), and phosphoric acid (1%).The rest (27%) of the phosphorus is imported among others as food, crops and metals (Figure 5a) (Richards & Dawson, 2008). Part of the rock phosphate is further processed to phosphoric acid, of which 80% is used to produce fertilizer (Figure 5b). The size of phosphorus-containing material streams, which enter and leave the food production system of the EU are depicted in Figure 6.

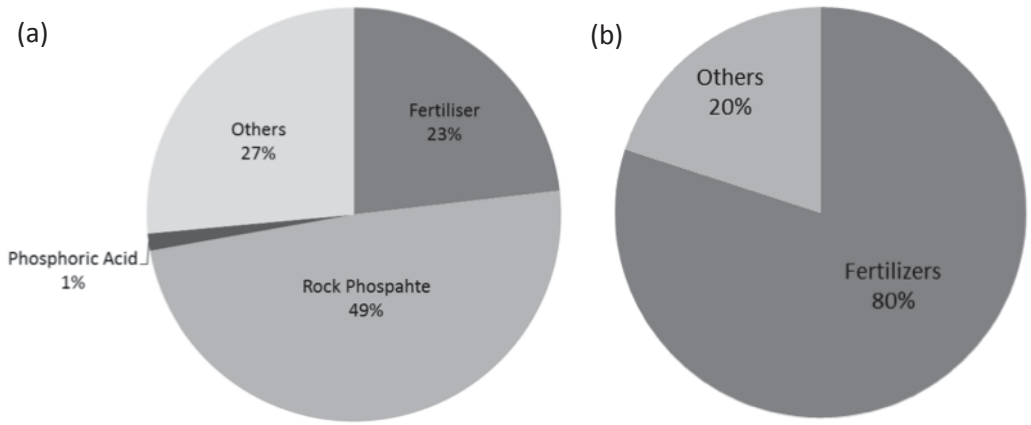

Figure 5: (a) Phosphorus imports into EU (b) further processing of phosphoric acid (Richards & Dawson, 2008) (The Essential Chemical Industy online, 2013)

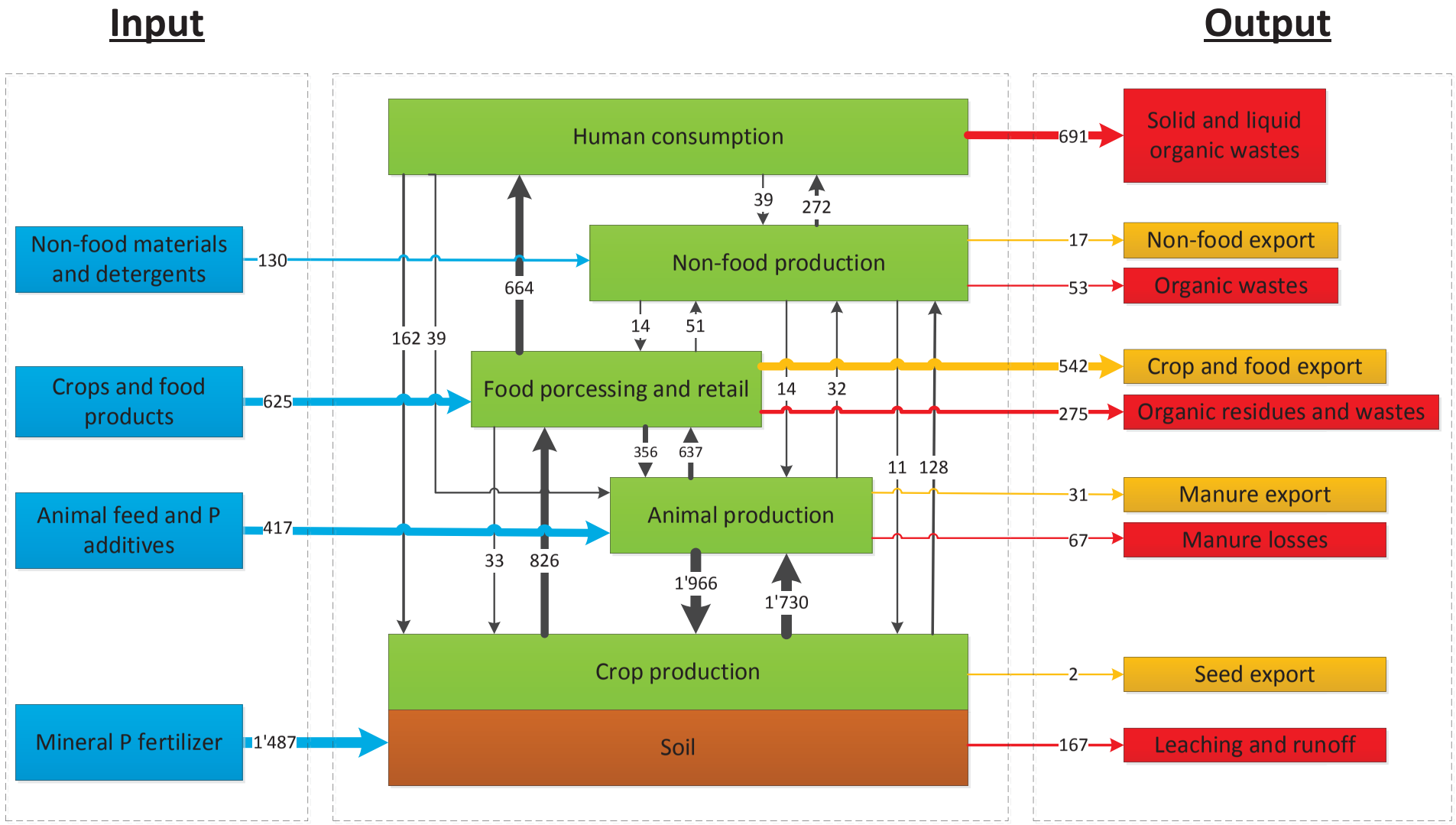

Figure 6: Phosphorus flows in EU-27 (2005) [in 1000 t] Source: Van Dijk (2013)

According to van Dijk et al 55% of the phosphorus is used as mineral phosphorus fertilizer and is applied to the soil. Another 23% is imported in the form of crops and food products. The rest is partly animal feed and phosphorus additives (15%) and partly non-food material and detergents (7 %).

Figure 6 suggests that only 70 % of the phosphorus entering the food production system in the EU-27 also leaves the cycle either as exports or as waste. This indicates that Europe has phosphorus accumulation in the soils in certain regions. The highest output flow enters the subsystem "Solid and liquid organic waste". In 2005, 691 kt of phosphorus, 25% of the total input to the system, were transformed to solid and liquid organic waste, e.g. sewage sludge. Part of this stream and about 42% (RPA Milieu Ltd and WRc , 2008) reenters the food production system (not shown) through direct application in agriculture.

In 2011, 1'026 kt of phosphorus was used as commercially available fertilizer in EU-27 (Eurostat, 2013). Figure 7 shows the development of used phosphorus. The significant decrease in 2008 (43% compared to 2007) is related to the increase of the rock phosphate prices (Jasinski, 2009).

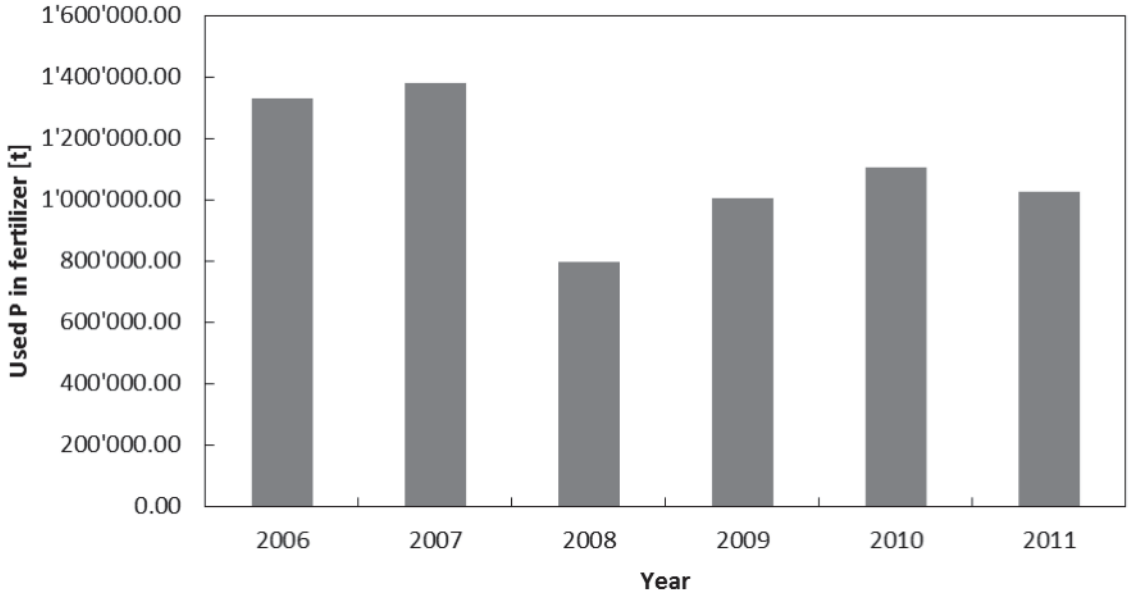

Figure 7: Phosphorus use in EU-27 in tons per year (Eurostat, 2013).

3.4 Fertilizer production

3.4.1 Processes

Starting from phosphate rock and various acids, three principal routes (Figure 8) lead to a whole range of intermediates which are then incorporated into finished fertilizer products, mostly complex, multi-nutrient fertilizers (Figure 9).

Table 12 gives an overview of products containing phosphorus and explains abbreviations. The three routes applied to transform the phosphorus in rock phosphate are as follows. By addition of mineral acids, single superphosphate (SSP), wet phosphoric acid (WPA) or nitrophosphates are formed (Figure 8). SSP is formed by digestion of the rock without separation of byproducts. It can be used directly as fertilizer or further processed to produce NPK fertilizer. Nitrophosphates are directly processed to NPK fertilizer. WPA can be used to produce triple superphosphate (TSP), diammonium phosphate (DAP) and magnesium ammonium phosphate MAP, which again can be directly applied to the soil or further processed to NPK fertilizer. Next to the desired products, also byproducts and waste are formed such as phosphogyp-

sum (i.e. gypsum $CaSO_4.2H_2O$) formed as by-product of phosphoric acid production, and the insoluble material of the rock phosphate which is separated (European Commission, 2007).

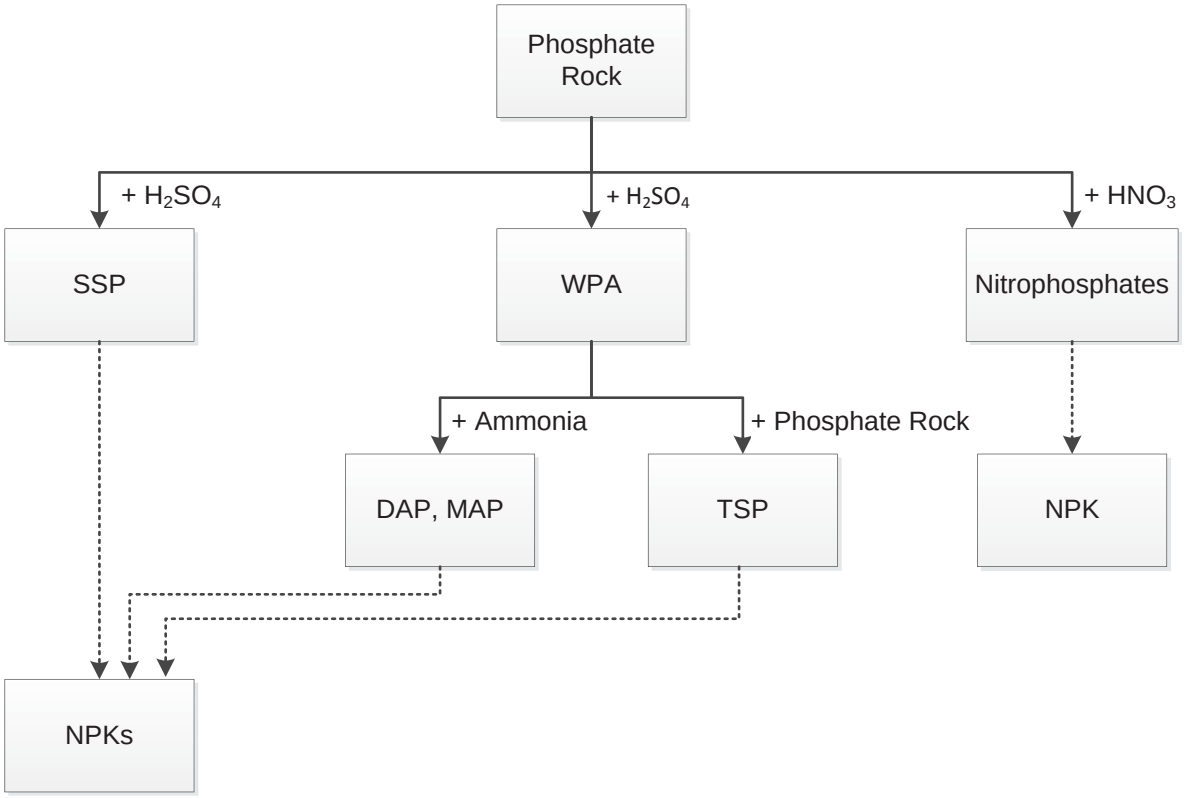

Figure 8: Process scheme for producing different types of fertilizer (International Plant Nutrition Institute , 2010)

Table 12: Common abbreviations of products containing phosphorus

WPA	Wet Phosphoric Acid
SSP	Single Super Phosphate
TSP	Triple Super Phosphate
ASP	Ammonized Super Phosphate
DSP	Disodium Phosphate
NPK	Nitrogen-Phosphate-Potassium fertilizer
MAP	Mono Ammonium Phosphate
NP	Nitrogen-Phosphate fertilizer
PK	Phosphate-Potassium fertilizer
DAP	Diammonium Phosphate
MPP	Mono Potassium Phosphate

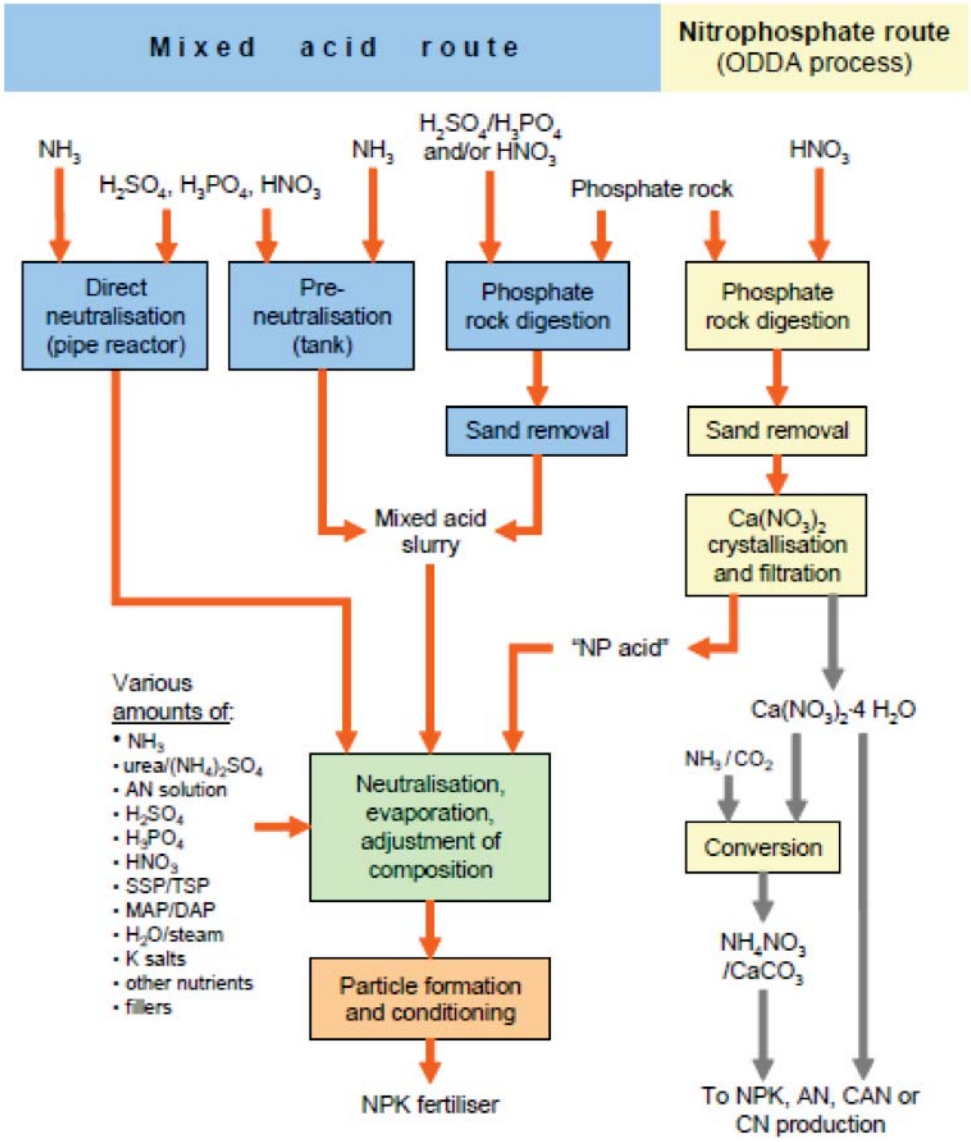

Figure 9: Overview of the production of NPK fertilisers from phosphate rock or SSP/TSP (European Commission, 2007)

Part of the rock phosphate is processed to phosphoric acid. In 2006 phosphoric acid containing 2640 kt of P_2O_5 or 1150 kt of phosphorus was produced in EU-25 (European Commission, 2007), but the number of production sites has decreased since then. Different types of extraction techniques are used for phosphoric acid production of which the dihydrate process (Figure 10) is most common (9 out of 17 companies). The plants listed in 2007 had a production capacity of 1'770 kt P_2O_5 or 770 t of phosphorus per year (European Commission, 2007).

Rock phosphate is processed with water and sulfuric acid to phosphoric acid. This process does not require any particular quality of rock phosphate and also wet rock can be used in this process (European Commission, 2007). The possibility of using sewage sludge ash instead of rock phosphate seems to be promising (Ecophos , 2014) (C.P. Langeveld and K W ten Wolde, 2013).

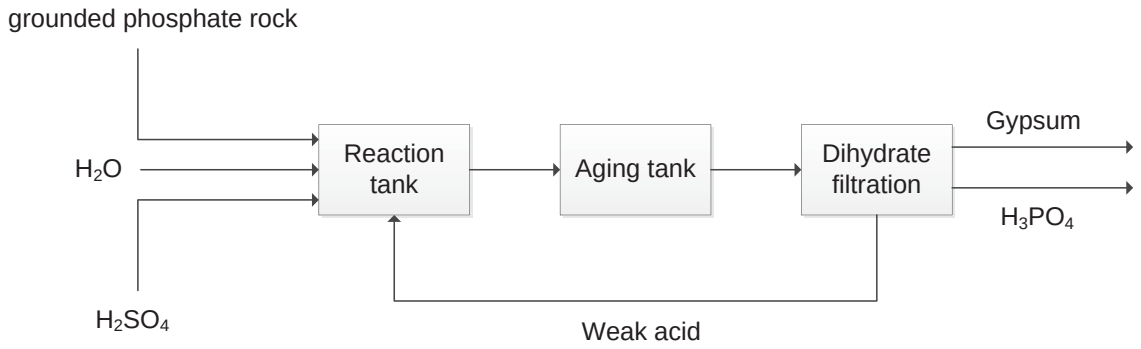

Figure 10: Process scheme of the Dihydrate process (European Commission, 2007)

3.4.2 Results

An list of NPK-producers doing chemical processing by the process schemes in Figure 9 was established by updating the BAT document (EC) with information on site openings and shutdowns from public sources and branch associations (Figure 11; Annex A) (European Commission, 2007). Many other sites perform mechanical blending and steam granulation, some of which are listed in the market studies in chapter 4 to 8 of this report and in the market study of Ceresana.

A total of 76 NPK production sites were identified. For 34 production sites the product volumes are known (European Commission, 2007) (Annex A). Altogether 10'8800 kt of NPK is produced by these companies. Assuming 7 weight % phosphorus content of the produced NPK fertilizers, the known production volume can be summed up to 761 kt. Recent production volumes (2010) were 1'000 kt phosphorus (Chapter 2.1.2.2). Thus 75% of the phosphorus used in fertilizer production is covered by the known NPK production capacity listed in Annex A. Some sites produce TSP-SSP (total of 14). These are marked with a red circle in Figure 11.

According to the P-Rex survey, 5 sites are already using or highly interested in using recycled phosphorus-rich materials. These companies are located in Germany, the Netherlands, France and the UK. They are marked in Figure 12 with the P-Rex symbol. Another 13 sites were identified which are interested, but wait for increased amounts or a change in quality of recycled materials. These are marked with a green triangle in. Figure 12. Altogether 18 production sites are already ready to use recycled materials or recognize the future potential of these materials (Table 13).

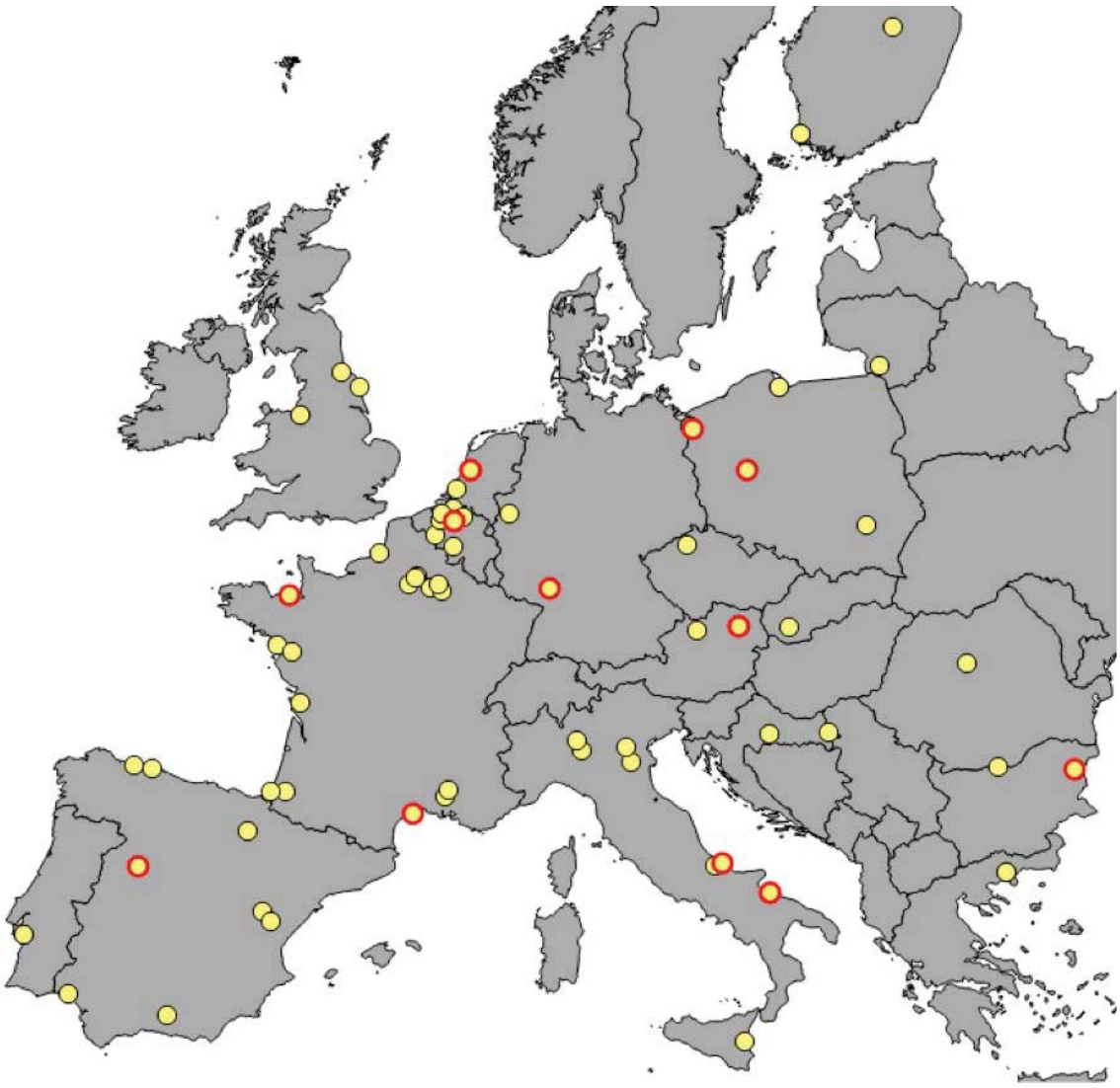

Figure 11: Sites processing fertilizer containing phosphorus in EU-27. Sites marked with a red circle produce TSP/SSP (European Commission, 2007) (Public Sources , 2014)

Table 13: Sites using or interested in using recycled phosphorus materials (P-Rex, 2013)

Country	Location	Company	Using or prepared to use recycled materials today
Belgium	Marchienne-au-Pont	Roullier Groupe	
Belgium	Doetinchem	Triferto	
France	Vireux-Molhain	France Champagne Appro - Fertilisants	x
France	Le Treport	Roullier Group	
France	Nantes	Roullier Group	
France	Bayonne Tarnos	Roullier Group	
France	Saint-Malo	Roullier Group	
France	Plan d Orgon	Roullier Group	
France	CFPR St. Malo	Roullier Group	
France	Sète	Roullier Group	
France	Ribecourt	SECO Fertilisants SA	x
Germany	Ludwigshafen	ICL Fertilizers Deutschland GmbH	x
Italy	Ripalta	Roullier Group	
Italy	Barletta (BA)	Roullier Groupe	
Netherlands	Amsterdam	ICL Fertilizers Europe C.V.	x
Spain	Lodosa	Roullier Group	
Spain	Lodosa	Roullier Groupe	
UK	Suffolk	John Hatcher & Co Ltd	x

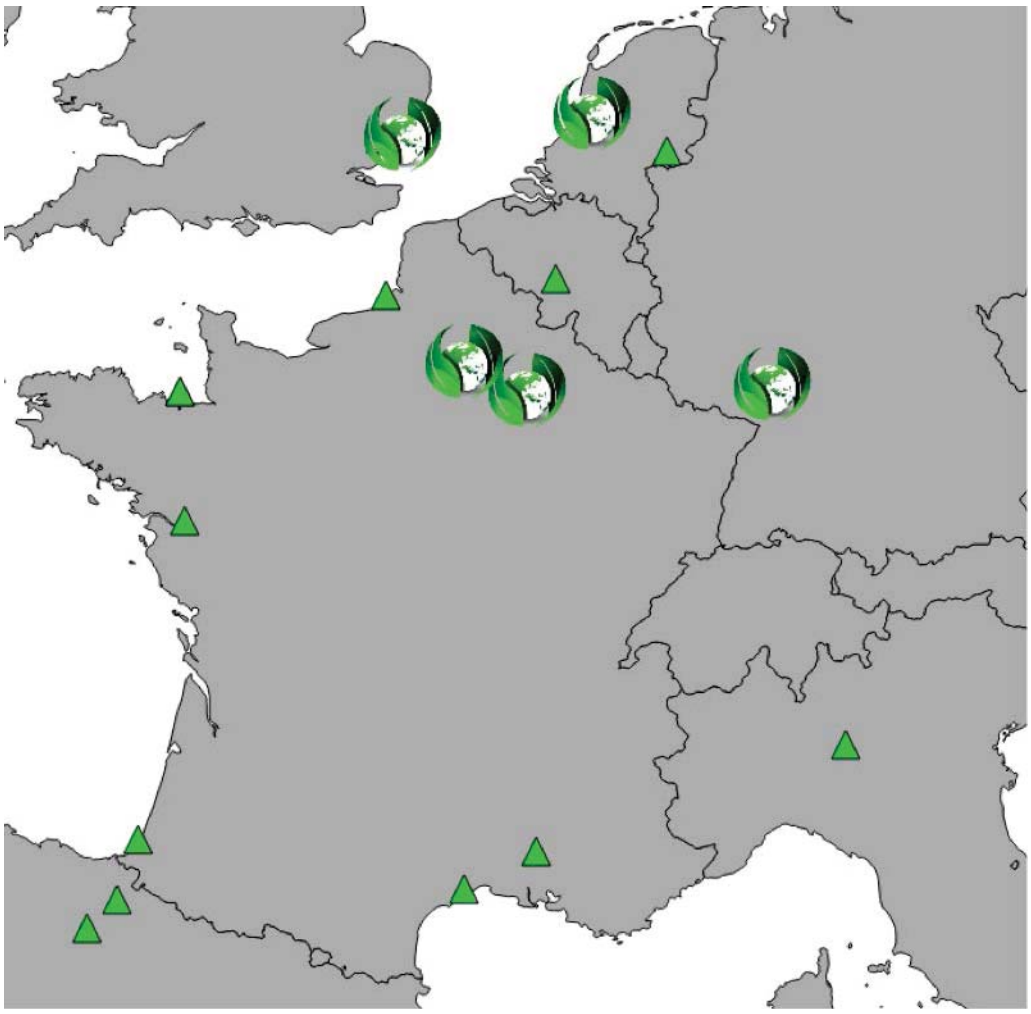

Figure 12: Sites marked with the P-Rex symbol are interested in using recycled phosphorus products, companies marked with a green triangle are interested but not at the current status (P-Rex, 2013).

Figure 13 shows phosphorus recycling plants and companies which are able to use recycled phosphorus. Next to 150'000 t of rock phosphate ICL Fertilizer Europe C.V in Amsterdam already processes 1000 t of stuvite and 5000 t of sewage sludge ashes. They apply chemical and granulating process steps. ICL Fertilizers Deutschland GmbH in Ludwigshafen processes 100'000 t of phosphate rock per year. In this site NP, PK and NPK fertilizer is produced. In France two companies are interested in recycled phosphorus materials. France Champagne Appro-Fertilisants granulate NPK and PK fertilizers from rock phosphate and DAP. John Hatcher & Co Ltd sells around 90'000 t PK recycled fertilizers from chicken litter per year. This company is interested in integrating additional recycled phosphorus-rich materials in their product line.

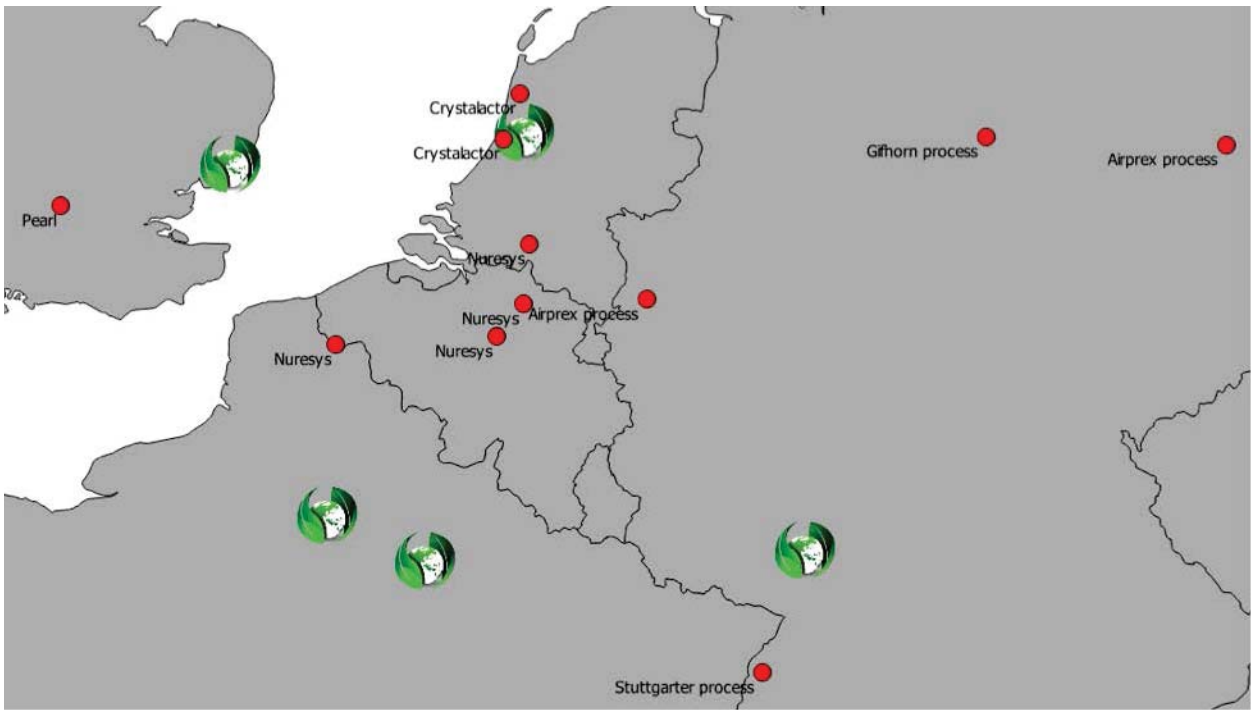

Figure 13: Companies interested in using secondary phosphorus-containing materials are marked with the P-Rex symbol and sites which already recycle phosphorus are marked red (P-Rex, 2013).

3.5 Outlook

According to the survey of P-REX and literature, there is a great potential to create a well working market for recycled phosphorus-rich materials in Europe. The size and the diversity of the fertilizer market allow for a fruitful cooperation between phosphorus recyclers and fertilizer companies. The potential for niche applications in the surroundings of a phosphorus processing sites is high, considering low transport costs. However, some fertilizer companies also look for large amounts of phosphorus, to match their production capacities. Here transportation from a series of small phosphorus sources may be less competitive in comparison to current direct transport from phosphorus mines by ship.

Altogether the current recycling of mineral phosphorus-containing materials is marginal in comparison to total volumes processed by fertilizer companies, but the survey revealed that a certain number of fertilizer producers are interested in recycled phosphorus-rich materials. Currently the information on phosphorus-rich waste and recycled products is not well known. Thus the contact between providers of phosphorus-rich waste, recyclers and fertilizer producers needs to be closer and more information needs to be provided and shared.