Urban farming in Rotterdam: an opportunity for sustainable phosphorus management?

An approach for linking urban household waste management with urban farming

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"*Take a moment to think about your next meal. It will contain phosphorus. You contain phosphorus. In fact, you can't survive without phosphorus: it's in our DNA and our cell membranes.* ***Nothing can survive without phosphorus****....*"

Dana Cordell, The Institute for Sustainable Futures, co-founder of the Global Phosphorus Research Initiative

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[1] Formerly known as Roteb

Abstract

This research was formed during my internship at the Municipality of Rotterdam from April to December 2013. At the beginning of this 8-month journey, the author of this paper was given relatively much freedom in terms of research topic. However, the framework which it had to fit was set by the biannual project Architecture Biennale 2014. The project is specifically designed for Rotterdam in order to investigate the performance of several urban flows (energy, fresh water, biomass and food, waste, sand and sediment, information, transport of goods and people) in order to make their functioning more sustainable whilst using creative design strategies.

Out of personal interest, the author of this paper decided to focus on the food flows within the city of Rotterdam. The more specific research topic was formed deriving from this. Having set the agenda towards urban agriculture (UA), the set approach was to link this with more sustainable household phosphorus (P) management.

The issue of food production in today's cities with their increasing populations has become a hot topic. It has long been discussed that developing urban agriculture in cities can have many benefits for the urban environment, not only in terms of growing its own food, but also issues such as developing ecosystems, job creation, improving access to healthy lifestyle, as well as local solutions to address municipal waste problems.

In this paper, urban agriculture in Rotterdam is first of all investigated via interviews which were carried in 11 UA areas. This was as important as it was to understand what is happening in those sites in general, who are the people involved, how the visited UA areas can be classified, how do they manage financially, to what extent they recycle their organic waste which is produced at sites, and what is generally their main aim of functioning.

As follows, the research concentrates on the performance of P flows from the households of the city of Rotterdam in order to make it more sustainable in connection with local urban farms. The base year for the study was selected as 2011. Flow diagrams have been drawn using the material flow analysis method. P is an essential element in our environment, being an important nutrient for plants, animals, and humans, or, simply put – without P life would not exist. Whilst large amount of our P resources are not recovered, urban agriculture creates a perfect opportunity for practicing the reuse of urban organic waste, which naturally includes P.

In the city of Rotterdam, it was investigated that 99% of the potentially recoverable P (572 tons) is not being reused on agricultural land. This is largely due to the fact that most of the organic waste is not collected separately and therefore incinerated all together with other solid waste types, as well as due to no P recovery during wastewater treatment. Based on that finding the estimated demand for that P in terms of urban agriculture was calculated based on its current estimated surface area and whilst taking into account the demand needs of certain crops. The study shows that there is currently lack of urban agricultural land in the city of Rotterdam to close the P cycle. The amount of P which is thrown away in Rotterdam urban households is as significant 500 times higher of the present UA demand. Therefore, taking into account the P flow calculations which were made for this specific study, it was estimated that closing the P loop within the city would only be possible if all the green surface area in Rotterdam would be used for growing crops, and even more. This, however, requires an enormous change to the whole socio-economic urban system. In chapter 2.4 at the end of this manuscript, future suggestions for more sustainable waste management have been summarized in tables.

Contents

Acknowledgements....4

Abstract....5

Contents....6

I Introduction....8

1.1 What is urban agriculture?....9

1.2 Urban agriculture in the Netherlands....10

1.3 Research focus & problem: the issue with phosphorus....11

1.4 Local solutions for the phosphorus challenge....11

1.5 The phosphorus situation in the Netherlands....12

1.6 Research objectives & questions....15

1.7 Research methodology....16

1.7.1 Case study....16

1.7.2 Snowball sampling....16

1.7.3 Data collection....16

2. Findings....32

2.1 Interview findings for urban agriculture in Rotterdam....32

2.1.1 Classification of urban agriculture types....32

2.1.2 People involved....33

2.1.3 Starting up & funding....33

2.1.4 Local food production & consumption....34

2.1.5 Environmental performance of urban agriculture in Rotterdam....36

2.1.6 Benefits....39

2.1.7 Challenges....39

2.2 Calculated phosphorus flows of Rotterdam households....40

2.3 Closing the P cycle locally – linking supply with demand....46

2.4 Suggestions for sustainable P management in Rotterdam....49

3. Conclusion....52

4. Research recommendations....53

5. Research pitfalls....54

References....55

Annex 1 Interview questions to ‘urban farmers’....59

Annex 2 Phosphorus in food consumed by Rotterdam population....60

Annex 3: Household & non-household human food P intake....61

Annex 4 Phosphorus inflow via detergents....62

Annex 5 Phosphorus contents in different materials....62

Annex 6 Different phosphorus inflows to Rotterdam households....63

Annex 7 Human excreta phosphorus inflow to wastewater....64

Annex 8 Organic retail waste 64

Annex 9 Wastewater phosphorus outflow from Rotterdam households - Waterboard Schieland en Krimpenerwaard 2011 65

Annex 10 Wastewater phosphorus outflow from Rotterdam households - Waterboard Hollandse Delta 2011..65

Annex 11 Solid waste phosphorus outflow from Rotterdam households 66

Annex 12 67

Table 1: Pet feed & phosphorus consumption in Rotterdam 67

Table 2: Average pet weight & weight factor..68

Table 3: Pet feed & phosphorus consumption per pet......................................69

Annex 13 Food waste to different destinations 70

Annex 14 Rotterdam solid waste data 2011 71

Annex 15 Balance sheet of household & non-household in- & outflows of phosphorus 72

Annex 16 Comparison of urban agriculture farms in Rotterdam...........................73

Annex 17 Green surface in Rotterdam & present spots of urban agriculture.........75

Annex 18 Original & by STAN re-calculated flow values 76

I Introduction

This paper has been written for the Municipality of Rotterdam while being an intern from April to December 2013. The internship position was formed within the framework of International Architecture Biennale 2014 (IABR 2014).[2] This is an international event held every 2 years which brings together an international community of experts under a thematically designed research biennale. (Sijmons *et al.,* 2013) IABR 2014 examines city as a complex active system, just as a human body, which drinks, eats, breathes, uses its senses, and excretes waste, so can vital material flows be identified in a city. This can be called 'the metabolism of a city[3].' Ten flows for Rotterdam are being examined by a group of experts.[4] These flows are energy, fresh water, biomass and food, waste, sand and sediment, information, transport of goods and people.

Within the scope of this internship, the author of this paper focused the research on a specific topic. In terms of a personal interest, urban farming[5] and sustainable phosphorus (P) management (e.g. P content in Rotterdam household waste) were selected as general study themes, as these form part of the food and waste flows and would therefore fit within the framework of IABR 2014.

[2] The first one was held in 2001.

[3] Within this approach, cities are looked into as living organisms *"organisms need energy and resource inputs, transform them to do work, and produce waste, much like cities do."* (Pincetl *et al.*, 2012, p. 194)

[4] In general the project IABR-2014 operates on a wide platform of experts, designers and other relevant professionals from the Netherlands (landscape architecture company – Fabric, Netherlands Environmental Assessment Agency - PBL) and abroad (James Corner Field Operations from New York - JCFO) work together. This type of knowledge exchange and research through wide arrange of active partners, public events and presentations make IABR unique in the world. As a final outcome of the project, an exhibition will be held at the Rotterdam Art Centre of Kunsthal where all the proposed design solutions are to be presented, explicitly for the city of Rotterdam (May 2014). (Sijmons *et al.*, 2013) However, as an outcome of the overall Biennale, it is widely hoped that the role of design in local and regional projects will be strengthened both in the Netherlands and abroad. (Sijmons *et al.*, 2013)

[5] The concept is further explained under section 1.1 of this paper.

The main aim of this study is to connect Rotterdam urban farming with more sustainable household waste management than has been organised and managed now. Most of organic household waste in Rotterdam is not separated from the rest of solid household refuse and ends up incinerated in the ashes, resulting in a loss of P. P is an essential nutritional component in our soils for food production and plant growth in general, but which unfortunately is a scarce resource. The two main aims of this research are (1) to find out how much potential P[6] is actually lost (in other words, the amount which is not being reused in agriculture) via Rotterdam household[7] waste management and (2) how could this P be recycled to the city's current and potential future farmland.

Since urban farming in Rotterdam and its concept has not been described coherently in one single work, one of the aims of this investigation was to learn more of the issue and write it down into a concise, yet thorough description.

The research has been built up in two sections. The first part of the study forms an introduction to urban farming in Rotterdam. It is based on interviews and gives a socio-economic assessment to urban agriculture in the city of Rotterdam in general. Eleven interviews with individual urban agricultural areas were therefore conducted in order to understand what is happening in those sites and how they are currently managed.

As follows, the second part of the research takes a slightly different turn and is based on the approach to link urban farming with sustainable usage of household P (as part of household waste) by using material flow analysis (MFA) as a method for investigating how much P is lost in that sector. This amount of P could be brought back to the city's land instead. Urban farms in the city play an important role in urban nutrient flows and would be therefore perfect places for practicing the

[6] The P problem is further explained under section 1.3 of this paper.

[7] The study is only focused on household waste sector and not industries or other. The reason for that being the fact that the sector which contributes the most waste in the Netherlands, and where the losses of P are the highest, is the household sector. See section 1.5 of this study

reuse of urban organic waste and wastewater. Based on the outcome of the calculations of the so-called lost P, calculations have been made (based on Dutch nutrient application directives) for the capacity of the current UA areas in Rotterdam to 'host' the potentially reusable P.

The general idea behind this research is to raise the awareness of the citizens and officials (different Waterboards, waste company) about waste management in the city of Rotterdam in terms of P recovery and integrate this issue more closely with spatial planning. The role of spatial planners in waste management is still relatively limited[8], despite the fact that urban farming is becoming more intertwined with cities' plans and is the hot topic on the urban agenda. However, it can be argued that whilst promoting urban agriculture, community composting is also indirectly facilitated, and therefore re-using compost in urban agriculture has a connection to spatial planning. Whereas this connection could be enhanced. In this paper, suggestions have been made on how to recover P in the city of Rotterdam in connection to its urban farms. However, further research and specific steps are required to develop and plan the transition towards more sustainable use of nutrients in Rotterdam.

This paper consists of three main chapters, each containing several sub-chapters. The first chapter explains the aim, scope and methodology of this study with the connection of the relevant theoretical framework. As follows, the second chapter goes directly on the elaboration of the findings. In the last chapter the findings of urban farming in Rotterdam are discussed followed by the outcomes of P flows from the city of Rotterdam. This final chapter ends with suggestions to close the P cycle in Rotterdam via local urban agricultural initiatives. Finally conclusion will be presented covering the most important research outcomes.

[8] The integration of food waste to planners' everyday work has not been accomplished (Broekhof and van der Valk, 2012) However, it can be argued that spatial planning must be linked with (food) waste management since composting e.g., requires space, infrastructure and policies, which are form part of planners tasks.

1.1 What is urban agriculture?

It is estimated that by 2050 as many as 6.5 billion people out of 9 billion will be living in urban areas (Wiskerke & Viljoen, 2012). As a consequence, high demands are set by increasing consumption on agricultural practices and natural resources. The world's increasing population is facing struggles such as food quality and food security, unequal consumption and environmental damage. (Foley *et al.*, 2011) Urban agriculture (UA) is therefore widely acknowledged as a promising tool for a type of urban development that would lead cities towards greater urban resilience.[9] Concepts such as urban gardens, green roofs, parks, community gardens or coastal wetlands can make cities more vulnerable to change[10] (Montenegro, 2011). After having been absent from the urban agenda for the last decades, the issues of food production in cities has recently gained more and more attention (de Graaf, 2011; Mougeot, 2006). UA has been recognized as a tool which can improve the welfare of urban communities by strengthening poor urban households' food security, improve the citizens education on food and sustainability, increase opportunities for physical exercise as well as create jobs and community activities that can improve social cohesion (de Graaf, 2011; Mougeot, 2006). Additional benefits include treating, recovering and reusing urban solid and liquid waste, saving or generating income and employment and managing freshwater resources effectively. The fact that urban agriculture is multi-functional makes it so sustainable (Wiskerke & Viljoen, 2012).

Urban agriculture is different from rural agriculture in a way that UA is integrated into local urban economic and ecological systems. The concept of UA is defined

[9] This terms was first introduced by Canadian ecologist C.S. Buzz Holling in 1973. According to his approach, humans and nature are highly coupled and co-evolving and looked as one "socio-ecological" system. It is wrong to think that systems respond to change in a linear fashion, but they are in constant flux (Montenegro, 2010). Walker and Salt (2006) have later defined resilience as "the capacity of system to respond to change or disturbance without changing its basic state" (in Ahern, 2011).

[10] As to give an external example of city vulnerability, in New Orleans e.g., a loss of large number of wetlands (due to natural gas and oil exploration) within the last 60 years, have contributed to disastrous effects of Hurricane Katrina. It is researched that restoring 1 km of wetland would reduce the wave height by one meter (Montenegro, 2011).

by Mougeot (2006, p.11); *"an industry located within (intra-urban) or on the fringe (periurban) of a town, a city or a metropolis, which grows or raises, processes and distributes a diversity of food and non-food products, (re-)using largely human and material resources, products and services found in and around that urban area and in turn supplying human and material resources, products and services largely to that urban area."* Moreover, Richter *et al* (1995 in Mouget, 2006, p. 9) have made the distinction that *"it is not its urban location which distinguishes UA from rural agriculture, but the fact that it is embedded in and interacting with the urban ecosystem."* The extent to which agriculture is urban depends on the extent to which the urban ecosystem is used and in turn used by the same urban ecosystem (Mougeot, 2006).

Based on the Resource Centers on Urban Agriculture & Food Security foundation (RUAF)[11], eight urban agriculture production systems have been distinguished (Kanokwalee, 2009):

1. Micro-farming in and around the house
2. Community gardening
3. Institutional urban agriculture
4. Small-scale commercial horticulture
5. Small-scale commercial livestock and aquatic farming
6. Specialized urban agriculture and forestry production
7. Large-scale agro-enterprises
8. Multifunctional farms

In this report, UA in Rotterdam was investigated through interviews conducted with selected people working on local UA. It was discovered that it was at times rather difficult to place the visited UA areas under the mentioned typology and thereof a new typology was developed based on the function and aim of each UA area. The results and thorough reasoning can be found in the Results section of this paper. Under the next following title, urban agriculture in the Netherlands has been introduced in general.

1.2 Urban agriculture in the Netherlands

In the Netherlands, urban agriculture has a growing popularity (van der Schans, 2010). However, unlikely to developing countries, growing your own food is not the main concern for the urban poor in the Netherlands – social security is presently adequate and the unemployment rate is relatively low (van der Schans, 2010).[12] The concept of urban farming has also been embraced by the Dutch Minister of Agriculture, setting the main importance on their symbolic function, rather than an instrument to improve access to fresh food: 'they have the potential to act as a bridge between city dwellers who are increasingly ignorant about food production and professional farmers, who feel more and more misunderstood, especially when they adopt large-scale high-tech solutions in the pursuit of sustainability' (van der Schans, 2010, p.1).

In the contexts of pre-dominate export-oriented agricultural sector in the Netherlands, which is capable of providing fresh food efficiently, van der Schans (2010) has questioned how UA initiatives can financially survive. The answer to that question is the three marketing strategies which can be chosen from (1) specializing on a few activities can reduce production costs, (2) providing produce that is clearly different from conventional agricultural produces, or (3) adding more value to produce by incorporating subsequent steps of the supply chain: processing, packaging, distribution. However, in latter case adding value to product also adds costs, the more so as labour in the Netherlands is relatively expensive. For this, urban farmers in the Netherlands have found a solution – whilst operating close to cities, a considerable number of volunteers, including also

[11] International network on Urban Agriculture and Food Security which was set up in 1996 in response to the need of local governments and organizations in the South for effective mechanisms for the documentation and exchange of research data and practical experiences on urban agriculture (derived from: www.ruaf.org, last accessed in 2013).

[12] This does not mean as if accessing food in the Netherlands is not a problem – access to fresh food is relatively more expensive than to processed food and people with lower incomes this is an important issue (van der Schans, 2010).

partly disabled volunteers (still capable to perform certain tasks) are happy to help out in the gardens. A step like that is taken even further by allowing participants to take some of the grown food for free, whilst the rest is sold in local farm shops or delivered to different customers (shops, cafes, restaurants) in the cities. In Rotterdam there are some good examples of both commercial as well as social farms. Urban farming in Rotterdam has been described in section 2.1 of this paper: *Interview findings for urban agriculture in Rotterdam*.

In the next chapter, a thorough explanation of the research problem will be given: the importance of P for life and food production, its linkage to the innovative approach to reuse urban organic solid waste and wastewater in UA (containing P and other nutrients essential for agriculture), as well as comments on the issues specifically in Rotterdam.

1.3 Research focus & problem: the issue with phosphorus

Phosphorus is an essential element for our food production (fertiliser, necessary ingredient in soils) and therefore for our lives in general. Without this element in agricultural soil, agricultural production would decrease significantly (Rosemarin *et al.*, 2011). This, however, is a rather contradictory situation when taking into account the world's growing population and the increasing demand of food which comes with it.

In the past, there has been a lack of nutrients available for agriculture. Since the Green Revolution[13], mineral fertilisers were used to solve this issue. This in turn resulted in the oversupply of nutrients, leading to eutrophication of waterways and the environment. Some years ago this issue turned from an excess problem into an issue of sustainability: the non-renewability at the human time scale of primary P (mined from P rock) and the inefficient and non-cyclic use of secondary P in present society (Cordell *et al.*, 2011).

[13] This term refers to the renovation of agricultural practices beginning in Mexico in the 1940s. In 1950s and 1960s its technologies spread worldwide due to its success in producing agricultural products (Shiva, 2011).

Being a non-renewable resource (main fertiliser source is rock phosphate), the usage of P worries many countries (Rosemarin *et al.*, 2011). Instead of recovering it from 'waste streams', the P is extracted from phosphate rock[14] being a non-reproducible resource that cannot last forever. The lifetime of this scarce resource is estimated to vary from few decades to few hundred years. Therefore, more efficient P recovery options should be developed and introduced, especially in terms of waste management. The current practices in our society are inefficient with high losses of P to waterways and infrastructure, and accumulation in soils and society.

1.4 Local solutions for the phosphorus challenge

Many cities have growing financial problems that influence their waste management, as it is assumed that it can consume up to 50% of cities' operating budget (RUAF, last accessed in 2013). However, urban and peri-urban farmers are at the same time in a need of organic matter to enhance or keep the quality of the soils by the addition of a fertiliser and a conditioner. Clean and nutrient rich organic waste flows are therefore a valuable resource for urban agriculture. On the other hand, farmers and people working with UA have often difficulties with accessing industrial fertilisers and animal feed. It is therefore suggested that reusing urban organic waste and wastewater in urban agriculture would be a good solution for farmers to access fertilisers and for government officials to turn their waste management more sustainable. Mougeot (2006) agrees that by linking waste management to urban farming, a 'triple-win' situation can occur – urban environment gets cleaned up, health hazards are reduced, and agricultural production is increased.

Additionally, there are also a number of limitations which obstruct the reuse of urban waste and make the management of it therefore more challenging. For

[14] Phosphorus is geologically also unevenly distributed - 85% of the global reserves are located in five countries: China, Morocco, US, South Africa and Jordan. Given the fact that Europe has almost no own reserves, this imbalance makes EU countries vulnerable to geopolitical tensions and prices (Rosemarin *et al.*, 2009).

example when organic waste is mixed with other types of waste, there is a high possibility that this organic waste gets contaminated with heavy metals, plastic particles, organic pollutants, etc. (EU Commission, 2011a). The same applies to wastewater. It is important to consider its chemical constituents when using it for irrigation. The potential uptake of chemicals by crops, as discussed by Chang *et al.*, (1995) as well as Birley and Lock (1997) is most likely to lead to chronic and long-term toxic effects in humans. Therefore, serious technical measures should be taken before applying waste on land, i.e. appropriate wastewater treatment for P recovery.

Taking into account the fact that currently a relatively high amount of solid waste and especially sludge (final end product of wastewater) from Dutch households is incinerated, a large amount of P entering the households is not returned to agricultural production areas (Buck *et al.*, 2012). In fact, there are many previous studies that discuss the issue of different waste recycling approaches from the perspective of more sustainable P management in cities (Kalmykova, 2012). For example, in developing regions, such as in Kampala, Uganda, a group of young people started Community Life Skills Empowerment and Development Centre (CLEDC) in 2004 (van Beek *et al.*, 2008). This group set up a demonstration site in order to involve the community in waste-problem solving. Part of their aim was to show what community action can achieve in this matter. Waste was collected from households, sorted and reused; peels were picked by volunteers and sold as feed for animals[15] or used to make organic manure. At the demonstration site, vegetables were grown in sacks filled with manure. Additionally, CLEDC also promotes door-to-door sensitisation on issues of waste management.

Activities have also been taken up in developed countries. For example, in Sweden, impacts of five waste management strategies/scenarios on P flows were evaluated for the city of Gothenburg. These strategies include incineration of all waste[16], comprehensive food waste separation, installation of kitchen grinders in sink stones, urine diversion, and separation of blackwater and food waste (Kalmykova *et al.*, 2012). The activity aimed to set targets of the total P flow that can potentially be recovered in Gothenburg.

Based on Dutch national calculations (Buck *et al.*, 2012), it was calculated that 18.6 Mkg[17] P is lost from all Dutch households. Compared to the 6 Mkg of lost P from the industrial sector, the amount of lost P via production of household waste is two times larger[18]. This finding is one of the reasons for this study to focus further on the Rotterdam household sector in order to try to find options for more sustainable organic solid waste and wastewater management. In the following sub-chapter, a more in depth overview is given for P situation in the Netherlands.

1.5 The phosphorus situation in the Netherlands

Research institute Alterra Wageningen UR in Wageningen has undertaken the task to investigate the P flows in the Netherlands (Smit *et al.*, 2010). Figure 1 below gives the summary of the main P flows in the Netherlands. According to Smit, *et al* (2010), the Netherlands is a net P importer by importing 108 Mkg P mainly from agricultural feed and fertiliser. The gross export is 49 Mkg P mainly from food products (as estimated in 2005). Overall this annual balance leads to an

15 Selling an average 20 bags a week (van Beek *et al.*, 2008).

16 It is not a desirable scenario for maximing the reuse of P as fertiliser. Even if P would be recovered from ash, it would still be needed to other elements as to stoichiometrically balanced fertilisier product. (Kalmykova *et al.*, 2012).

17 In practice Mkg is more known as Kton, those two are equivalent.

18 Most of the lost P is the result of unsustainable waste water treatment since the communal sludge is mostly incinerated with no P being recycled. This can also be proved by the statistics for EU countries which show that NL is in the list of countries with the least recycled sludge (Milieu Ltd, WRc and RPA, 2008), whilst in terms of organic solid waste recycling Netherlands is one of the best (Eurostat data, derived from: epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/database, last accessed in 2013). Read more about national P flows in the Netherlands in section 1.5 of this paper.

accumulation of 60 Mkg P/year in 2005[19] (Smit *et al.*, 2010). Half of this accumulated within agriculture in agricultural soils and the other 28 Mkg P accumulated either in the environment (in-land water and seas) or was sequestered via the waste sector in infrastructure and non-food products. It was estimated that the agricultural area in the Netherlands is around 2 Mha (including arable, grazing land, maize land, vegetables, etc.), which in turn implied that the accumulation per hectare was more than 15 kg of P/ha/year (Smit *et al.*, 2010).

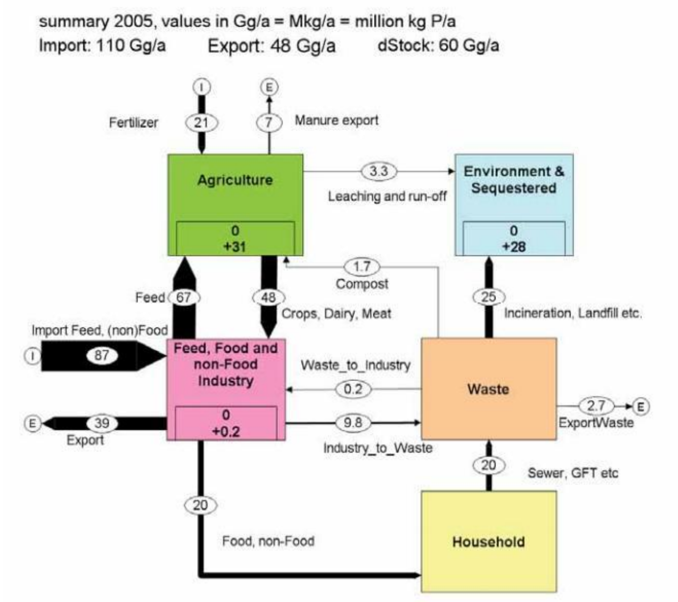

Figure 1: A summary of the main phosphorus (P) flows in the Netherlands in the year 2005 for different sectors in society: agriculture, environment/sequestered, food/feed/non-food industry, waste management and the household sectors. The flows are in Mkg P per year. E = Exported, I = Imported. Surplus for some sectors are indicated in the boxes (Figure 4-2 in Smit *et al.*, 2010)

On the other hand, whilst Netherlands is the country of P accumulation, recycling from society (households, industry) back to agriculture is minimal (Smit *et al.*, 2010). It was concluded that households in the Netherlands are a major contributor to main input (66%) of the waste industry (Smit *et al.*, 2010). The waste flows from Dutch households back to agriculture are almost negligible since not more than 2 Mkg out of total amount of 30 Mkg of P which is processed is recycled to agriculture or gardens (Smit *et al.*, 2010) (see Table 1). From this 2.7 Mkg about 7% is exported *abroad* and the remainder of 25 Mkg of P ends up either in surface water (from wastewater plants), cement or in incinerator ashes (Smit *et al.*, 2010). The P which enters the households consists almost entirely of food, supplemented with detergents such as automatic dishwasher detergents (Smit *et al.*, 2010). It was calculated that almost 60% of this input leaves the household in the sewer system and 30% in household refuse that is almost fully incinerated (Smit *et al.*, 2010). Moreover, it was estimated that 6% of the household waste output is organic kitchen and garden waste separated from household refuse and eventually composted (see Table 1). The authors argued that the Netherlands could secure their P demand without the import of P by using P from secondary sources more sustainable.

[19] In order to reduce accumulation in agricultural soils, a number of measures have been proposed by Rosemarin *et al.*, 2009: "(1) reducing the production of P in manure by using feeds low in P (i.e. via lower excretion of P per animal) or via reduction in the number of animals. And (2) by processing manure followed by exporting nutrients. Further possibilities for more sustainability exist in recycling of P in sewage sludge or slaughter waste e.g. by applying advanced technologies nowadays available to recover the P."

Table 1: Input and output of phosphorus (P) of the Dutch household sector (in million kg- Mkg P), derived from Smit *et al.*, 2010, p. 31

Household	In\Out	Products	Mkg	%
	In	Food (animal based)	11.4	57%
		Food (plant based)	7.1	36%
		Non-food (detergents)	1.3	7%
		Total	19.8	100%
	Out	Sewer	12.4	63%
		Landfill\Incineration	6.2	31%
		Compost	1.2	6%
		Total	19.8	100%

The 2005 flow scheme was updated in 2012 based on the base year of 2008 (Buck *et al.*, 2012). An update was required due to the introduction of new mineral legislations in 2006 which set the lower allowed application standards for nitrogen and P fertilisers (Buck *et al.*, 2012). As a response to that, the updated flow assessment shows the main difference with the P situation in 2005. The results show a decreased national surplus by 9 Mkg P. The P accumulation on agricultural land decreased by 12 Mkg, mainly on grassland and maize fields (Buck *et al.*, 2012). Moreover, the P leaching to surface – and groundwater decreased slightly, most probably due to cleaner effluent from wastewater treatment plants (Buck *et al.*, 2012). Another main difference was the reduced fertiliser import from 21 to 12 Mkg P and consumption, and increased animal feed import, from 108 Mkg in 2005 to 115 Mkg P in 2008 (Buck *et al.*, 2012). However, this is compensated by P export which similarly increased from 49 to 64 Mkg P. Therefore, it was concluded that over the study period the national P surplus was more in balance (Buck *et al.*, 2012).

However, the P sequestered in waste increased by 3 Mkg (in 2005 it was 21 Mkg whilst in 2008 it was an estimated 25 Mkg). This means that more household P was taken to a landfill or was incinerated in 2008 than in 2005; more P was sequestered in incineration plants and the cement industry (see Table 2). This increase was due to increased P input in the Dutch system from animal and non-food products (Buck *et al.*, 2012).

This is the main reason why this research continued to focus on household waste flows. Households is a sector which contributes most to waste, the more so whereas during the period of the study conducted by Buck, *et al.*, the amount of lost P from household waste sector even increased. More household waste is produced now than a few years ago, which implies the necessity of more sustainable management in order to recover the P content. In general, the study of 2008 concludes that the flows in agriculture and the waste sector in 2005 and 2008 did not disclose a trend for increased use of recycled material in agriculture (Buck *et al.*, 2012).

Tabel 2: Phosphorus (P) flows (Mkg P/year) in households in 2005 and 2008 in the Netherlands. Derived from Buck *et al.*, 2012, page 16.

	From/to subsystem	Products	2005	2008
Input	Food industry	Food (milk, eggs, meat)	11.4	12.9
		Food (vegetables)	7.1	5.3
	Non-food industry	Non-food (detergents)	1.3	3.1
		Total	***19.8***	***21.3***
Output	Waste sector	Sewage	12.4	11.6
	Waste sector	Landfill/incineration	6.2	8.7
	Waste sector	Compost	1.2	1.0
		Total	***19.8***	***21.3***

In the next chapter, the findings of the study are presented. First of all, urban agriculture in Rotterdam is introduced as a general introduction before going to the findings of the main research problem: investigation of the P flows for Rotterdam household waste and the opportunity to make P usage more sustainable via urban farming.

1.6 Research objectives & questions

This research consists of two parts. The objective of the first part of this study is to introduce the current situation of urban farming and its different types in Rotterdam. The objective of the second part of the study is to investigate the balance between the nutrient demand of the current UA areas in Rotterdam and the potential supply of nutrients with a focus on P. This P is now lost via incineration and sequestration into infrastructure and the environment and currently not being reused in agriculture. Additionally, measures and a concept will be proposed on how to connect this demand and supply at the urban scale.

Given the objectives, the research questions set for the first part of the study are:

1. How can the interviewed urban agricultural areas be classified?
2. How are the urban farms in Rotterdam managed financially and what have been the financial sources for their start-up?
3. Who are the people involved in Rotterdam urban farms?
4. What happens with the products grown in UA gardens, where are they delivered to or end up?
5. What happens with organic waste that serves as potential source of organic fertiliser (compost) and is produced at a site; and are there any additional organic fertilisers being delivered to gardens from elsewhere (leaves, branches, manure, organic kitchen and garden waste)?
6. What type of energy and water is used by the UA areas in Rotterdam?
7. What are the benefits and challenges of UA, as indicated by the interviewed people who have their own farms?

The research questions set for the second part of the study are:

1. How much phosphorus is lost (i.e. not reused in agriculture) based on the material flow analyses calculations of Rotterdam household waste?
2. What would be the calculated balance between the potential phosphorus supply from Rotterdam households compared to the demand of P (physical capacity in contrast with the P application limit set by the Dutch government) by current urban agricultural land within the city of Rotterdam?
3. Which measures can be taken to manage Rotterdam household waste content more sustainably in connection to urban farms in Rotterdam, specifically looking to phosphorus?

1.7 Research methodology

In this study, both qualitative and quantitative research methods were used. The first part of the study is purely qualitatively based on literature study and interviews, whereas the second part of the study is both qualitatively and quantitatively based on calculations.

1.7.1 Case study

Problems can be solved within a specific context by using a case study approach (Flyvbjerg, 2005). On the request of Municipality of Rotterdam, the research location was restricted to the municipality of Rotterdam. However, it is important to mention that this research is mainly limited to the Rotterdam city limits, apart for one urban farm that was interviewed for the first section of this study and which was located in the peri-urban area outside the city limits. The focus of this case study is to investigate urban farming in Rotterdam and make a connection with household waste management in terms of sustainable use of P.

1.7.2 Snowball sampling

Snowball sampling is a research technique used for finding a research topic. One subject or source leads the researcher to another, which in return provides the following, and so on (Vogt, 1999; Spreen, 1992). For this research, constant link-tracing between different sources was done in order to find the most suitable research topic that would be most useful for all parties involved. However, pre-appointed framework for the research was the project of International Architecture Biennale 2014. This international meeting is where the foundation of this research topic lies. One of the issues to be involved in this project was food, which lead to the choice of a more specific theme of food production through urban farms. This in turn snowballed into researching Rotterdam household waste management, because of interest in knowing how and if to recycle P back to Rotterdam urban (farm) land. The research gained much from the interviews carried out with urban farmers, through literature research and through meetings with professionals who were encountered during the internship.

1.7.3 Data collection

1.7.3.1 Interviews and meetings

For this study, 11 interviews at 11 urban farms in Rotterdam were conducted between June-August 2013. The interview procedures were based on semi-structured interviews, which means that the same list of questions (see Annex 1) were asked from each of the interviewee, but a new question was sometimes free to be raised as a result of the answer of the interviewee (Drever, 1995) The information for this part of the research is purely based on the interview results. The list of the interviewees can be seen in Table 3 below.

Table 3: Interviewed urban agriculture (UA) practicers in Rotterdam city.

Urban farm	Interviewed person
Pluktuin	Erik Wemmers
De Bytenhof	Ad Visser
BuurtLab	Edward Boele
Voedseltuin	Angela Vermeule
Carnissetuin	Abigail Wall
Moestuinman	Max de Corte
Gandhituin	Rutger Henneman & Daniel
De Enk	Gerrit Routgers
Tussentuin	Wolbert van Dijk
Dakakker	Wouter Bauman
Uit je Eigen Stad	X (person did not identify himself)

In the text, however, the interviewed people have been cited anonymously as: (UA, personal communication, 2013). In the second part of the study, data (figures) for Rotterdam P flows (the P flows in the human consumption and waste handling system of the city of Rotterdam) was collected through interviews with staff from relevant organizations as shown in Table 4 below.

Table 4: Conducted professionals for data collection in Rotterdam city.

Organization	Contacted person
The waste department of the Municipality of Rotterdam – formerly known as Roteb	Joost van Maaren
Waterschap Hollandse Delta	Pieter van Dongen
Hoogheemraadschap Schielanden en Krimpenwaard	Alex Sengers
Inaver Groen Compost	Marcel Coenen
Klok Containers	Edwin Kolk
AVR	Joost van Rooienn

Similarly to interviewed UA activists, these are referred anonymously in the text as (Expert name, personal communication, 2013).

1.7.3.2 Literature

Many relevant articles related to urban farming and P flows were studied. The topic of urban farming and its relation to urban waste management was well accessible through the RUAF website. Other articles were accessed via scientific databases such as Google Scholar or Wageningen University online library. In terms of P flows, most of the relevant literature was provided by various research teams from research institute Alterra Wageningen UR in Wageningen.

1.7.3.3 Calculations Material Flow Analysis

A *Material Flow Analysis* (MFA) was made for the P flows in the consumption and waste system of Rotterdam city. The major focus was on the P losses in household and municipal waste flows.

MFA allows a systematic assessment of the flows and stocks of materials within a system defined in space and time (Cencic, O. and Rechberger, H., 2008). This method was therefore considered as the most suitable for this research, as it provides a systematic assessment of the flows and stocks of P by the application of the 'conservation of mass principle' (Cencic, O. And Rechberger, H., 2008). This universal principle requires that the mass of a closed system will remain constant over time, e.g. balance equation; sum of inputs = sum of outputs + change in stock. (Brunner and Rechberger, 2004). Software STAN 2.5 (Beta) was used. The named software has been developed in the Vienna University of Technology in order to support performing material flow analysis[20]. MFA can be done at the level of good or elements. In this study the author focused on P as an indicator of nutrient cycling in the city of Rotterdam, specifically for household waste sector. In general P flows as such are not provided by data and has to be calculated by multiplying a mass flow with a certain P content of the products involved. Data availability is mostly limiting and assumptions and simplifications were therefore made. The most important data has been derived from different sources which are described in tables 3 and 4.

This study focuses on the flows of P to and from the households within the Rotterdam city limits (map can be found in Annex 17). However, it was difficult to find data about the inflows of different materials specifically to households only. Furthermore the domestic supply of products like food and paper are consumed both in households and outside households such as public places, work, schools, restaurants etc. It was decided to include shops, supermarkets, and distribution centres, as well as consumption outside the households to our in-and outflow sectors. As such, a balance was achieved between the inflows and outflows. The exact procedure is explained further in the text.

Since most important data for the calculations was accessible from the year 2011 onward[21], this year was chosen as the main year of reference (base year) in terms of the data input. If data was not available for the base year or at the Rotterdam

[20] The link and access to STAN software can be made via http://www.stan2web.net, last accessed in 2013.
[21] However, in some cases, no data for year 2011 was available and therefore it was derived from another source with a different year number, depending on the accessibility. All sources used are explained under research mythology.

level, it was recalculated based on the most recent year or national data respectively. In these cases the population number or surface area were taken as recalculation factor.

Figure 3 shows the conceptual flow diagram based on the available data, knowledge and research scope. The mentioned figure represents the main P flow system ’Household and non-household P flows in the city of Rotterdam’, which in turn consists of several subsystems. These are: “Consumption in Rotterdam city”; environmental station; food distribution and selling (supermarkets and distribution centres); household (HH) consumption; non-household (NHH) consumption; kitchen and sanitation; non-food consumption in households. In the results section, the most important sub-systems in respect of the research aim are presented. These are: HH and NHH P-flows in the city of Rotterdam; consumption in Rotterdam city; and HH consumption. The next sections explain in more depth the main data sources and calculation methods.

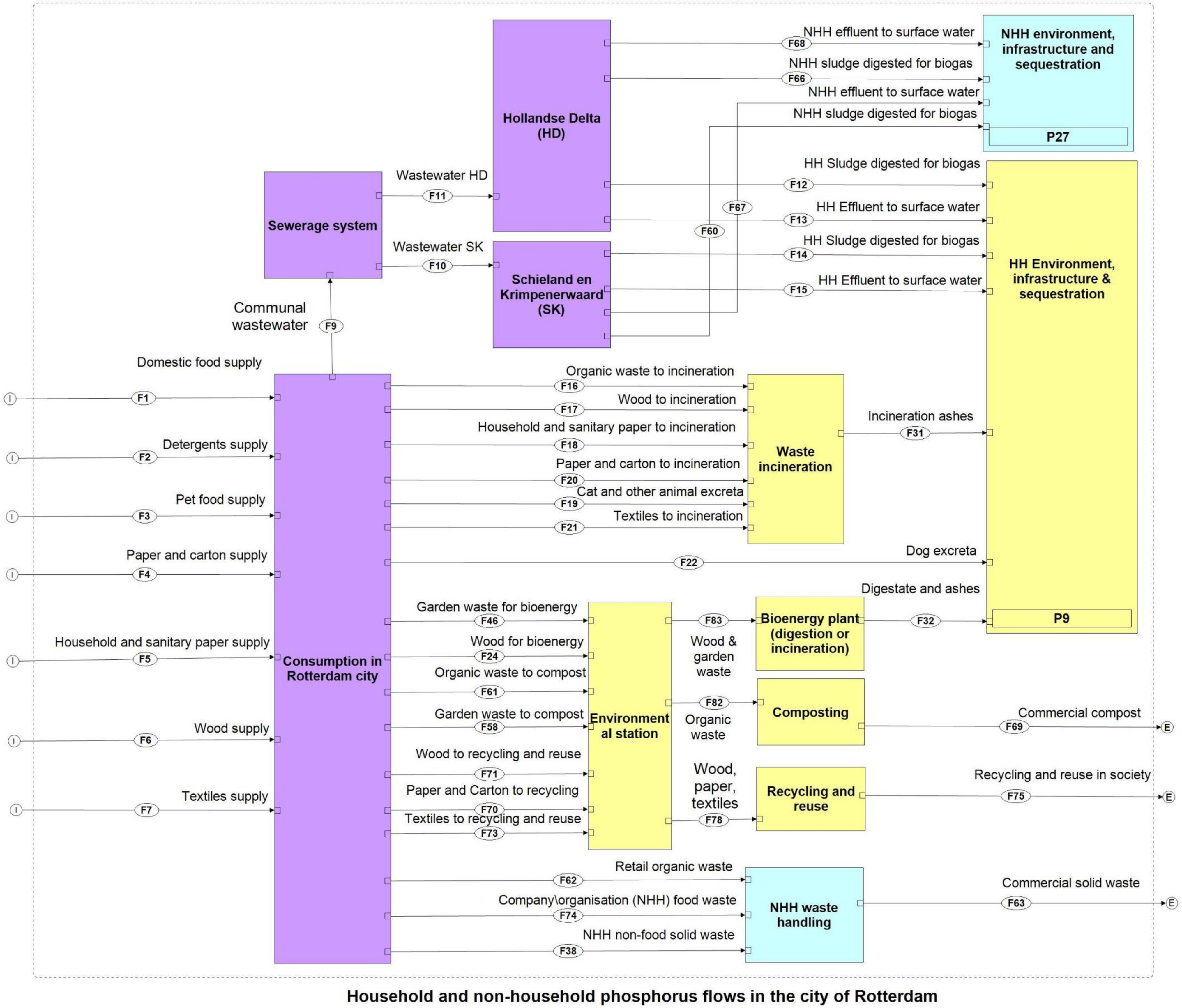

Figure 2: Flows and stocks of phosphorus (P) in the city of Rotterdam describing the imports, exports and internal flows between subsectors and process. Flows are indicated by the flow number and name. Input flows of the city of Rotterdam (left side) are consumed in households (HH) and non-houshold (NHH) which creates municipal and commercial waste flows (right side).

1.7.3.3.1 Phosphorus inflow to households

The total domestic P inflows to the city of Rotterdam were identified as seven different flows of the following products: food, detergents, pet food, paper and carton, household and sanitary paper, wood products and textiles. The domestic supply is defined as the quantity of the product that is available for human consumption. The consumption can take place in households (referred as HH) and outside households (referred as non-household, NHH). The NHH supply can be consumed in public spaces, offices, schools or restaurants for example. For each input and consumption flow the ratio between HH and NHH consumption has been based on data or assumptions (see Table 5). Annex 15 describes all the calculated in-and outflows and the ratio between HH and NHH sector.

Total domestic food supply

No reliable detailed local data was available for food products entering the urban households and their amounts in the study area. Therefore, national calculations made by Smit *et al* (base year 2011, personal communication Bert Smit, publication in preparation) were used. Based on their study, the total domestic food supply (TDFS)[22] was calculated as 17,500 tons P for the Netherlands. By taking the fraction of people living in Rotterdam (3.7% [23]) into account and assuming similar diets, it was estimated that the domestic food P supply is 641 tons.

As follows, the TDFS was distributed between HH and NHH sector. However, it is important to also take into account the retail food waste which was first of all deducted from the total domestic food supply before the distribution was calculated. For that, the retail food waste was first of all deducted from the TDFS. This is the organic waste which is already discarded from the supermarkets and distribution centres. In order to calculate that, a recent food waste study of FAO (2011)[24] was used as a simple estimate of food losses from the retail sector (Annex 8).

After retail food waste was deducted from TDFS, it was possible to make an assumption how much of that amount which was left from TDFS is bought by HH and how much by NHH sector. For that, the Report on the Relations Between Manufactures and Retailers in the Food Sector (2011, Comisón Nacional de la Competencia) was used. In that report, it is stated that the *„Overall spending on food and beverages amounted to 86,851 million euros in 2009, of which 64,911 million (74.7% of the total) was done by households, 19,342 million (22.3%) by hotels, restaurants, cafes and bars [...] and 2.599 million (3%) by institutional buyers.“* (p.15). Although this data is about the spending on food in Spain, the assumption was made that 75% of all food supply in Rotterdam is bought by households, whereas non-households buy the remaining 25%.

Food intake by humans at the mouth level

The food intake was calculated at human mouth level per person in order to balance the food outflow to wastewater by human excreta (faeces and urine) with the outflow of food to solid waste (food bought > food actually consumed (the rest mostly thrown away as food waste) > human excreta > P to wastewater). These calculations were based on the Dutch National Food Consumption Survey 2007-2010: Diet of young children and adults aged 7 to 69 years, was used, in line with what the inhabitants of Rotterdam who were divided into 8 age groups including (1) 0-2 (2) 2-3; (3) 4-6; (4) 7-8; (5) 9-13; (6) 31-50; (7) 51-69; and (8) 70-99.

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[22] In Buck *et al.*, (2010) study, it is referred to this number as it is the food supply only to households. Cross checking with the authors made clear that actually it is the overall domestic supply, including also food supplies to the retail sector such as shops, supermarkets and distribution centers.

[23] Based on the data provided by the researcher of the Municipality of Rotterdam, the number of inhabitants in the city of Rotterdam in 2011 was 610 412. The total Dutch population, according to CBS data 2011 was 16655799. The percentage of Rotterdam inhabitants out of all national population was therefore calculated as 3.7%.

[24] See the reference list at the end of this manuscript

For the age groups starting from 7, Dutch National Food Consumption Survey (2007-2010), was used (National Institute for Public Health and the Environment, 2011). The data and calculations can be found in Annex 2.

The P intake of starting from age 69 was calculated based on Ockeet *et al.*, (2013) (see Annex 2 for calculations).

Moreover, the P intake for small children (age group 2-7) is also different and therefore the calculations were based on Dutch National Food Consumption Survey-Young Children 2005/2006 (RIVM, 2008). Due to missing data about the age group 0-2, it was taken as same as the age group 2-3.[25] The figures and calculations made based on the mentioned survey can be found from Annex 2.

The number of inhabitants per age groups in the city of Rotterdam is based on the 2011 data provided by the Municipality of Rotterdam[26] (see Annex 2).

For adults it can be assumed that human food P intake and excreta P output are in balance. To simplify, this was also assumed for youngsters (<18 years). The actual net uptake and retention of P can be neglected since P accumulation as stock in the human body during the first 18 years is on average 700 grams (total amount in average adult). This storage is relatively small compared to the P intake (0.3- 0.6 kg per year for ages 0-18) cumulated over these 18 years. Furthermore, the population represents a dynamic equilibrium: the population of Rotterdam is relatively stable, and human body P outflow by people that die and go to graveyards is not taken into account. The total number of people that died in Rotterdam in 2011 was 5503 (Hoppesteyn, 2011), making the P losses to graveyards 3.8 tons P per year.

[25] Although the P intake is much smaller in age 0-2 than in age group 2-3, the number of children in age group 0-2 was relatively large. We therefore decided to include them.

[26] Available at http://www.rotterdamincijfers.nl/, last accessed in 2013.

Additionally, it was important also to make the distinction between the HH and NHH consumption. The same food consumption survey studies provided also information about the locations of the food and P intake for the same age groups as shown above. The total amount of man and females in each age group (same age groups as used for P intake) was divided by the given percentage for HH and NHH consumption. The data and calculations can be found in Annex 3.

Phosphorus inflow via detergents

Besides the food consumption, P also enters the HH and NHH sector in the form of detergents. Unfortunately no reliable data was available specifically for Rotterdam and therefore the detergent P consumption was estimated based on a national survey of Rijkswaterstraat (2013) and estimates provided by Willem Schipper[27] (ex-Thermphos, see Annex 4). The total domestic household detergent supply in the Netherlands is estimated at 970 tons P (p.16). Additionally the percentage of Rotterdam households compared to the national number of households (4.1% [28]) were used to downscale the national detergent supply to the supply in Rotterdam. The underlying data and calculations methods of the total domestic detergent supply can be found in Annex 4. It must be noted however, that the calculations provided by this method is only the P in automatic dishwasher tabs. This is so because the other detergent products contain almost no P anymore since regulations are in place.[29]

Since the above provided calculation includes detergent supply only to the household sector, an assumption was made on the quantity of detergent supply to a non-household sector. It was estimated that the fraction of detergents supplied to the non-household sector could be 50% of total household supply (see Annex 15: Balance sheet between Household and Non-household in-and outflows). On the

[27] Schipper, Willem; former Thermphos International, Vlissingen, The Netherlands.

[28] Total number of households in the Netherlands, based on CBS 2011 data was 7.4 millionmake numbers as small as possible in text. The total number of households in the city of Rotterdam, based on the 2011 data provided by the researcher of the Municipality of Rotterdam was 307 thousand . In line with that, 4.1% of all the Dutch households are located in the city of Rotterdam.

[29] Upcoming regulations or dishwasher detergents will also ban the P use in these products by the year 2015.

one hand the food service sector, like restaurants, generally uses a lot more and much stronger cleaning products than households. On the other hand, the number of households is much higher.

It was assumed that the P in domestic supply of detergents entering Rotterdam is fully consumed and leaves via domestic wastewater. Consequently, the detergent P in wastewater is already covered by the communal wastewater statistics.

Phosphorus inflow via paper & carton

Based on the report Kerngegevens Bos en Hout in Nederland (2012), the total amount of nationally consumed paper and carton in 2011 was estimated.[30] This mass flow was converted into P that is based on P content in paper and carton (0.024%) provided by Antikainen *et al.*, (2004) and based on the Finnish situation. Subsequently, to downscale from national supply to the supply in Rotterdam the relative population size was compared to the Dutch population (see Annex 6).

As a result of no available data, it was assumed that the safest method is to distribute the total domestic paper and carton supply between household and non-household sector as equal, i.e. 50:50 (Annex 15). People in households generally use printing and writing paper, carton is entering household by product packaging, and almost every household consumes paper by ordering and/or receiving newspapers and other mail. In addition, it was assumed that paper used in offices also finds its way to households as magazines and other mail. It was assumed the same holds true for consumption in non-household sectors. However, the number of households in the city is assumed to be at least two-three times larger than the sector of shops, supermarkets, and distribution centres[31]. In addition, it was assumed that all the paper and carton entering non-household sector, also leaves all as solid waste. More precise outflow figures of paper and carton from household sector was derived from the data which was received from the waste department of the municipality of Rotterdam (Annex 14). This is further explained under the next sub-chapter: P outflow from households.

Phosphorus inflow via wood products

The information about the amounts of wood products/building elements entering the households and non-households, was derived from the same national statistics which was used for paper and carton supply: Kerngegevens Bos en Hout in Nederland, Probos Stichting (2012). Based on that study, the total amount of nationally supplied wood in 2011 was calculated.[32] This amount was then converted into a P quantity by using the P content of fresh wood (0.0075%) provided by Antikainen *et al*., (2004) and based on the Finnish situation.

The domestic supply wood P inflow was equally split between HH and NHH assuming a 1:1 ratio (see Annex 15). In order to simplify the material flow analysis and take the mass balance into account, the total inflow of wood entering and leaving the non-households was taken similar. For the household sector, the outflow calculations are made more precise by using the waste data derived from the waste department of the municipality of Rotterdam.

Phosphorus inflow via household and sanitary paper

Household and sanitary paper data was derived from the FAO statistical database (FAOSTAT 2011)[33] (Annex 6). The total national domestic supply for the year 2011 was calculated by using the production, import and export quantities in tonnage calculated as: production + import – export. This resulted in a mass flow of 31 tons. This mass flow was downscaled for Rotterdam and converted into a P quantity by using the P content of 0.024% for in paper and carton provides by Antikainen *et al.*, (2004) (see Annex 5).

[30] See page 10 of Kerngegevens Bos en Hout in Nederland (2012). Amount of total paper and carton consumption is calculated based on the percentage of that product consumption given on the pine chart (48%). This percentage was taken from total wood consumption = 4.3 Mtons (12.2 mln m^3).

[31] No hard data was found within the scope of this research to check this.

[32] Amount of total wood consumption is calculated based on the percentage of total wood consumption (See page 10 of Kerngegevens Bos en Hout in Nederland (2012).) which is other than paper and carton, given on the pine chart (52%). This percentage was then taken from total wood consumption = 4.3 Mtons (12.2 mln m^3).

[33] Derived from: http://faostat.fao.org/, last accessed in November, 2013.

It is assumed that this domestic supply is the yearly consumption. Similarly to other inflows, estimation was also made about the division of the consumption of household and sanitary paper between the HH and NHH sector. Based on our assumptions, it was estimated that 85% of all the total domestic supply is entering the HH, and the remainder 15% goes to NHH (Annex 15). Furthermore, to simplify all the household and sanitary paper inflow to NHH sector was assumed to end up in wastewater. This was not the case for the HH sector, as the flow of household and sanitary paper was made even more specific based on additional data received from the waste department of the Municipality of Rotterdam (Annex 14) that specifies the amount of household and sanitary paper found in solid waste.

Phosphorus inflow via Textiles

The total domestic supply of textiles to the city of Rotterdam in year 2007 was 311 Kton. This data was derived from *a recent study on the environmental impact assessment of textiles in the Netherlands* (CE Delft, 2010)[34] (Annex 6). In order to convert the mass flow into P flow, the average P content[35] for the textiles mass flow was calculated. The average P content was calculated based on the P content in three textile types (Annex 5).[36]

Similarly to other inflows, an assumption for the distribution between HH and NHH sector was made (Annex 15). It was assumed that most of the textiles are supplied, consumed and discarded in households since most textiles are household products and the use of uniforms is less and less important and relatively small compared to the total amount of clothes. It was therefore assumed that approx. 80% of the total domestic textile supply most probably ends up in HH waste, and the rest of the 20% in NHH waste. While the amount of textiles leaving the NHH sector was taken as equal to the calculated inflow, for the household sector more specific data derived from the waste department of the Municipality of Rotterdam.

Phosphorus inflow via pet food

There are a lot of pets in urban environment. It is therefore important to include the flow of pet food as P containing flow to households (Annex 12). Whilst doing that, it was assumed that no pets are kept in NHH sector.

The amount of pet food entering the households was calculated based on the pet food consumption of cats, dogs and some other pet types that were considered as having the highest probability of being kept as pets in Rotterdam: rabbits, rodents, singing and ornamental birds, and reptiles. Also, some wild animals such as birds on the street were taking into account since people feed them food waste like bread example. The amount of pet food consumed was calculated based on national data from the report Borst & Beekhof (2011). This report indicates the total pet feed production in the Netherlands in 2010 (433, 550 tons). The national number of pets per households was converted into number of pets per households in Rotterdam, taking the urban specific occurrence for cats and dogs into account. As follows, the total pet food consumption per year was assigned for each type of animal based on the total pet food consumption and the occurrence and weight of each animal type assuming a linear relationship between weight and fresh matter feed intake requirements. Pet food consumption was redistributed based on distribution and difference between animal weight as a proxy for feed requirements. We multiplied that mass flow with a feed P content specific for each animal type. The mass flow was converted into P, whilst making the assumption based on the % of P content in each pet food type as show in Annex 12, Table 3. The final results for cats, dogs and rabbits were cross checked and had a good fit with the results of our bottom-up calculation method using the feed requirements and average P content, as well as the results of other publications for cities in other countries.

[34] This CE Delft study has in turn used the textile data from CBS 2007 statisics.

[35] The sum of P content in cotton, wool and linen distributed between 3 = (0.3% + 0,03% + 0,054%) / 3 = 0.13%.

[36] Such as cotton (0.3% - *Table 1 in Rochester, I. J. (2007). "Nutrient uptake and export from an Australian cotton field." 77(3): 213-223.*), wool (0.03% - *A. W. and P. A. Kemme (2002), based on dirty wool so overestimated*) and linen (0.054% - *derived from: http://www.feedipedia.org/node/12103; made of flax, assuming flax straw nutrient content*).

Home composted food

Some of the food from households is composted directly at home gardens. For this, the Dutch food losses study in households and catering was used *(CREM, 2010)*. This study was taken into account in order to calculate the amount of P composted in Rotterdam household gardens directly (see calculations in Annex 13). This home composting is then taken into account as the inflow to gardens (see figure 8). As an outflow, garden waste data was derived from Rotterdam waste company, further explained under the next section of this chapter: *P outflows from households*. In addition, gardens are presented as a process with a stock in our MFA-system and the stock number represents the yearly accumulation or depletion.

An overview of all input data, calculations, assumptions and flows in Rotterdam city are presented in Table 5 below.

Table 5: Overview of phosphorus (P) inflows in the consumption sector of Rotterdam city split for the household (HH) and non-household (NHH) sector, based on different data sources and assumptions

Type	Data source	Rotterdam domestic supply	Assumption between Rotterdam household and non-household sector	Source of assumption made to find the fraction between household and non-household sector
Domestic food supply	Buck *et al.*, (2010). A quantification of P flows in the Netherlands through agricultural production, industrial processing and households.	3,7% taken from total Dutch domestic food supply based per capita downscaling from the national data.	75% of the Rotterdam domestic supply bought by HH and 25% by NHH.	Based on Comisón Nacional de la Competencia (2011), the % to what HH and NHH spend money on food distributes as 75% HH and 25 % NHH.
Food intake by humans	van Rossum, C. T. M., H. P. Fransenet, (2011). Dutch National Food Consumption Survey 2007-2010: Diet of children and adults aged 7 to 69 years. Bilthoven, The Netherlands, National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieuhygiëne, RIVM).	Phosphorus intake calculated for all Rotterdam age groups given by the researcher of the Municipality of Rotterdam (Annex 2).	All age groups starting from 69 have the same average P intake as the last age group studied. Additionally, based on personal communication Van Rossem, RIVM, 10% was added to total food consumption on mouth level. As a result of the calculations made for P consumption at home and not at home: 71% of the P is consumed at home, 29% in not at home (NHH) (Annex 3).	Sources: Dutch National Food Consumption Survey Young Children 2005/2006; Dutch National Food Consumption Survey 2007-2010 : Diet of children and adults aged 7 to 69 years Ocke, M. C., E. J. M. Buurma-Rethanset al. (2013). Diet of community-dwelling older adults : Dutch National Food Consumption Survey Older adults 2010-2012. Bilthoven, The Netherlands, National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieuhygiëne, RIVM).
Detergents	Buck *et* al.,(2012). Agricultural scenarios to reduce the national P surplus in the Netherlands, Wageningen, Netherlands.	3.70% taken from total Dutch household consumption.	50% of total household supply to NHH sector (HH sector stays the same as calculated, thus total domestic supply = total HH supply + NHH supply (50% of total HH supply).	Author's assumption, see Annex 15.
Total Household and sanitary paper	FAOSTAT Household + Sanitary paper 2011 data, derived from: faostat3.fao.org/faostat-gateway/go/to/search/sanitary paper/E/. Calculated as: Consumption= Production + Import Value- Export Value	Percentage (%) taken from total Dutch consumption (Annex 6).	85% of total household and sanitary paper consumed by HH and 15% by NHH.	Author's assumption, see Annex 15.
Household and sanitary paper to toilet	Household+Sanitary paper 2011 data derived from: faostat3.fao.org/faostat-gateway/go/to/search/sanitary paper/E & Rotterdam solid waste hard data, Annex 14. & Beleidsnota Huishoudelijk Afval 2013-2018, chart on page 19: Figuur 2.	Calculated sanitary paper to toilet = Total sanitary paper entering the households of Rotterdam (see above) - sanitary paper found in total household waste (1.70% of total municipality waste, hard data accessed from the waste department of the Municipality of Rotterdam/ (Annex 14).	All the sanitary paper consumed by NHH also leaves the NHH via wastewater. The household and sanitary paper to toilets in HH was calculated as: total household and sanitary paper consumed – household and sanitary paper found in municipal solid waste = household and sanitary paper going to toilets in HH sector.	Author's assumption, see Annex 15.
Paperand carton	Kerngegevens Bos en Hout in Nederland, December 2012, Probos Stichting, page 10, 48% of all wood consumption.	3.7% taken from total Dutch consumption.	60% of total paper and carton supply consumed by HH and 40% consumed by NHH.	Author's assumption, see Annex 15.
Wood	Kerngegevens Bos en Hout in Nederland, December 2012, Probos Stichting, page 10, 52% of all wood consumption.	3.7% taken from total Dutch consumption.	50% of total wood supply consumed by HH and 50% by NHH.	Author's assumption, see Annex 15.
Textiles	Ten behove van prioritaire stromen ketengericht afvalbeleid, Milieuanalyses textiel, Rapport, Delft, maart 2010, textile data based on CBS 2007.	3.7% taken from total Dutch consumption.	80% of total textiles supply consumed by HH and 20% consumed by NHH.	Author's assumption, see Annex 15.

1.7.3.3.2 Phosphorus outflows from households

The outflows of households are solid and liquid waste flows, and dead people. An average human body contains around 0.7 kg of P. This potential stock in the human population of Rotterdam is not taken into account since it is relatively small compared to the annual P turnover. The liquid waste flow is wastewater and the solid waste flow is biodegradable solid waste (BSW, in Dutch GFT) that can be part of municipal solid waste (MSW), bio waste (food/kitchen waste) and green waste (garden waste). In addition, other P containing outflows linked to the non-food inflows were included. These were textiles, wood, paper and carton that can be collected separately to be recycled or be discarded in the MSW going to incineration plants that have ashes as final end products.

Wastewater

The wastewater of the city of Rotterdam is managed by two different wastewater treatment plants (WWTP):

1. Hollandse Delta (HD); and
2. Hoogheemraadschap Schielanden en Krimpenerwaard (HHSK)

Based on the expert interviews, these two are the only WWTP which receive wastewater from the city of Rotterdam. However, despite of knowing that Hollandse Delta and Schielanden en Krimpenerwaard collect Rotterdam city wastewater, it is still mixed with wastewater from other Rotterdam administrative districts. Therefore each Waterboard contacted, provided the percentage of which the wastewater is coming from the city of Rotterdam only. Another assumption was made how much of that water is then coming from households though, and how much from non-households. Annexes 9 and 10 provide the in depth data, assumptions and calculations regarding the wastewater flows. The data is based on the figures which were provided for the year 2011.

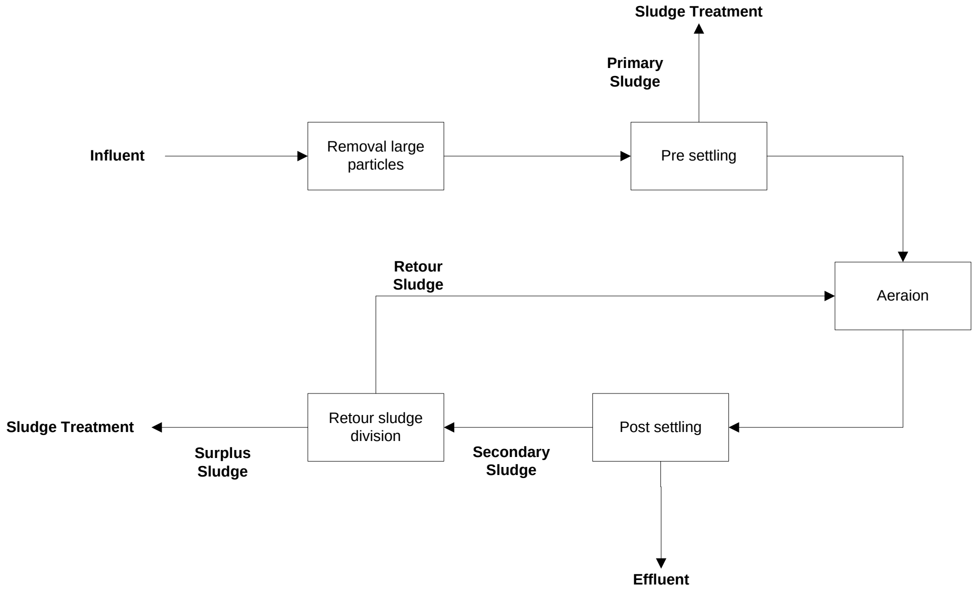

Figure 3: Schematic overview to how the waste water treatent in Rotterdam works. Derived from 'Seering on Sludge Age at HHSK', an internship report written by Luit Kamminga, accessible from Hoogheemraadschap Schielanden en Krimpenerwaard Waterboard (HHSK)[38]. The sludge is currently incinerated with no phsophorus recovery during the process and from the ashes.

In addition, it is important to understand how wastewater in the Netherlands currently is treated. Figure 3 above explains that WWTP consists of water treatment and sludge treatment. In the water treatment plant water is processed and cleaned biologically. As a result sludge is created which before its incineration has to be dehydrated in the sludge treatment[39] (Kamminga, year not specified). Since 1995 all communal sludge has to be incinerated according to national law. As a result, P in sludge is not recovered and reused in agriculture.

[38] The report is officially not published and was provided to the researcher by the SK Waterboard contact person (see section 1.7.3.1 Interviews and meetings)

[39] Briefly, sludge treatment consists of: (1) Removing the large insoluble particles from the incoming water, influent; (2) Biological purification of the water by bacteria. Sometimes chemicals are added as to increase the purification process; (3) Removing the sludge, created during the biological purification, from the water (Kamminga, year not specified).

Alternatively it is incinerated in special incineration plants, or co-fired in solid waste incineration plants or cement ovens. As a result the P is sequestered in infrastructure, porcelain and coal mines since the residual ashes are handled as waste.

The data and results show that in Rotterdam, P recovery from Rotterdam city wastewater/sludge and subsequently the reuse in agriculture is zero. Most of the P is removed from the wastewater: about 90% is trapped into sludge and the remainder is discharged to waterways. Sludge is digested anaerobically for biogas production. The final (dryer) sludge is then incinerated by co-firing in the municipal energy plant. Since the remaining ashes on the bottom of the ovens are not reused, neither is the P recovered, let alone that the P is reused in agriculture. Besides this loss, the P that is not trapped in the sludge is discharged and lost as effluent wastewater directly entering the surface water. This is the part of influent (total amount of wastewater entering the treatment plants) which is treated. The P which ends up in surface water is considered as 'emitted to the environment'. This flow is not considered as 'reused P' with the respect of the research aim of this paper, since it is not reused in agriculture and recovery from surface or seawater is financially not viable at the moment (Schröder *et al*., 2009).

Most of the P within the wastewater is originating from human excreta, detergents and a small amount from household and sanitary paper. In the MFA diagram, the flow of human excreta was combined together with both HH and NHH sector, and therefore connected with the total domestic wastewater production. The P amount in HH and NHH sectors are calculated separately based on the measured data received from relevant Waterboards and can be found in Annexes 9 and 10.

For the NHH sector it was assumed that all P inflow by detergents and household and sanitary paper leaves via NHH wastewater.

The calculations made for HH sector in this study were made more specific. The household and sanitary paper to toilet for instance, as explained before, was calculated by subtracting the amount of house and sanitary paper found within municipal solid waste from the total inflow.

Due to a lack of data, the amount of detergents entering the wastewater was assumed as the same with the total outflow. Additional P inflow to HH wastewater was calculated as the food waste from sink stones. The latter was calculated based on food waste discarded via sewerage (CREM, 2010) and P contents for the items of the composition. It was assumed that the total amount of food waste into the sewerage system is 0.02 kg/capita/year.

Human excreta P

Based on Zeeman *et al*., (2006), humans excrete 0.8 grams P in urine and 0.5 grams in faeces per day. This information was converted to the total human excreta produced in the city of Rotterdam in 2011 (see Annex 7). This is the total excreta produced by humans both in HH and NHH sanitation that are both collected and treated by the same municipal wastewater system. In the sub-process of our MFA "Consumption in Rotterdam city" the flow of human excreta is therefore presented as one total outflow connected to both sectors. See Figure 6 for the flow diagram.

Retail organic waste

As already explained under the inflows, one of the outflows was considered the retail food waste from the shops, supermarkets and distribution centres. This outflow is neither part of HH nor NHH sector, but is discarded directly from the sector "Food distribution and selling (shops, supermarkets and distribution centres)" (see Annex 8). It was calculated based on the FAO food waste study which was already mentioned under the inflow section of this paper. As follows, the amount was deducted from the total domestic food supply in order to get the amount of food left for HH and NHH consumption.

Solid waste: non-household

The NHH waste flows were not the main research focus of this study. It was difficult and even impossible to find hard data from companies and organisations. By making assumptions and use other known flows it was possible to quantify the NHH waste flows at undetailed level. See Annex 15 for the distribution of all the solid waste types between the NHH and HH sector.

Solid waste: household

The waste department of the Municipality of Rotterdam was interviewed for figures about solid waste (everything but wastewater) from Rotterdam households. Specific figures regarding solid waste from the households of the city of Rotterdam in 2011 were received (see Annex 14). All the P calculations made for solid waste flows are based on these numbers and can be found in Annex 11. On this page, it can be seen that some of the items are collected separately, whilst the others are discarded together with MSW. This MSW is collected separately and is incinerated without recovery and reuse of P from that process or final residues (ashes). The fraction of waste items within the total MSW is presented on Figure 4 below.

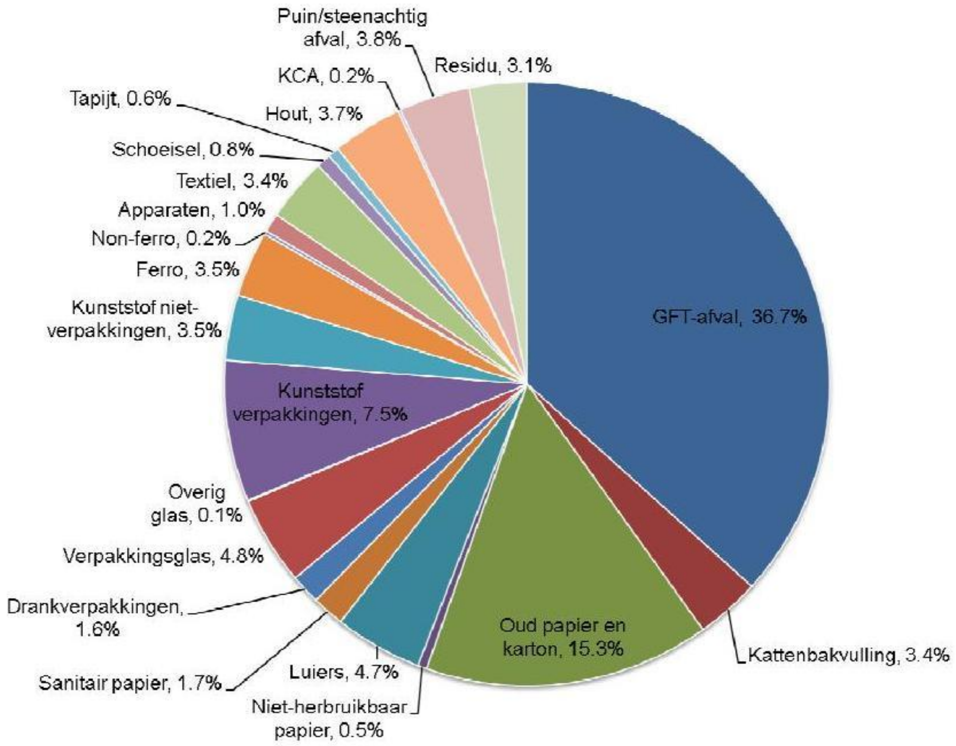

Figure 4: Composition of household waste in Rotterdam, 2011. Derived from Municipality of Rotterdam, 2013.

Based on the information provided by that chart on Figure 4, 36.7% out from total solid waste makes organic waste (in Dutch GFT); 3.7% makes wood; 15.3% makes old paper and carton; 4.2% makes textiles[40]; and 1.7% makes household and sanitary paper. The waste items which are collected separately, are depending on the type, somewhat reused, somewhat incinerated in the bio energy plant for green energy production (wood[41] and garden waste[42]); and a small fraction of organic

[40] Textiles in general by the data provided by waste department of the Municipality of Rotterdam is combined with shoes. For the simplification in this research shoes were assumed to be textiles.

[41] Data from the Municipality Rotterdam, (2012) (specifically 2011 data used from that sheet) says that there was 9158 tons of wood waste produced within the year of 2012 in the city of Rotterdam (in Dutch: "houtafval A-en B-

kitchen and garden waste is eventually composted. This is the only P that is actually reused in agriculture. The discarded paper and carton, textiles and wood that are collected individually consist of P. These materials are collected and partly recycled but the P deriving from these is not reused in agriculture since it is not part of the food P cycle. Paper and carton are reused in the paper industry. Textiles are recycled by second hand shops, or the fibres are recovered for the production of new fabrics. Wood that is clean enough can be reused by the wood industry. Paper, carton, textiles and wood of low quality or too dirty are incinerated and the final ashes are not reused but sequestered in infrastructure or the environment. For example, paper can only be reused or recycled approx. 6 to 7 times and the fibres that have become too small must finally be incinerated. Since this research lasted for one year, the textiles are in their reuse cycle.

All the mass flows of different waste types were converted into P flows based on the information about the content of P in different materials, which can be found in Annex 5.

Pet excreta

Additional outflow is the pet excreta from households (Annex 15). Based on the data on pet food inflow, pet excreta were distributed as 'dog excreta' and 'cat and other animals excreta'. Other pets can be rabbits, rodents, songbirds or ornamental birds, reptiles, or other wild animals to which people in the city environment might feed their food waste; e.g. bread to pigeons or ducks.

Due to lack of data, the total pet/animal excreta was taken as equal with the inflow of all the total calculated pet food inflow, as well as additional household food feed to animals. It was already explained to the reader under the previous sub-chapter: *P inflow to households*, how the amount of pet food consumed was calculated and how is this distributed between different animals (see Annex 12, Table 1).

However, since it was decided to also take into account the amount of HH food feed to pets and other wild animals (based on Borst and Beekhof, 2011), it is important to explain here how this feed was distributed between the two different types of animal/pet excreta. In the other words, this means that it was assumed that all the pet food eaten also leaves as pet excreta (as explained before, two groups were made – dogs; and cats and other animals). Since household food fed to animals was distributed between 'pets' and 'wild animals', the sum of the food, feed to wild animals, was merged together with ½ of the household food feed to pets, as well as the total household food fed to 'wild animals'. It must be noted though that the household food feed to pets was distributed equally only as between dogs and cats. The amount of HH food feed to wild animals goes all under the 'cats and other animals' excreta. In general this kind of distribution is not too important for this study, as in general all the animal/pet excreta ends up as lost P anyway. In short, the cat and other animal excreta was calculated based on the following formula = pet food consumption as shown in Annex 12, Table 3 for cats, rabbits, rodents, singing and ornamental birds, reptiles + ½ of the HH food feed to pets as presented in Annex 13 + HH food feed to wild animals as presented in Annex 13.

For dog excreta, the other ½ of household food waste fed to pets was merged with the dogs pet food supply (see the previous sub-chapter under 1.7.3.3.1 Phosphorus inflow to households: phosphorous inflow via pet food or Annex 12, Table 3). In the other words, the following formula is used: dog excreta = dog food supply + ½ of the HH food feed to pets.

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hout + houtafval C hout"). From this amount, the Klok Containers indicated, that 20% is used for biomass and the rest 80% reused.

[42] Data from the data sheet received from the waste department of the Municipality of Rotterdam: Gemeentelijk afval 2012, Hoeveelheden, 0599 Rotterdam (2011 data used from that sheet) says that there was 2989,7 tons of kitchen/garden waste in the year of 2012 produced in the city of Rotterdam. Indaver Groen Compost indicated that out of this total amount, about 70% is composted and the remained 30% is used for green energy production (biomass).

The final destinations of the pet excreta differ per pet type. For dogs it was assumed that the excreta ends up in vegetation and public parks (environment) or at the streets were it is removed by municipal cleaners or the owners finally ending up in the MSW (sequestration). For other pets (cats and others) it is assumed that the excreta are discarded directly via MSW. In general, all animal excreta end up either in the incineration ashes or in the environment and no P is recovered nor reused from pet excreta.

Garden waste

The outflows of garden waste from HH were derived from data received from the waste department of the Municipality of Rotterdam (Annex 13). This mass flow was converted into P flow by using the percentage of P found in fresh garden waste compost (see Annex 5). Furthermore, garden waste is the only waste type for which a direct inflow has been presented. Citizens probably use P fertilisers, but we assumed the quantities to be negligible. Consequently the garden was modelled as a process (see Figure 8). The stock identifies the amount of P that accumulates in or is removed from gardens in Rotterdam on a yearly basis.

In Table 6 all waste outflows from Rotterdam households are presented, including their final waste handling destination, and data sources which these were derived from.

Table 6: Description of the data used for the calculation of phosphorus (P) outflows from households (HH) within the city of Rotterdam, showing the sources for mass flow and P content data.

Type of waste	Method of waste processing	Data source for mass flows
Organic waste (GFT in Dutch) (separately collected)	Composted.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam.
Organic waste as part of (36,7%) total household waste (in Dutch "huishoudelijk restafval")	Incinerated.	Percentage of organic waste in total household waste provided by "Beleidsnota Huishoudelijk Afval 2013-2018."
Garden waste (in Dutch "grof tuinafval")	- 30% of separately collected garden waste. Used as fuel in bio-Energy plants.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam.
	- 70% of separately collected garden waste. Composted.	Percentages between composted garden waste and incinerated in bioenergy plant provided by Indaver Groen Compost.
Wood	- 80% of separately collected wood. Reused.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam ", received from the waste department of the Municipality of Rotterdam.
	- 20% of separately collected wood. Used as fuel in Bio-Energy plants.	Percentages between reused and incinerated in bioenergy plant provided by company Klok Containers.
	- 3.70% of total household waste collected together. Incinerated.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam. Percentage of wood in total household waste provided by Beleidsnota Huishoudelijk Afval 2013-2018.
Paper and carton	Total separately collected paper and carton. Reused.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam
	- 15.30% of total household waste. Incinerated.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam. Percentage of old paper and carton in total household waste provided by Beleidsnota Huishoudelijk Afval 2013-2018.
Textiles	Reused.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam.
	- 4.20% of total household waste. Incinerated.	Data sheet " Gemeentelijk afval 2011, Hoeveelheden, 0599 Rotterdam", received from the waste department of the Municipality of Rotterdam. Percentage of textiles in total household waste provided by Beleidsnota Huishoudelijk Afval 2013-2018.
Pet excreta	Dog excreta = dog feed + ½ of organic waste feed to pets. Incineration and environment sequestered	Borst, N. and B. Beekhof (2011). Facts & Figures for pet industry in 2011. Den Bosch, HAS Knowledge, Hogeschool HAS Den Bosch.
	Cat and other pet excreta = cat feed + ½ of organic waste feed to pets + organic waste feed to wild animal. Incineration and environment sequestered	
Retail organic waste	Mainly incinerated.	Gustavsson *et al*., (2013). The methodology of the FAO study: 'Global Food Losses and Food Waste – extent, causes and prevention' – FAO, 2011, SIK- The Swedish Institute for Food and Biotechnology, page 34.

2. Findings

2.1 Interview findings for urban agriculture in Rotterdam

2.1.1 Classification of urban agriculture types

Within the following research, 11 types of urban farms in Rotterdam were interviewed. All the comparisons described here can be found from Annex 16 at the end of this paper. Whilst RUAF has already come up with UA classification, it was decided to re-categorize those more suitable for Rotterdam. The rationale for this being that the RUAF classification cannot be taken as 'anything goes' since the foundation is mainly concerned with the issue of food security and is focused on the research of developing countries. In Rotterdam, as it will be explained, the main concern with urban farming is not about food security but about creating a closer community. The more so because the urban farming situation in each city depends largely on the network of people who are involved, and their situation and perspectives (van Veenhuizen, 2006). Therefore, the decision was taken to re-categorize the interviewed urban farms in Rotterdam based on their socio-economic role in their urban environment (the agents involved and their situation) (see Table 7).

Table 7: Author's classification of urban agriculture (UA) farms in Rotterdam.

Urban farm	Classification
De Enk	Institutional garden
De Buytenhof	Commercial-social peri-urban farm
Voedseltuin	Social community garden
Pluktuin	Community garden
Moestuinman	Community garden
Gandhithuin	Social community garden
BuurtLab	Institutional garden
Tussentuin	Community garden
Uit je Eigen Stad	Commercial farm
Carnissetuin	Social community garden
Dakakker	Roof garden

However, it must be noted that it was, and it stays relatively difficult to make such distinction since there is always some overlap. For instance, being a community gardens such as Pluktuin and Tussentuin does not necessarily mean that these do not offer any social benefits as indicated for social community garden Voedseltuin for example. The interviewee of this garden just did not put as much emphasize on the issue of feeding people with low-income via establishment of this garden, but their aim is rather to be a healthy and green city space for all kinds of people regardless of their income. The provided classification of urban farms in Rotterdam can thus be defined as follows:

Institutional garden – De Enk and BuurtLab are both standing for children's education. Every kid has its own plot in the garden where they can learn to grow their own vegetables and take them home (or learn to cook collectively directly in the garden). They are considered institutional since these kinds of gardens are normally connected with kindergartens or schools in order to attract children in particular.

Commercial - Social peri-urban farm – De Buytenhof, located a little bit outside of the city limits in an peri-urban location, was the only so-called real farm which was encountered within this research. Compared to other urban farms, it has -r scale agro-enterprises, the only one growing cows and pigs. The attribute 'social' is used to address the farm's concern to help people who are not doing well by the society's standards, e.g., the disabled, socially isolated or otherwise impaired, or people who have suffered from mental health or other such problems (e.g., burn-out, job-loss). This farm is a care community that people join to get a sense of belonging. The farm's objective is to bring benefit for both people and the planet. Besides that, organically grown local food is delivered to several catering businesses within and around Rotterdam and as such contributes to the farmers' income.

Social community garden – These are the types of so-called urban farms which besides similarly to De Buytenhof contribute to the social well-being of people who work at the garden at the same time growing food for Rotterdam Foodbanks. Foodbanks are voluntary organizations operating in several areas of the city that donate food to people of a low income. In many of those farms, the mentally disabled, or people with other health problems, who work there, are paid for by the Dutch social services for their contribution (AWBZ Dutch health care law).

Community garden – These are gardens that have mainly been established on the city's vacant land (although this is also the case in some other types of farms) in order to improve the neighbourhood and 'fight' against the government's plans to build those areas up. The food production for (poor) people in those gardens is generally not the main purpose (although it is a benefit). Rather it serves as an outdoor area for people in the neighbourhood where to create a close community and organize outdoor events, such as music evenings, outdoor cinemas, or educational workshops (permaculture, mushroom growing).

Commercial farm – Uit je Eigen Stad is the only commercial urban agriculture type in the city of Rotterdam. Organically grown food is sold in several locations within and around the city and extra financial profit is made through running the local restaurant. Thus, similarly to De Buytenhof, financial profit is an important aspect in terms of the farms' income.

Roof garden – Dakakker is the only roof garden which has been managed to realize in Rotterdam so far. It is to some extent commercial, as besides growing food for the people who work\volunteer there, it is also sold to some nearby restaurants around.

2.1.2 People involved

Whilst in most developing countries, UA areas are set up to secure food production and support poverty, it was first of all investigated what are the different motives for people in Rotterdam for setting up UA areas.

The average age of the people who are leading or who have started up the UA initiatives in the city of Rotterdam falls between 40-50 years. These are mainly rather highly educated and active people, who in approx. 50% of the cases are not even interested to gain personal financial profit out of this activity but use it more like a hobby for themselves and for the neighbourhood people or other volunteers (Moestuinman, Tussentuin, Pluktuin, BuurtLab). However, in gardens such as Voedseltuin, De Enk, Ghandithuin, Carnissetuin or Uit je Eigen Stad, there are people working with contracts. In those cases the average number of people benefitting financially contribute to 1-5, depending on the type of garden. These are mostly projects with higher financial profit or higher social funding.

All the discussed UA areas are accessible for everyone and every person wishing to volunteer can do so. The main motivation of the volunteers comes from their wish to spend time outside whilst enjoying carrying out physical activities in the garden, gain better health and meet other people. The average amount of volunteers contributes between 10-15 people per day, taking into consideration that most of the visited gardens are not open every day, but only 1-3 days per week. It is hard to assess the total number of volunteers per garden, since sometimes a volunteer comes only for once and never returns. The volunteers have very different backgrounds – there are full-time or part-time employed people, but also unemployed peoples; some volunteers may have diagnosed with psychological or other health-related conditions. Being a care community for the disabled does not mean that healthy people are not allowed to join. These initiatives are open for and welcome everyone.

2.1.3 Starting up & funding

Whilst it appeared that most of the visited UA areas are voluntary projects with no real financial income, it is relevant to establish, who funds such projects as well as who owns the used land.

It was found that 50% of the visited UA areas are situated on land that is owned by the city or a social housing corporation (Uit je Eigen Stad) and is rented for gardening activities (Ghandithuin, Carnissetuin). Since these farms are mainly so-called charity projects, the money for rent comes from donations, e.g.: Stichting Doen, Oranjefunds, Physico, Bufgroen, Deltafunds, Mileau Centrum Rotterdam, or Rabobank. Sometimes the money is won through gardening awards – e.g., Aardig Onderweg Award. In general, the interviewees shared the opinion that not much money is actually needed – after the first year of investment, most of the necessary equipment and plants are already there.

The other 50% of the visited UA areas are given by the city for free use. In many of those cases the land was a former vacant plot that the City Government planned to use for real estate development, but was convinced otherwise by UA activists (Pluktuin, Tussentuin, Moestuinman), who pressed the importance of maintaining the city's green space instead. An exception within the visited sites is De Bytenhof, which is the only privately owned farm, as well as Dakakker rooftop which is owned by an architecture bureau.

Moreover, in line with the interviews, it can be concluded that urban farms in Rotterdam are 'spreading organically' around the city – everyone knows a little bit about each other and the farms are connected to each other via foundations such as Eetbaar Rotterdam[43], Rotterdam Oogst (Rotterdam Haarvest)[44] or Transition Town Rotterdam.[45] In most of the cases it is not the city, but active private individuals who approached the City Government with their ideas. The city in turn tends to respond rather positively, lending the approval of most of the projects. Despite the city's 'grey building plans' that the citizens actively protests against, in case of almost every UA site, the city has still financially contributed to the initiatives. Mostly in start-up, but, in many cases also by granting a yearly funding, although the amounts allocated are relatively low.[46]

2.1.4 Local food production & consumption

As can be seen from the definitions of UA types, food production is currently not the main concern of urban farms in Rotterdam. The few urban farms which make some money out of growing their crops or animals are Uit je Eigen Stad, De Buytenhof and Dakakker (the latter in a somewhat lesser extent).

The rest of the urban farms have set themselves social objectives – offering citizens an active green space, creating a close community, offer environmental education for children, be a meeting place and a care community. Food production is thus often given a secondary place.

However, some sort of food security is still existent, because amongst the volunteers there are often people with lower incomes. According to food flow habits, grown food is mostly given to the people who work in the garden (children, volunteers etc) or donated to Foodbanks[47], an organisation that provides food to the poor (Voedseltuin, Ghandithuin, Carnissetuin). Some of the vegetables are also used directly on site for local cooking projects. Therefore in most cases food flows become fragmented (different people working in the garden taking small amounts of food with them) and hard to map. However, some more commercial urban farms have specific restaurants or farmers' markets where they deliver their products. A food flow map was created in order to better express this (see Figure 3).

[43] Activist group\ advocacy group started in 2008 for urban farmers in Rotterdam with the purpose to bring them together and share each others knowledge for better development (www.eetbaarrotterdam.nl www.eetbaarrotterdam.nl).

[44] An organization which aims to strenghten the the regional food chain by organizing events and marketplaces inRotterdam. (their website: www.rotterdamseoogst.nl =)

[45] A network of people who can work together for more resilient and healthier city. (their website: http://www.transitiontownrotterdam.nl)

[46] The interviewees did not indicate any specific numbers though.

[47] This are the type of non-profit organizations which collect food and other occasional things from the supermarkets, packs them into equal packages and distributes to people who have low income and who are also able to prove that through their personal income documents.

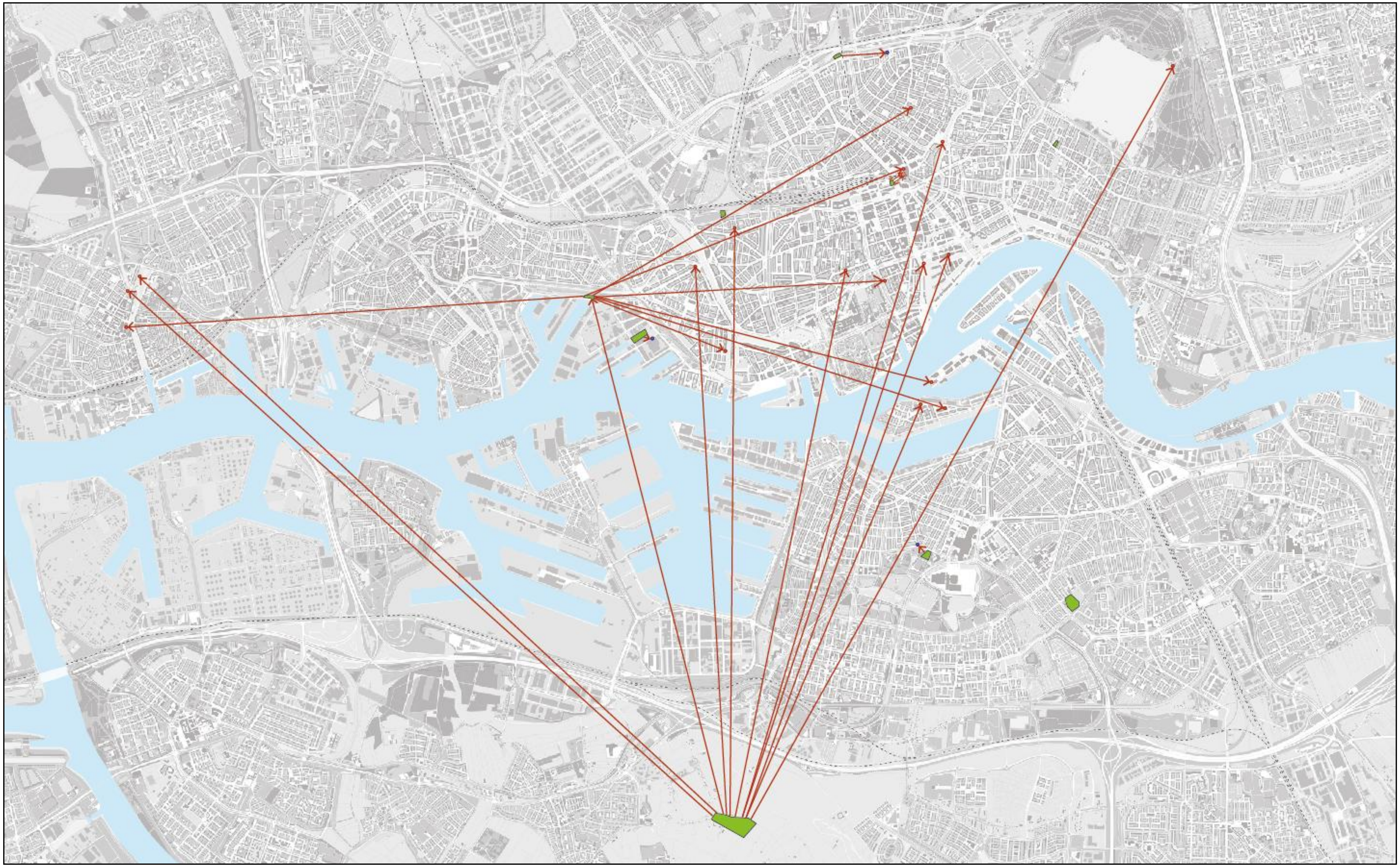

Figure 4: Food flows in researched urban farms in the city of Rotterdam. The green areas are the visited urban agriculture (UA) areas. From all the UA areas, volunteers are allowed to take food with them. The red arrows from some of the farms indicate where the food is being transported, mainly shops and restaurants. The UA areas without arrows do not deliver their food anywhere, but it is used by people who work there.

The types of grown crop are very diverse in every garden and thus it is unnecessary to mention them all[48]. The more so as the preferences may change by year or season. The same is with the amounts of food produced, since most of the gardens do not keep any specific track on how much food they grow but they are managed rather informally (not much paper work). However, when it comes to meat production, it is only De Bytenhow who, besides its commercial fruit and vegetable production, also grows cows, pigs and chicken and to some extent also De Enk and Uit je Eigen Stad with some chicken. During the winter time most of the gardens (except De Buytenhof and Uit je Eigen Stad) are either closed or have decreased winter activities, e.g., making furniture out of reusable wood, building fences around the garden, doing some maintenance works, grow some amounts of food suitable for wintertime – e.g., winter salad or potatoes, or organize some social events (yoga classes in the garden house, music evenings, Christmas markets).

2.1.5 Environmental performance of urban agriculture in Rotterdam

One of the aims of the research was to evaluate how well are the urban farms in Rotterdam performing in terms of their environmental management. Based on the personal conversations with the so-called urban farmers, questions were asked about soil health, species richness, sustainable water and energy usage and the organic waste management of the gardens. The assessment criterion has only been based on verbal assessment given in interviews and no quantitative or technical data or measures have been taken into consideration.

Soil health

Some of the visited UA areas were former polluted lands left vacant. This was a case for Uit je Eigen Stad which used to be a railway station and was heavily polluted underneath. It was therefore tested several times before any agricultural action was allowed to take place. However, with several improvements (e.g., adding compost) the interviewee considered the soils today to be relatively healthy and productive.

[48] As to give some examples, the long list includes products such as potatoes, cabbage, tomatoes, pumpkins, carrots, beetroots, lettuce, onions, different kinds of herbs, beans, many kinds of berries, sometimes fruit trees such as peers, cherries or apples, cucumbers etc.

Besides Uit je Eigen Stad, some (oil) pollution has been also found from the territories of Voedseltuin (former harbour), Pluktuin (former car park), Moestuinman, and BuurtLab (former chemical plants). In Pluktuin the land is still covered by pavement and the plants are grown in plastic bags (peer trees) or boxes. The reason for that is the high cost of demolishing the pavement, but also the Municipality’s wish to get back their land in the same condition as it was handed out. The other gardens have been improved a lot by using compost or additional soil (Voedseltuin) and, according to the interviewees, the soils are now healthy. In BuurtLab and Pluktuin, so-called box gardening is used. This means the grown plants do not have any contact with the deeper ground.

In general, all the interviewees were pleased with the quality of the soil in their gardens[49], claiming that plants normally grow well and there are no particular problems with soil quality. They claimed that the crop yield is generally good and problems with occasional low yield can be assigned to weather conditions, e.g., heavy rains. In addition, many UA areas in Rotterdam are initiating to follow the permaculture principle (Ghandithuin, De Enk, Voedseltuin, Pluktuin), which plays a role in enriching the soil quality. This is important to the farms because most of them do not preface to use any chemical fertilisers.

Organic waste

In all the visited UA areas the organic waste (plants) is composted (in heaps) and re-used directly on site, except Uit je Eigen Stad who also stores its plant waste, but it is transported to an organic farm in Vlaardingen once a year where it gets composted and then delivered back to Uit je Eigen Stad. The reason for that being lack of suitable equipment for large-scale compost making (in Vlaardingen they also add cow manure). However, re-using all the organic waste directly on site does not necessarily mean that no other extra input is needed. The more so as getting compost out of organic waste takes a lot of time. Therefore, extra organic fertilisers are sometimes bought (different types of organic grains e.g., from a company named Florisan in Friesland).

There is no reuse of wastewater, sludge or source separated excreta on site, except in Moestuinman, were the project leader is imitating compost toilet principle for

[49] The research did not take into account any quantitative data or tests made as to look behind the scenes to proof that aspect.

people who visit\work in the garden. However, in general the cycle of soil-food-human-excreta-agriculture is not closed for the sanitation waste flows. This is an important flow that is not reused, but could be one of the solutions for closing the P loop.

Organic waste is not exported from any of the farms, but in some cases extra is imported instead. This is done from other nearby farms (mostly from different children's farms as these were considered less likely to use chemicals compared to so called bigger normal farms with larger agricultural production), from the waste department of the Municipality of Rotterdam or Landschapsonderhand[50]. These flows are visualized in a flow map (see Figure 5) De Bytenhof indicated that also manure is used directly on the site (the only farm having cows though). Manure is also used in Ghandhituin where it is transported to garden from a nearby children's farm Kinderparadijs.

[50] An organization which stands for the nature and landscape conservation in and around Rotterdam through an ecological approach. More about it via: www.landschapsonderhoudrotterdam.nl/.

Figure 5: Flow map of plant materials to urban farms in Rotterdam. Only 4 out of 11 interviewed farms import extra organic materials from nearby children's farms in order to compost that on their site.

Species richness

One of the important benefits of UA is providing habitats for different species and thus increasing the city's ecosystem services. It was unnecessary for the interviewees to mention all of these species one by one. However, the general impression on the issue was positive, 'the garden offers habitat for many species – there are a lot of butterflies, worms, bees, rabbits, frogs, hedgehogs, and birds (magpies, pheasants). The garden is full of life,' (personal conversation, 2013). However, supplementary measurements are needed as to research the exact number and typology of species.

Water usage

Most of the visited gardens have their own rain water collection system. Plus, normally they would also use water from nearby canals (De Enk, De Buytenhof, Pluktuin, Carnissetuin). Only a few farms rely mostly on groundwater, such as Uit je Eigen Stad, whereas Ghandithuin and others use the combination of rainwater and groundwater. With the latter only used when rainwater supply is insufficient. Such farms are, e.g., Tussentuin, which uses its irrigation from a nearby restaurant, Voedseltuin, which uses water from surrounding buildings, and Moestuinman, which uses tap water from a nearby shop in dry periods. Water from the drain and sink stone are not recovered and reused in any farm.

Energy usage on sites

Out of the 11 visited gardens, only Pluktuin has its own sustainable energy sources (solar panels). The others have a contract either with sustainable (Ghandithuin with Green Choice) or non-sustainable (De Enk, De Bytenhof, Voedseltuin, Carnissetuin, Uit je Eigen Stad) energy providers, or do not need energy at all (Moestuinman, BuurtLab, Tussentuin). In conclusion, the use of sustainable energy in UA areas is still on a relatively low level and unbalanced compared to sustainable energy usage.

2.1.6 Benefits

The list of benefits which the UA areas offer for cities in general is relatively long. Many of these have already been described in this paper. However, based on the interviews, the most important ones for Rotterdam can be summarised to be:

- Offer a healthy green space for the citizens who are interested in gardening.
- Promote green roofs (in case of Dakakker) with all the benefits it offers Dakakker also brings a lot of fame and press for the city.
- Offer a healthy green space for all kinds of people to socialize and meet each other.
- Create a care community for mentally disabled or for people with other health problems.
- Offer a healthy green space for cultural services – yoga lessons, music and cooking events, outdoor cinemas, furniture or clay product makings.
- Offer educational services for the citizens, both kids and grown-ups – environmental education for children, permaculture courses, eatable plants course, growing mushrooms course, 'learn how to conserve vegetables' course.
- Grow fresh food for people with all kinds of income (food security), localise the food network, decrease food miles.
- Grow fresh food for low income people and deliver it them via so called foodbanks.
- Offer a living space for several species, increase the city's biodiversity
- Help to reduce the urban heat island effect.

2.1.7 Challenges

Whilst UA can contribute to many benefits, the interviewees indicated also a list of challenges which made them worry. These are summarized as follows:

- How to focus on the energy and time of the volunteers, how to make them work independently.
- Another mentioned challenge for UA activists is the continuation of their farm in general in terms of the growing competitiveness with other similar farms which might take over their ideas. This, however, can also be seen as an opportunity and has a positive effect since UA in general contributes to sustainable development.

- Future uncertainties – economic crises, which might affect financial management and have an effect on the survival of the gardens; unsure contract extensions give no security on the length of the stay, which makes investment-decisions hard.
- More difficult to get children involved nowadays than it used to be – social media consumption is overtaking healthy outdoor activities. Also, the schools do not have the money to transport their children to the gardens with school busses.
- How to be a care community and not too much labour oriented
- Not enough food for the poor.
- The management of the garden might be considered to be too informal by the city government.

In the following chapter, the research continues to investigate P flows from Rotterdam households. This part of the study aims to find out how much P is lost from Rotterdam households or, in other words, how much P is not recycled back into agriculture. As follows, links from this potential supply of nutrients to Rotterdam urban farming are made.

2.2 Calculated phosphorus flows of Rotterdam households

As explained under section "*P flows in the Netherlands*" we used the household waste sector as the main focus of this research. The increasing quantity of P in national household waste from 2005 to 2008 (Buck *et al.*, 2012) proves that its management must be made more sustainable in respect to recovering P and other nutrients. Even though the import of mineral fertilisers has been increased compared to 2005, it has been argued that by increasing the recycling of local 'waste' flows back to agriculture, it would even be possible to manage without P import into the Netherlands. Since the household sector contributes the most to the waste industry input (Rosemarin *et al.*, 2009), the focus in this research is on biodegradable household waste in Rotterdam with the aim to make it more sustainable in connection with Rotterdam urban agriculture at local farms. One of the options is to reuse urban organic waste and wastewater in urban agriculture in order to recycle the essential P back into the food chain.

However, it is first of all important to take a look at the in – and outflows of P flows in Rotterdam households in order to investigate its performance, as well as the capacity of the local UA areas to apply the recovered and recycled P from organic household waste.

In order to evaluate the lost P from Rotterdam households specifically, the P containing inflows and outflows were investigated whilst using the method of material flow analysis (explained in the research methodology section of this paper).

The result of the outcome of the calculations made for Rotterdam household sector can be found on Figures 6-8 and Table 8 below, followed by more detailed explanation and analyses. It is important to note that the original data is not always consistent and in balance, some of the original calculations were re-calculated by STAN using a statistic balancing procedure. All the original flow values and the changes made by STAN, can be seen in Annex 18 in the end of the manuscript.

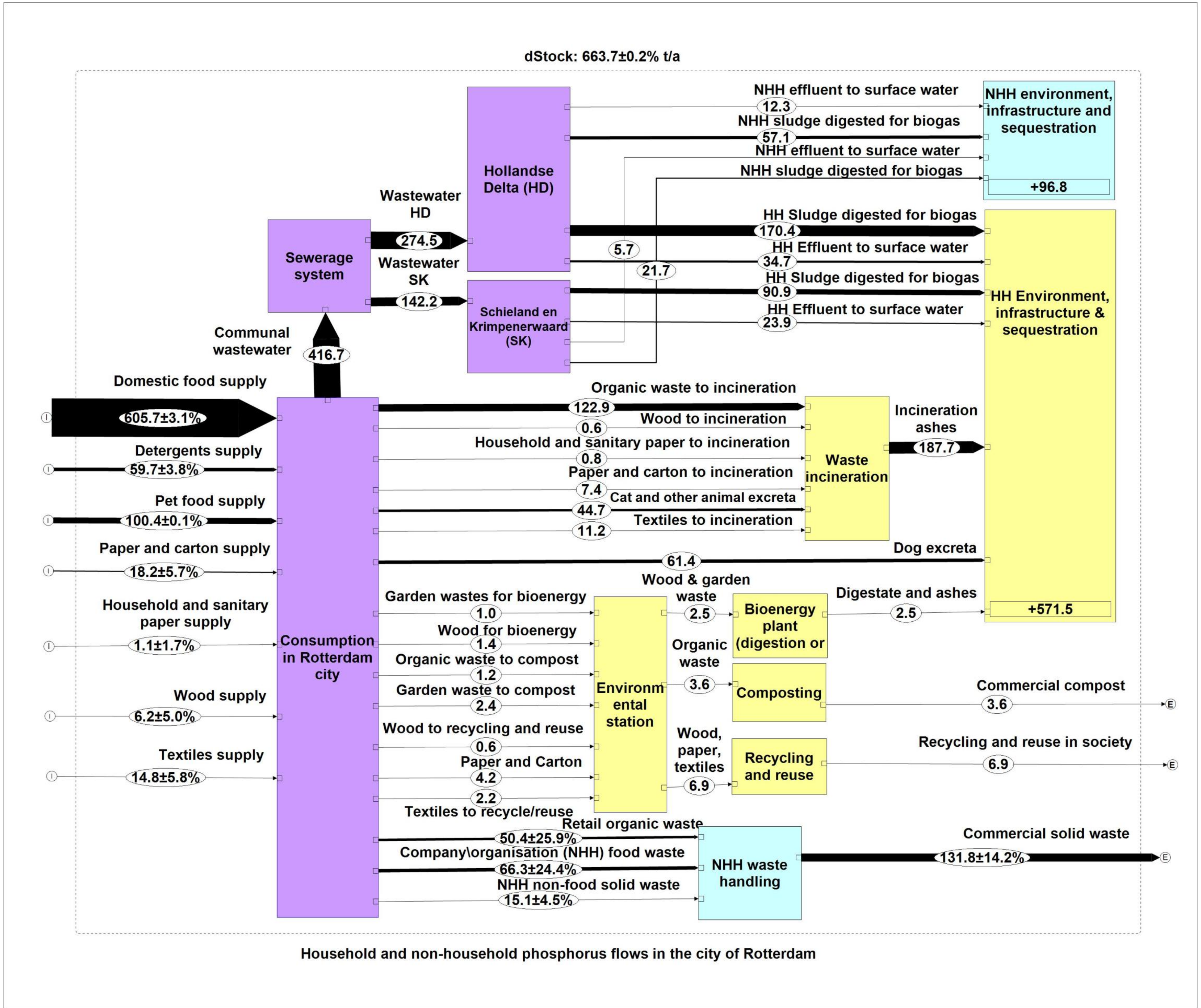

Figure 6: Calculated phosphorus (P) flows [tons P/year] in the household sector of the city of Rotterdam. Showing inflows, internal flows and outflows in for the year 2011; based on data and assumptions from the municipality, companies and expert. The purple colour represents the processes which are common for both household (HH) and non-household (NHH) sector; blue stands for NHH processes and yellow is the colour for HH sector. The thickness of the arrows represents the size of the flow quantity.

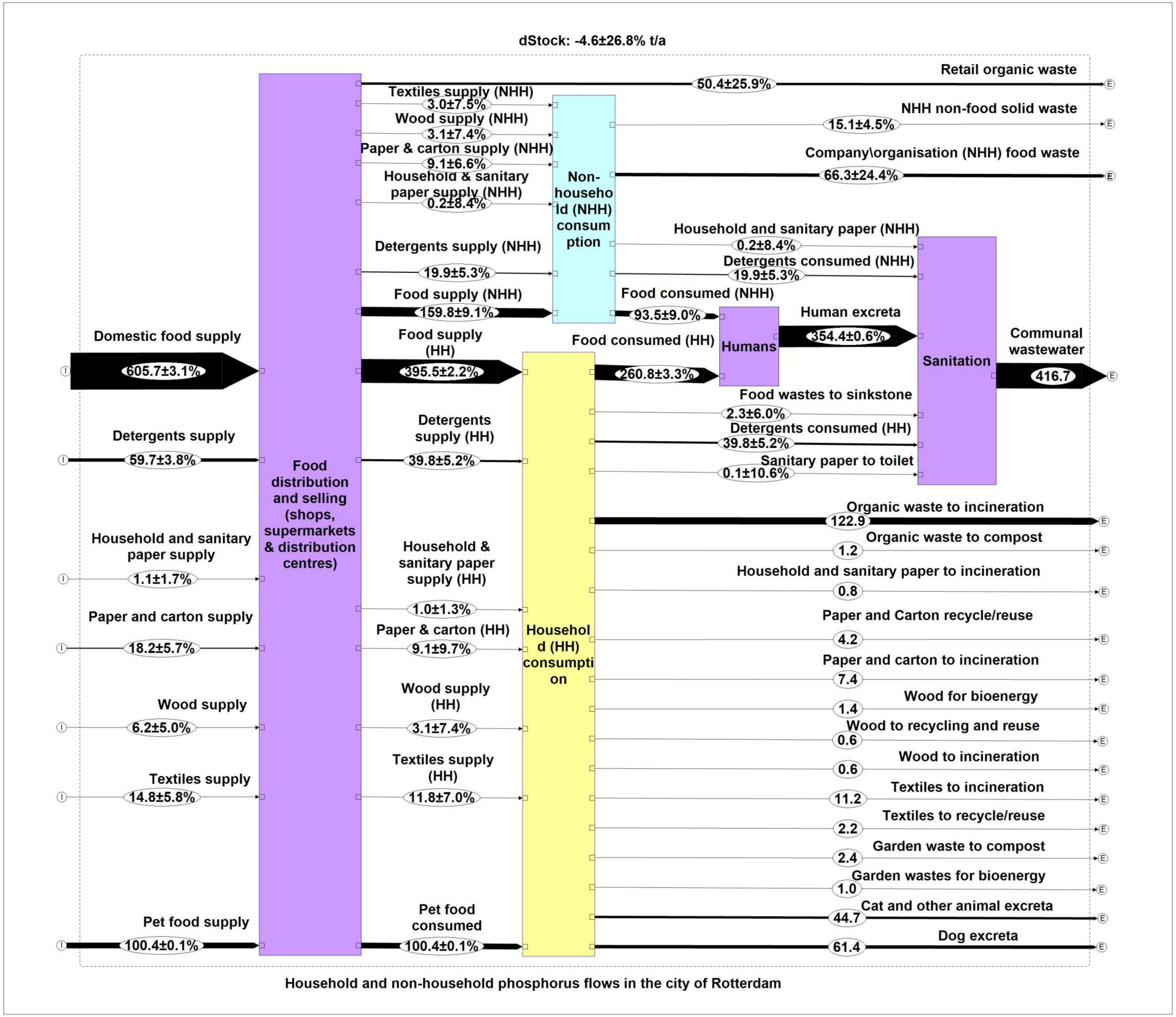

Figure 7: The phosphorus (P) flows in the sub-system "Consumption in Rotterdam City" distributed between household (HH, in yellow) and non-household (NHH, in blue) consumption sectors sector; depicted similar to Figure 8 (see more explanation).

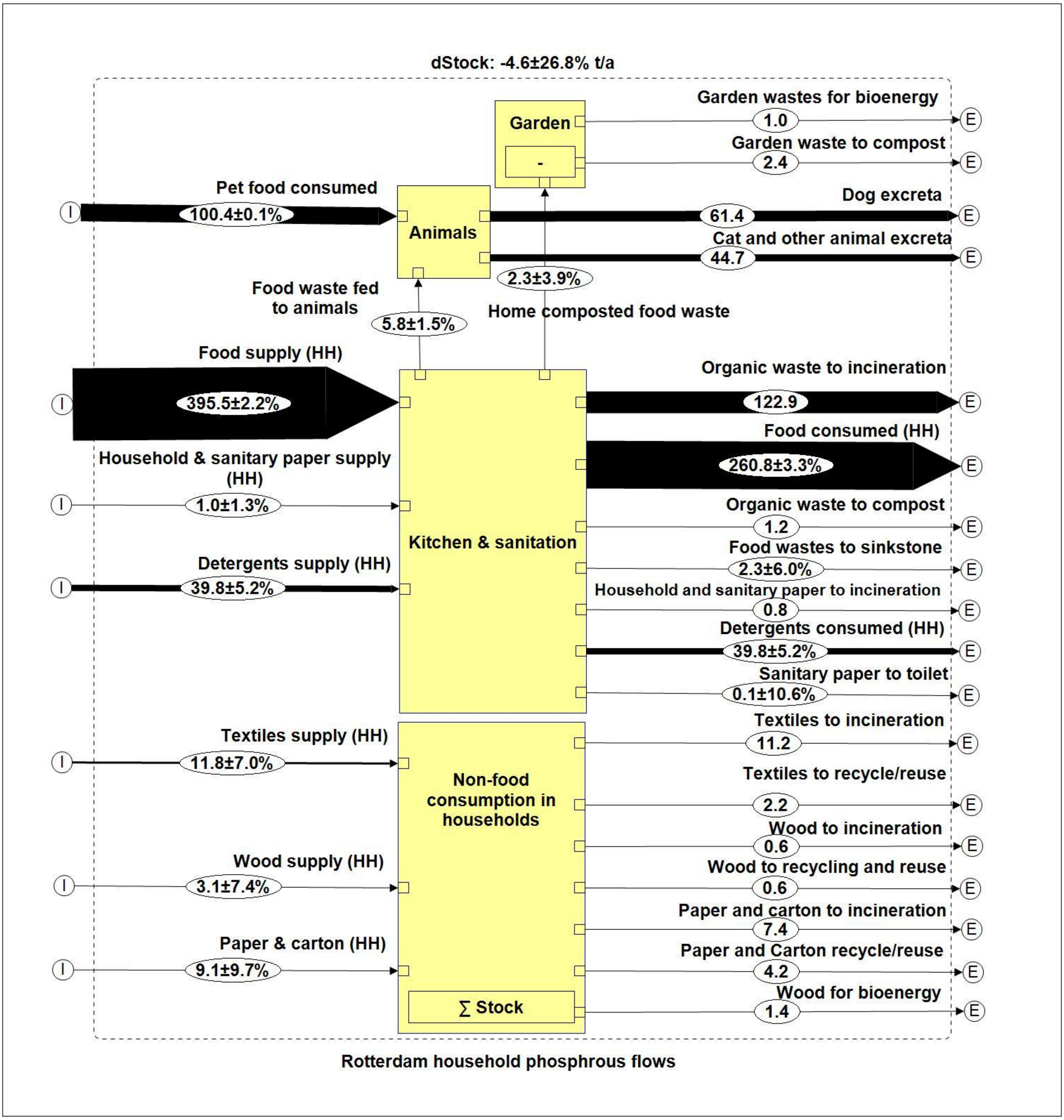

Figure 8: The phosphorus (P) flows in the sub-system "Household (HH) consumption"; depicted similar to Figure 8 (see more explanation).

Table 8: Phosphorus (P) outflow [tonnes P/year] from Rotterdam urban households.

Destination	P outflows from households	Tons	%
Incineration	Organic waste	122.9	21.1
	Textiles	11.2	1.93
	Paper and carton	7.4	1.3
	Wood	0.6	0.1
	Household and sanitary paper	0.8	0.1
	Cat and other animal excreta, including food waste to animals	44.7	7.7
	Sludge	261.4	44.9
Environment and sequestration	Effluent wastewater	58.5	10.1
	Dog excreta, including food waste fed to animals	61.4	10.6
Compost	Organic waste	1.2	0.2
	Garden waste	2.4	0.4
Bioenergy plant	Garden waste	1	0.2
	Wood	1.4	0.2
Recycling and reuse	Wood	0.6	0.1
	Textiles	2.2	0.4
	Paper & carton	4.2	0.7
	Total P quantity	**582**	**100%**

As can be seen, the only sector which contributes to the reuse of P in agriculture is the waste sector that compost bio (kitchen) – and garden waste. All the other waste flows containing P are not recovered and reused in agriculture. In addition it is important to identify though, that some of the textiles, wood, paper and carton are reused in society and these were not taken into account neither as lost P or reused P. This is so because it was assumed that within one year period, as taken as the base for this study, they are still circulating in society before the fibres have become too small and they must be incinerated.

Overall the total outflow of P from households contributes to 582 tons. Out of this total amount, 98.2% of the P is considered as the lost P, not being reused on agricultural land. The rest of the 1.2% is the non-food products which during one year period are being reused or recycled and still used in the society, and 0.6% is the amount which is eventually composted.

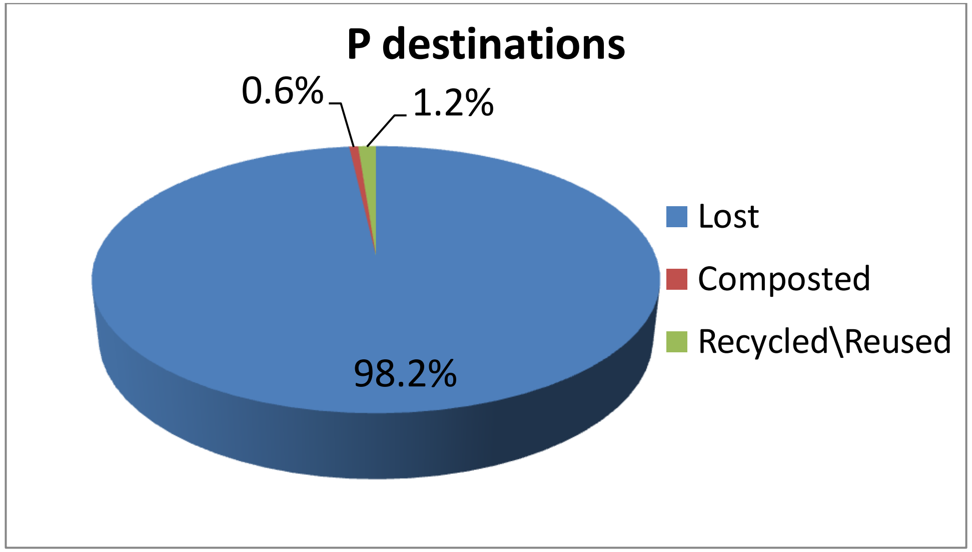

Figure 9: The final destinations of household waste stream phosphorus (P).

The amount of P which is not recycled back to agriculture contributes to 572 tons (Table 8: Everything which goes to incineration, environment and sequestration and bioenergy plant is referred to as lost P in this paper), and only 0.6%, (3.6 tons) of the total waste flows is eventually reused in agriculture (see Table 8). This is the part of the organic kitchen and garden waste which is being collected separately, as well as the assumed amount of organic waste which is composted at homes directly (called as reused P since it is reused in agriculture). By recycled P it is meant the P which consist in materials such as textiles, wood, paper and carton and which in one year period are still in use\in cycle somewhere in the society. These products can be reused or recycled 6 to 7 times until the fibres get too small and the products will most probably incinerated in the end, contributing to lost P. In this report, it is therefore not yet considered as lost P which in turn could then be potential recoverable P. Figure 10 describes the potential recoverable P (in the other words this is lost P) within one year period (not including recycled/reused non-food products). However, differently from the aim of this research, the saved P is mostly not reused on agricultural land within the city. It is instead delivered elsewhere, mostly to farmers much further outside the city limits (Expert, personal communication, 2013). As it is unclear yet where the compost exactly ends up or how it is reused, it is called in this report as ’commercial compost’.

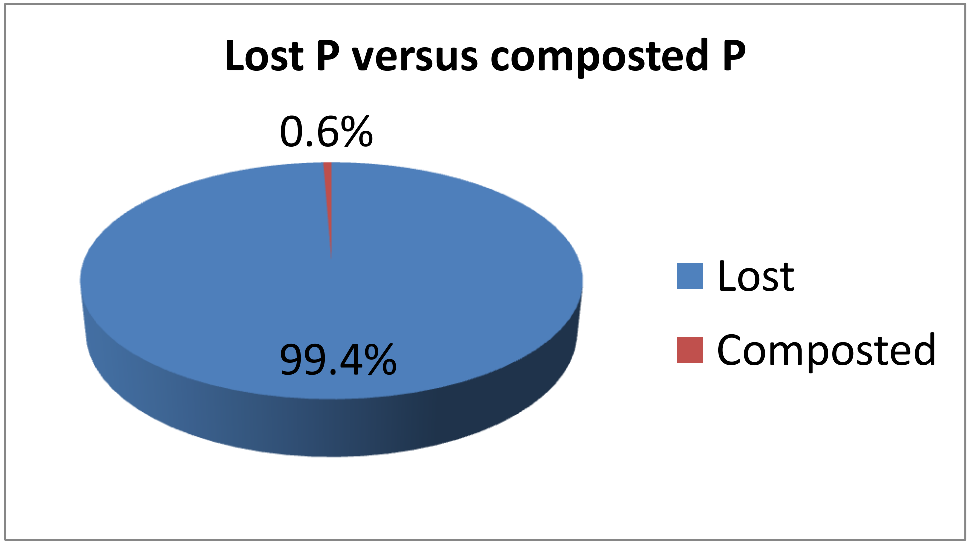

Figure 10: The distribution of reused/recycled and lost phosphorus from the flows of the household waste of Rotterdam city; the recycling of non-food products is not taken into consideration due to an assumption that in one year period these are used by society.

Most of the P from Rotterdam household (78.6%), is getting lost via incineration of the waste flows. Approximately 45.7% of lost P is originating from the incineration of the communal sludge from wastewater treatment and 11.3 % is the incineration of non-food solid waste (Figure 11). It is important to notice though that a relatively large part, 21.5% of lost P is the incineration of the organic waste. The P within the incinerated waste ends up in the residual ashes of the incineration plants (HVC in Dordrecht, AVR in Botlek Rotterdam) and is not yet recovered. Additional P losses next to the ones just described, contribute to (Figure 11):

(1) 0.4% - production of green energy (biogas) out of wood and garden waste;
(2) 10.8% - dog excreta left in parks, environment sequestered sector/ or incineration when collected; and
(3) 10.2% of lost P makes the effluent water to surface water[51]

[51] Phosphorus is going back to environment, however since it does not end up in agricultural land and it is hard to extract P from the water, it was considered as lost P.

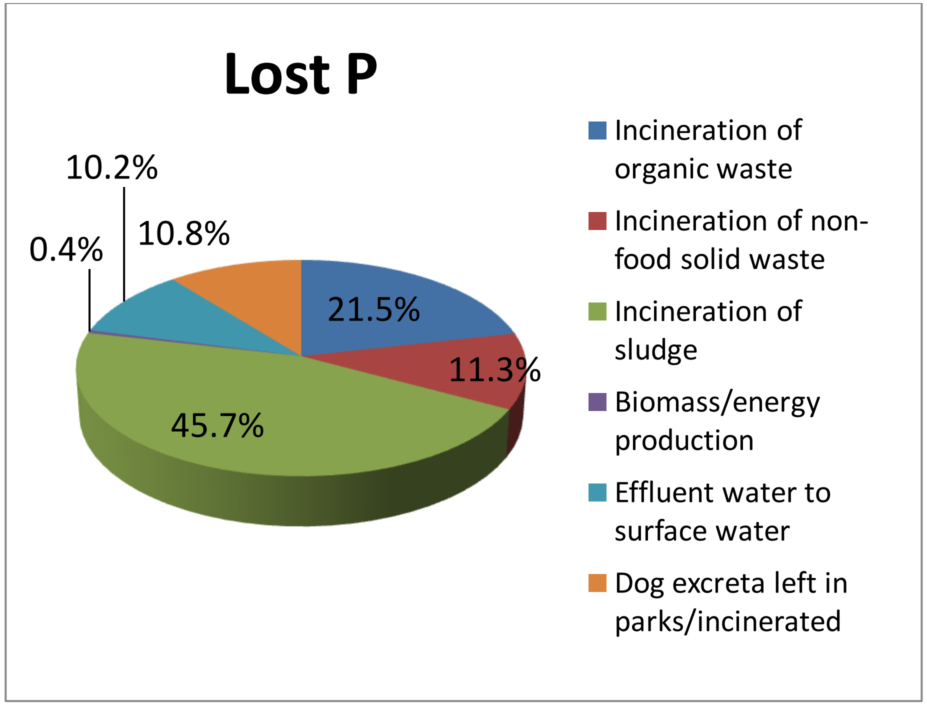

Figure 11: The different destinations of lost phosphorus (P) from Rotterdam households waste flows.

2.3 Closing the P cycle locally – linking supply with demand

The calculated amount of lost P in this paper can be a potential P source for urban agriculture if this P is recycled back to farmland. This recycling can be done by direct use of P rich flows or by recovery and reuse of P. In all cases the aim to close the nutrient cycle, without compromising public health and the quality of the environment.

According to our study in the previous chapter, almost all P inflows from households are lost. This is P from all the influent (sludge incineration and effluent), biodegradable solid waste incineration, biomass production, as well as P from the reuse of wood, paper and textiles (Table 9). During those mentioned processes, no P is recovered and brought back to agricultural land. However, it is important to address that whilst re-using materials and producing green energy out of biomass are actually supporting sustainability, P could be still recovered during those processes.

Table 9: The potential recoverable P (P) flows per type of the household waste in the city of Rotterdam; current recycling and reuse flows of non-food products (Table 8) are not shown since within one year period these materials are .still used somewhere in cycle in the society.

Potential source of P recovery	Potential recoverable P in tons
Incineration of solid waste including organic waste	187.8
Incineration of sludge	261.36
Wastewater Effluent to surface water	58.52
Biomass production for green energy	2.5
Dog excreta incinerated/environment	61.45
Total:	**572**

Application limits

According to Dutch Government regulations, the farmers are currently allowed to apply 65 kg of phosphate (P_2O_5) per ha on arable land that has an average soil P status. It was assumed that urban agricultural land and its use is more comparable to arable land than to grassland (see figure 7 below) (Dutch Government, 2009). Converted into elemental P this gives 28.6 kg P per ha on arable land. In the near future this application limit can be reduced to 24.2 kg P per ha (55 kg of P_20_5) (Dutch Government, 2009).

Table 10: Dutch Government regulations (2009) for the application of phosphorus (P) on arable- and grassland for different soil P statuses. (In Dutch- grassland –grass land; arable land - bouwland[52])

	Third AP		Fourth AP				Fifth AP	
	2006	2009	2010	2011	2012	2013	2014	2015
Grassland								
Land with high phosphate level	110	110	90	90	85	85	85	80
Phosphate neutral ground	110	100	95	95	95	95	95	90
Land with low phosphate level	110	100	100	100	100	100	100	100
Farmland								
Land with high phosphate level	95 (85)*	85	75	70	65	55	55	50
Phosphate neutral ground	95 (85)	85	80	75	70	65	65	60
Land with low phosphate level	95 (85)	85	85	85	85	85	80	75

In the city of Rotterdam, the results of lost P from households contributed to 572 tons per year. This makes in a total of 2.9 % out of all the lost national household P (based on the national survey explained previously, 19.8 million kg). This would be the total potential available supply which could be applied on the urban agricultural land.

Demand versus supply

As follows, it would be relevant to calculate the potential demand in comparison to this supply. Taking into account the maximum P application set by the Dutch Government (Table 10), 20 thousand ha of surface area of arable land (urban agricultural land) is needed in the city of Rotterdam to host the presently lost P from household waste. With new reduced requirements set for 2015 (Table 10), the amount of arable land needed would be even larger – 23.6 thousand ha.

According to the Municipality of Rotterdam, no specific data is available regarding the surface area of current UA sites in the region. That is why UA sites have only been indicated on a map via pointing them out through so-called spot-mapping, and no total surface area has been calculated (see Annex 17). On the map the UA areas', locations can be seen in relation to the city's green surface area, the latter being a total of 12.7[53] thousand ha. The total number of UA areas that can be seen on the map, amounts to 105 initiatives (calculated by GIS). Subsequently, we assumed an estimated average surface area of 0.3 ha[54] for each urban garden. However, most of the UA areas are probably even smaller, and a few larger than that[56], hence 0.3 ha was thought to be the most suitable average surface area for a farm. Therefore, after a simple calculation, the total surface area of UA in the city of Rotterdam is estimated to be approx. 31.5 ha.

Consequently, it can be concluded that the potential supply of P is high compared to the potential P demand. However, P removal of crops must also be taken into account. Therefore, to make the demand calculations more precise, additional data was derived from Ehlert *et al.*, (2009). This report presents P removal of main food crops in the Netherlands. By taking into account the P demand of all the potential crops presented in the named report, the demand calculation of P for the city of Rotterdam can be made even more specific. The crops with the highest and lowest removal per ha were selected in order to calculate the range of demand. In

[52] The numbers presented in this table are the figures for phosphate (P205)application. It was thus recalculated into elemental P, by using the principle you can better mention this conversion factor in the introeduction or abbriviation/unit list report, we took the phosphate neutral ground as the balance for calculations (in Dutch: „fosfaat neutrale grond").

[53] Based on GIS data which was given to the researcher from the Municipality of Rotterdam. The excel sheet used for calculations in Dutch was: Groenelementen_vlakken (due to the large size, it was not possible to add this data sheet into the Annexes). From this sheet, result of 12.3 thousand ha of green land within the city of Rotterdam was calculated. That green area is shown in Annex 9.

[54] The researcher did not include that as a specific question to her interviews since the scope of the research was different at the beginning. The more so, only 11 farms out of 105, as can be seen in Annex 5, were only visited and therefore an estimation would be needed anyways as no hard data is available.

[56] Some of the interviewed urban agricultural areas were quite large. For exa,ple farm „Uit je Eigen Stad" was estimated to be around 1.5 ha , whilst the „De Enk", as well as „Ghandithuin" were estimated around 1 ha at least (Expert, personal communication, 2013).

this way, the P demand of the crops which could be then potentially grown, or which are grown already in the UA areas, could be considered. Based on that:

1. the highest P removal by harvest belongs to field beans – 89.3 kg P_20_5/ ha = 39.292 kg of P/ha (Ehlert *et al.*, 2009, p.53)
2. the lowest P removal by harvest belongs to broccoli – 11.8 kg P_20_5/ ha = 5.192 kg of P/ha (Ehlert *et al.*, 2009, p.55)

The range of demand assuming total coverage of one of these crops was hereby made for the UA areas of the city of Rotterdam. As it was previously indicated, the total surface area of UA is currently assumed to be the maximum of 31.5 ha. This means that the calculated range of P demand for growing food in the city of Rotterdam is currently (assuming the total coverage of UA areas with the crops with lowest/highest P removal/demand) 0.16 – 1.24 tons P[57] (Table 11).

Another estimation can be made using the grain crops as the most common grown and consumed crop species. Based on the same report (Ehlert *et al.*, 2009, p.56), the P removal of grain crops is (40.8 kg P_2O_5/ha/year) 17.9 kg of P/ha/year. Whilst assuming the total coverage of UA land in the city of Rotterdam with these crops, the calculated max P demand would be as low as 0.56 tons.

In table 11, the P supply and demand in terms of urban farming in Rotterdam is presented.

[57] Surface area of UA multiplied with the highest and lowest P removal.

Table 11: Supply of phosphorus (P) by household waste flows compared to the demand of P based on crop P removal estimated based on the max current coverage of UA in the city of Rotterdam multiplied by the P removal of three crops field beans, broccoli and grain crops [tons P/year].

Crop type	P demand city	Total potential P supply (lost P)
Highest P removal **Field beans**	1.24	572
Lowest P removal **Broccoli**	0.16	
Most common consumed/grown crop **Grain crops**	0.56	

Now taking into account the amount of lost P which was calculated (572 tons), it clearly presents that the amount of P lost is much higher than the city could currently host on its UA land. It is therefore presently impossible to close the P loop within the city only, but the agricultural land on the outskirts must be considered.

This simple calculation shows that there is a regional surplus of nutrients in the household waste supply compared to the local demand of urban farms. However, despite of the P demand of current urban farms, it is still important for the environment to manage the waste and therefore also the P content in it more sustainably. It is likely that in the future the surface area of UA area in Rotterdam will be increased, since it is a hot topic and largely within the agenda of the Municipality of Rotterdam. By the idea of closing the P loop of urban households, it would, in a way, indirectly trigger the increase of urban farmland as well.

Interestingly, if one would estimate all the green surface area within the city of Rotterdam (as mentioned, 12.7 thousand ha) to be the urban farmland, then the calculated maximum demand of P based on the highest P removal crop (field beans) would be around 498 tons. This figure would be a considerable portion of the current P supply (572 tons) and could help to close the P loop. A situation like this is, however, a "dream scenario". It requires a huge overturn of the whole socio-economic system as there are many aspects of different sectors in the society which it eventually affects– largely the matter of money, people's perspectives and business; both in terms of increasing urban agriculture to its maximum level in the city, as well as in taking advantage of all the available P from solid waste and wastewater.

Furthermore, it is important to take into account that since urban agriculture does not necessarily need to take place on the land, but also rooftops, walls (e.g. vertical farming[58]) and waterways, an estimation of space needed is in reality made even more complex.

2.4 Suggestions for sustainable P management in Rotterdam

Under this section, future suggestions for more sustainable waste handling for the city of Rotterdam are suggested in order to promote recycling of P via urban agriculture.

As prerequisite for treatment, the first obvious suggestion that Rotterdam has to think of is the separation of organic waste from other household waste in the future. A first important step would be to compost all the organic kitchen and garden waste (for instance at the Indaver Groen Compost) and deliver the end product to local urban as well as peri-urban farmers. Measures for collecting organic waste in high rise buildings must be considered as this is found to be one of the pitfalls at the moment. One of the solution on how to start collecting food waste separately from other household waste, is to perhaps introduce compostable bags for organic waste collection (Garaffa, 2010). Separate food waste collection allows a high capture of organics, helping to optimize the nutrient recovery via composting or other further treatments.

On the other hand, since the amount of organic waste would be thereof much higher, several innovative solutions could be applied which could be helpful in handling the issue. Enough research has been done which compare different municipal waste management strategies and technologies. Under this section we have highlighted some of them which might be important for Rotterdam to consider in terms of the nutrient recovery. Though, most of the studies which were faced throughout this research, draw comparions between the challenges and benefits between incineration of organic (and other solid) waste and (home) composting.

For example, a case study carried out in southern Sweden proved that although anaerobic and aerobic biological treatment methods result to net avoidance of GHG-emissions, these give the largest contribution both to nutrient enrichment and acidification than compared to incineration. (Bern City *et al*., 2011)

On the other hand, whilst it is harder to access the nutrients through the incineration of solid waste, it has been studied that actually both incineration and home composting are good means to improve the environmental profile. From environmental point of view, incineration and home composting are suitable for diverting waste away from the composting facility in order to increase its capacity (Boldrin *et al.*, 2011).

For home composting, there is for instance a new idea developed about worm composting (at gardens for instance), according to which worms are allowed to eat organic waste, whilst humans or animals and birds (e.g., chickens) can eat the worms in turn (Zurbrügg *et al.*, 2004). This practice could be applied in UA areas, so the proteins in waste could be recycled back to agriculture via raising chicken.

[58] This idea was coined in Gilbert Ellis Bailey book 'Vertical Farming' in 1915. His idea was to farm underground with the use of explosives though, but its modern idea refers to cultivating animal or plant life on a vertically inclined surfaces or within a skyscraper greenhouses (Nelson, 2007).

However, most of the potential re-usable P is in wastewater though. Due to the lack of implementation of treatment technologies the P within the wastewater is not currently recycled back to agriculture. Nevertheless, both of the wastewater treatment plants indicated that they have plans to get P out of ash created when sludge is being burnt during its incineration, *‘’So in the future the ashes that are formed will be sent to a special plant where the P will be taken out from the ash.“* (Expert, personal conversation, 2013).

On the other hand, since the Waterboards still have not implemented their plans yet, several measures have been suggested to them in this report. Similarly to organic waste, the first suggestion is to separate organic fraction from wastewater, including: urine, faeces, grey water, animal manure and slaughterhouse waste (blood, hooves, bones, etc) (Schröder *et al.*, 2009). Table 12 illustrates some options which could be applied in order to have more sustainable wastewater management in the future applied by the Water Boards.

Table 12: Possibilities and challenge to recover P (P) from wastewater and to reuse it in agriculture.

Type of P recovery from wastewater	**Description**	**Benefits**	**Challenges**
Direct use of source separated and stabilized urine and faeces	Urine and faeces are the largest P source coming from urban areas. Approx. 60-70% of the P in human excreta is found in urine, which besides that also contains other essential plant nutrients and is essentially sterile and can be directly used in agriculture (Schröder *et al.*, 2009).		For large-scale systems, urine storage and transport can add high costs (Schröder *et al.*, 2009).
Direct use of wastewater (black water- urine and faecal matter containing wastewater)		A study was made in the city of Lund in Sweden, where the contents of nutrients and heavy metals were analysed in black water from holding tanks in the allotment gardens and compared to those in the sludge in the sewage treatment plant. The results showed that the quality of the black water was found to be sufficiently high to allow it to be used as fertiliser on agricultural land (Svensson *et al*.,2001).	The contents of nutrients and heavy metals must be regulated. It requires buildings to be rebuilt or built in a way that greywater (sinks, washing machines, bathtubs, showers) is separated from blackwater. In new buildings this is possible but if re-built, it is expensive to change/rebuilt the sewage system (Svensson *et al*.,2001).
Direct use of sewage sludge	As described before, most WWT processes produce P containing sludge which needs to be disposed of. This can be used for reusing P.	Application of treated\raw sewage sludge can reduce its disposal costs at the same time providing large parts of the P and nitrogen requirements of many crops (Natural Resources Management and Environment Department, derived from: www.fao.org/docrep/t0551e/t0551e08.htm, last accessed in 2013).	Sludge cannot be applied directly unless certain European Directive requirements\parameter are followed, including sludge and soil testing. This is so because sewage sludge contains also pathogenic bacteria, protozoa and viruses which can be hazardous for human, animal and plant health (Natural Resources Management and Environment Department, derived from: www.fao.org/docrep/t0551e/t0551e08.htm).
Recovery of P from wastewater as struvite (phosphate mineral)	During the wastewater treatment phosphate, magnesium and nitrate containing struvite (phosphate mineral) could be formed. This in turn could be exploited to produce fertilizers (Schröder *et al.*, 2009). This technology is called the Ostara nutrient recovery technology and was initially developed by the University of British Columbia in Canada. It involved a fluidized bed reactor that recovers P and ammonium from wastewater treatment plants. Wastewater centrate influent from sludge dewatering side streams enters the reactor from the bottom, moving up through increasingly larger reactive zones. At the same time, magnesium is chemically dosed to facilitate the crystallization process. The struvite is then harvested from the reactor (Schröder *et al.*, 2009).	Particularly important in areas of high livestock concentrations, where land available for manure spreading is not sufficient without risk of environmental pollution (such as Denmark, The Netherlands, Flanders, parts of France, Spain and Italy) (Schröder *et al.*, 2009).	Adding Fe and Al salts can stimulate the separation process but makes the P in the solid fraction less available to plants. This could make the product commercially less attractive for agricultural use (Schröder *et al.*, 2009).

3. Conclusion

This study was undertaken while being an intern at the Municipality of Rotterdam from April to December 2013. The research focus was framed in the project of International Architecture Biennale 2014, which investigates urban metabolism in Rotterdam.

The study was made in two parts. It was limited only by the physical limits of the city of Rotterdam. The first section of the paper focuses on urban farming in Rotterdam. Eleven interviews with as many UA sites were conducted in order to understand what is happening at those sites, who are the people involved, how UA areas can be classified, how do they manage financially, to what extent they recycle their organic waste that is produced at the sites, and what is their main aim of functioning.

However, as the general aim of this study was to explore the possibility to close the P cycle within the city of Rotterdam, the second part of the study took a slightly different approach. Household waste flows were studied in order to analyse how much P is lost in that sector instead of reusing it in agriculture. The achieved results were linked with the crop demand of P by current urban farmland in Rotterdam. The base year for the study was 2011 and P flows were calculated by using material flow analysis method (MFA) using the STAN program. All the waste flows' outflows were linked with matching inflows following the MFA principle of "inflow equals outflow". In all cases, no specific inflow data only for households was available and therefore the total domestic supply of each product that was taken into consideration was used (household and sanitary paper, food, textiles, wood, paper and carton, pet food, and detergents). This was based on assumptions, and divided by the household and non-household sector (businesses and organisations).

In the Netherlands, the household sector generally contributes to most waste, which is mostly incinerated with no P recovery from it. In Rotterdam, the total outflow of P from households was quantified at 572 tons P per year. The lost P of this total outflows contributes to 97.8% (572 tons). Only 1% (5.9 tons) is the so-called saved, or reused, P, being composted in home gardens or at the Indaver Groen Compost plant. In the latter case, however, the compost is sold as fertiliser to farmers city in the Netherlands and even abroad. Moreover, it was not within the scope of this study to investigate where the eventually produced compost ends up and if it is being reused on agricultural land and, furthermore, how much of it is reused in the Netherlands. What is more, the rest of the 1.2 % of P (6.9 tons) out of total waste outflows consists of non-food products that are recycled and reused and assumed that within a one-year period are still used by the society. This means that it was not yet taken into consideration as lost P, since normally these products can be reused or recycled 6 to 7 times until the fibres get too small and the products will most probably incinerated in the end.

Furthermore, it was specified that most of the lost P in 2011 was due to the incineration of wastewater sludge (45.7%; 261.4 tons) and the incineration of organic waste (21.5%; 122.9 tons). These are the main waste flows that should hence be studied in depth in order to make their management more sustainable and to recycle the P. The rest of the lost P originated in biomass and energy production (0.4%; 2.5 tons); incineration of non-food products (11.3%; 64.8 tons), effluent wastewater discharge to surface water (10.2%; 58.5 tons) and dog excreta left either in environment or collected and incinerated (10.8%).

After having calculated the lost P, the possibility to close the P cycle locally within the city was analyses. This was done by using the Dutch Government regulations for the application of P on arable land. Taking the maximum application rates for average soil P levels, it can be calculated that 20 million ha of farmland would be needed to host the lost P. With the new government regulations planned for 2015, the application limits are even lower and therefore much more land would be required – 24 million ha of arable land.

Since no reliable data was available for the total surface area of the current UA in Rotterdam, it was estimated that each of the 105 initiatives have an average surface area of 0.3 ha, meaning that the total estimated coverage would only be 31.5 ha.

This is clearly enough to say that the regional surplus of P is too high for closing the P cycle only within the city. Nevertheless, extra calculations were made to double check the results. The highest (field beans) and lowest (broccoli) P crop removal per hectare (31.5 ha) was estimated as the range of the P demand, leading to a demand result of 0.16 - 1.24 tons. However, this is in no way comparable to the 572 tons of lost P. It was therefore estimated that hosting that amount of lost P would only be possible if all the green surface area (12.7 million ha) would be used for UA. The possibility that this would happen is nevertheless a "dream scenario" as it requires a considerable transition of the whole socio-economic system.

As the main flows which contribute to lost P originates from the incineration of communal sludge as well as organic waste. Measures were suggested how the manage those flows also from the perspective of nutrient (e.g. P) recycling. As organic waste in Rotterdam is mostly collected together with other municipal solid waste, innovative ideas would be needed on how to start collecting it separately. This would be already a considerable step to more sustainable P management as there is relatively easy access to this potential recoverable P. If this would be made possible, organizations such as Indaver GroenCompost, should take the lead in a new project to stand for a higher amount of compostable garden – and organic food waste.

Another important waste flow is wastewater sludge which is incinerated. Both of the Waterboards relevant for this research (Hollandse Delta; Schieland and Krimpenerwaard) indicated that their plan for the future is to extract P out of incineration ash. This, however, might not be the only solution and therefore other relevant measures were suggested in this paper. E.g., the Waterboards could also think over possibilities such as direct use of source separated and stabilized urine and faeces; direct use of wastewater; direct use of sewage sludge; recovery of P from wastewater as struvite (phosphate mineral). A comparative table was provided in this report about the challenges and benefits of each of the suggested methods. However, more time is needed for evaluating the best opportunities and possibilities while taking into consideration various aspects, including economic and social restrictions and impact.

4. Research recommendations

Based on the calculations that were made for lost P, and the introduction of urban farming through interviews, there are several recommendations for steps which could be taken in order to continue this research.

First of all, this study focussed mainly on waste flows from households. The waste flows of non-household sectors were only simply taken into account. The city of Rotterdam is a large city with a lot of business, restaurants, shops and other public places. Nutrient flows are also present in all of these infrastructure and sectors. Future research is necessary to get a good overview of these flows. Additionally there are many more flows in the whole region that are linked to the seaport of Rotterdam. This seaport is part of a worldwide web of flows of goods that contain nutrients (e.g. crops, food and fertilisers) which are trade across the globe. On the one hand these flows creates surpluses (e.g. animal feed imports such as soybean). On the other hand, it brings opportunities to recover the nutrients and reuse them in agriculture in Europe or elsewhere.

Secondly, the soils in Rotterdam urban farms must be scientifically evaluated to find the current P content in it, since thereby the actual demand would become known. It would be important for research to know the exact surface area of urban gardens in Rotterdam. In other words, a better registered database would be needed to keep track of all the UA initiatives, including their exact surface area. This database could be extended to include also information on the type of crops grown, and the total amount of food produced.

The P flows in general are calculated based on many assumptions and therefore regular updating would be justified. Human population and consumption behaviour patterns are likely to change continuously, which furthermore calls for frequent updating of data and sources.

Thirdly, there is more in depth research required to get from this quantification study to practical steps necessary to make the transition towards sustainable use of nutrients. Action plans per relevant flow are necessary. In this development process there will be a need for qualitative studies about how to recover and reuse P most optimal for agriculture purposes. Theoretically most waste flows can be managed in a centralized and decentralized way. For both options there are benefits and barriers that have to be identified, compared and integrated in future plans in the city of Rotterdam.

5. Research pitfalls

Since research on P flows on the city level is relatively new, materials on P content concerning inflow and outflow data were difficult to find. The research is therefore based on many assumptions, which in most cases are scientifically grounded. However, the distribution between household and non-household food and material supply was based on the assumptions which were explained through common logic and supported as much as possible on available data. In addition, an uncertainty (in %) was for each of the inflow type was assumed due to the assumptions made. The plus side of those assumptions and uncertainties is that the focus in this research is on the household waste flows which fortunately had more precise data sources to rely on and were therefore not supported with any uncertainties. This means that the amount of lost or saved P, regardless of the inflow figures, remains the same. So even if the distribution would be different, the result of lost household P could not be much different.

In general, in this study it was relatively difficult to access various data in terms of the mass flow and P content in different in-and outflows of food and materials to and from households. In terms of the Waterboards for example, each contact person had to make an assumption regarding the amount of wastewater only collected within the city as well as the wastewater collected from households only. Hence the Waterboards were trusted based on their original data and verbal information.

Difficulty was also faced in terms of accessing the data about the number of dogs owned by the inhabitants of Rotterdam. The Rotterdam Municipality Tax Department was approached to get the number of dogs from dog tax data, but despite the efforts made no answer was received at the time of conducting this research.

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Annex 1 Interview questions to 'urban farmers'

Background study:

1. Who are the farmers: profession, gender, age?
2. How was the farm set up? Was there any funding?
3. What is the land use of the site: how much of the land is used for actual vegetable production and how much for other purposes (recreation, park, etc)?
4. Main purpose of the farm?
5. Number of people involved?
6. To what extent is the farm connected with other farms or is willing to do so? (food network)
7. Which months to you use the garden?

Food security and nutrition:

1. Type of vegetables grown?
2. Amount of food produced?
3. For who is the food grown for, how far it travels from site (food mile, food flow) (markets, self-consumption)?
4. Which kind of crops you grow to come through winter?

Economic benefits and constraints:

1. What are the economic benefits in terms of income and employment? How many people are employed, how much money made? (cash flow)
2. Funding or other help?
3. Financial handicaps faced by farmers (credit, access to input: seeds, fertiliser, equipment)

Environmental benefits and constraints and ecosystem services

1. What happens to organic waste? Compost production on site? Do you use organic waste from outsider the farm?
2. Type of water used for crop irrigation?
3. Soil health?
4. (Sustainable) energy usage on site?
5. Species?
6. Other benefits mentioned, what is important for farmers, people involved? (cultural services, tourism, health, spiritual experience, art inspiration)

Other challenges faced by farmers?

1. Institutional (institutional support, integrator of UA into city and land use plans, coordination between public agencies)
2. Lack of land....other

Annex 2 Phosphorus in food consumed by Rotterdam population

Calculated data of the Municipality of Rotterdam, based on 2011											
Man											
Age group	Age 0-1	Age 2-3	Age 4-6	Age 7 - 8	Age 9-13	Age 14-18	Age 19-30	Age 31-50	Age 51-69	Age 70-99	TOTAL
Total number of people	7938	7172	10061	6623	1657, 7	16, 894	59, 234	90, 151	60, 61 8	25, 079	300, 347
P intake in mg/day	927	927	1041	113, 5	1392	1591	1, 735	1, 803	1, 719	1, 511	13, 781
P intake in mg/year	33, 8355	33, 8355	37, 9965	414, 275	508, 080	580, 715	633, 275	658, 095	627, 435	551, 515	5, 030, 065
Source	DNFCS-Young Children 2005/2006			Dutch National Food Consumption Survey 2007-2010							
P intake mg/year	268, 586, 199	242, 668, 206	3, 822, 827, 865	2743, 743, 325	842, 244, 216	9, 810, 599, 210	3, 751, 141, 135	59, 327, 922, 345	3, 803, 854, 830	13, 831, 444, 685	1.78617E+11
P intake ton/year											178.6

Woman											
Age group	Age 0-1	Age 2-3	Age 4-6	Age 7 - 8	Age 9-13	Age 14-18	Age 19-30	Age 31-50	Age 51-69	Age 70-99	TOTAL
Total number of people	7599	6862	9523	6374	157, 11	16, 894	59, 234	87, 173	60, 618	38, 207	308, 195
P intake in mg/day	893	893	928	1136	1198	1, 259	1, 325	1, 381	1, 364	1, 511	11, 888
Source	DNFCS-Young Children 2005/2006			Dutch National Food Consumption Survey 2007-2010							
P intake mg/year	325, 945	325, 945	3387, 20	414, 640	437, 270	459, 535	483, 625	504, 065	497, 860	551, 515	4, 339, 120
P intake mg/year	247, 686, 055	2236, 634, 590	3225, 6 05, 6	264, 291, 536	686, 994, 897	7, 763, 384, 290	2, 864, 704, 325	43, 940, 858, 245	3, 017, 927, 748	21, 071, 733, 605	1.49054E+11
P intake in ton/year											149.1
										Total man+female	327.7
										Total male + female at home consumption	234.3
										Total man +female not at home consumption	93.4

Annex 3: Household & non-household human food P intake

Age group	Total number of man and females in each group		% of P consumption at home	% of P consumption not at home	
Source	Dutch National Food Consumption Survey Young Children 2005/2006				
Age 0-3	Man	15, 110	78.00%	19.00%	
			11, 789	2, 871	
	Woman	14, 461	78.00%	19.00%	
			11, 280	2, 748	
Age 4-6	Man	10, 061	78.00%	19.00%	
			7, 848	1, 912	
	Woman	9, 523	78.00%	19.00%	
			7, 428	1, 809	
Source	Durch National Food Consumption Survey 2007-2010: Diet of children and adults				
Age 7 - 8	Man	6, 623	74.20%	25.80%	
			4, 914	1, 709	
	Woman	6, 374	72.20%	25.80%	
			4, 602	1, 644	
Age 9-13	Man	16, 577	75.50%	24.50%	
			12, 516	4, 061	
	Woman	15, 711	74.00%	26.00%	
			11, 626	4, 085	
Age 14-18	Man	16, 894	74.60%	25.40%	
			12, 603	4, 291	
	Woman	16, 894	70.40%	29.60%	
			11, 893	5, 001	
Age 19-30	Man	59, 234	62.00%	38.00%	
			36, 725	22, 509	
	Woman	59, 234	68.60%	31.40%	
			40, 635	18, 599	
Age 31-50	Man	90, 151	67.10%	32.90%	
			60, 491	29, 660	
	Woman	87, 173	74.80%	25.20%	
			64, 508	21, 968	
Age 51-69	Man	60, 618	79.60%	20.40%	
			48, 252	12, 366	
	Woman	60, 618	81.00%	19.00%	
			49, 101	11, 517	
Source	Ocke, M. C., E. J. M. Buurma-Rethanset al. (2013). Diet of community-dwelling older adults : Dutch National Food Consumption Survey Older adults 2010-2012. Bilthoven, The Netherlands, National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieuhygiëne, RIVM).				
Age 70-99	Man	25, 079	92%	8%	
			23, 073	20, 063	
	Woman	38, 207	92%	8%	
Total			35, 150	30,566	
			At home	**Not at home**	**Total**
		Total Man+Female	**442, 311**	**176, 370**	**650543**
		Calculated %	**71**	**29**	**100%**

Annex 4 Phosphorus inflow via detergents

Phosphorus (P) inflow via detergents. Based on calculation method provided by Willem Schipper.	
20	g FM/tab
34 %	% P in NTPP
1.72	g P/tab
7	10^6x households
55%	coverage percentage automatic dishwashers
365	runs per year
2.4	Kton/year (this is the max, since assuming 100% of the tabs contains total amount of P, which is not the case)
40%	percentage of P containing tabs on total tabs consumed
0.97	Kton/year P from tabs used in household automatic dishwashers
7, 443, 801	Exact number of households in Netherlands
314, 324	Total amount of households in Rotterdam
0.04	Percentage of Rotterdam households from total NL
0.04	Kton/year from tabs in Rotterdam dishwasher
39.7	ton/year from tabs used in Rotterdam dishwasher

Annex 5 Phosphorus contents in different materials

Phosphorus (P) content in different materials			
Organic waste		van Dijk, W. and W. van Geel (2010). Adviesbasis voor de bemesting van akkerbouw- en vollegrondsgroentengewassen. Wageningen, The Netherlands, Wageningen UR - Praktijkonderzoek Plant & omgeving.	0.16%
Garden waste		van Dijk, W. and W. van Geel (2010). Adviesbasis voor de bemesting van akkerbouw- en vollegrondsgroentengewassen. Wageningen, The Netherlands, Wageningen UR - Praktijkonderzoek Plant & omgeving.	0.10%
Wood		Range 0.0055–0.01, based on finnish situation, Antikainen, R., R. Haapanenet al. (2004). "Flows of nitrogen and P in Finland--the forest industry and use of wood fuels." Journal of Cleaner Production 12(8-10): 919-934.	0.01%
Old paper & carton		based on finnish situation, Antikainen, R., R. Haapanenet al. (2004). "Flows of nitrogen and P in Finland--the forest industry and use of wood fuels." Journal of Cleaner Production 12(8-10): 919-934.	0.02%
Textiles	**Cotton**	Table 1 in Rochester, I. J. (2007). "Nutrient uptake and export from an Australian cotton field." 77(3): 213-223.	0.3%
	Wool	A. W. and P. A. Kemme (2002). Oriëntatie omtrent de gehalten aan stikstof, fosfor en kalium in landbouwhuisdieren. Lelystad, Wageningen UR Livestock Research\ based on dirty wool so overestimated	0.03%
	Linen	made of flax, assuming flax straw nutrient content, source: http://www.feedipedia.org/node/12103	0.05%
Calculated average P content in textiles (taking the average composition of textiles in the Netherlands into account)			0.13%

Annex 6 Different phosphorus inflows to Rotterdam households

Different P inflows to Rotterdam urban households / ton						
Total Netherlands		**Calculation into P (method/formula)**	**Source**	**Total Rotterdam city**	**Source**	**Calculation method**
Total population in 2011	16, 655, 799		CBS, 2012, derived from: http://statline.cbs.nl/StatWeb/publication/?DM=SLEN&PA=37325eng&D1=0-2&D2=0&D3=0&D4=0&D5=0-1,3-4,139,145,210,225&D6=14&LA=EN&HDR=G3,T&STB=G5,G1,G2,G4&VW=T	610, 412	Hard data from the Municipality of Rotterdam/2011	3.7
Food domestically supplied	17.5	17.5Mkg=17, 500 tons	Smitet al., (2010). A quantification of P flows in the Netherlands through agricultural production, industrial processing and households	641.4	3.70 % taken from total Dutch food supply	17500*0.037
Household and sanitary paper	30.8	Consumption P in tons= (121, 000+384, 00-259, 33)*0.024 % of P compound in paper	Consumption= Production + Import Quantity- Export Quantity/ Household+Sanitary paper 2011 data: faostat3.fao.org/faostat-gateway/go/to/search/sanitary paper/E	1.13	Total sanitary paper entering the households of Rotterdam = 3.70 % taken from total Dutch consumption	30.8*0.037
Total Textiles	404	310,6 kton = 310, 600 ton/ P compound in it = 310, 600*0.13 %	Ten behove van prioritaire stromen ketengericht afvalbeleid, Milieuanalyses textiel, Rapport, Delft, maart 2010, textile data based on CBS 2007	14.8	3.7 % taken from total Dutch consumption	404*0.037
Paper and carton	496	(total wood consumption = 12,2 Mm ^{3}= 430, 838, 93 tons); 48 % of that is paper = 2, 068, 026, 864; P compound in totally consumed paper = 206, 8026, 864*0.024 %	Kerngegevens Bos en Hout in Nederland, December 2012, Probos Stichting, page 10, 48 % of all wood consumption	18.2	3.7 % taken from total Dutch consumption	496*0.037
Wood products	168	(total wood consumption = 12.2 Mm^3= 43, 083, 893 tons); 52 % of that is other than paper (such as platen 16 %, gezaaghd houten 32 % and overig 4 %) = 2, 240, 362, 436; P compound in all consumed wood = 2, 240, 362, 436*0.0075 %	Kerngegevens Bos en Hout in Nederland, December 2012, Probos Stichting, page 10, 52 % of all wood consumption	6.2	3.70% taken from total Dutch consumption	168*0.037

Annex 7 Human excreta phosphorus inflow to wastewater

Based on: Roeleveld (2006)				
	Grams day/person	Days/year	Rotterdam population	Human excreta in Rotterdam
Urine	0.8	365	610, 412	178.2
Faeces	0.5	365	610, 412	111.4
Total human excreta in Rotterdam				**289.6**

Annex 8 Organic retail waste

Based on: Gustavssonet *al*., (2013). The methodology of the FAO study: 'Global Food Losses prevention' – FAO, 2011, SIK- The Swedish Institute for Food and Biotechnology, page 34

Food waste destination	Agricultural production	Post harvest handling & storage	Processing & packaging	Distribution	Consumption	Total
1000000 tonnes	74	22	26	14	69	205
%	36	11	13	7	34	100
			Total amount of retail food waste (= 680.8 (domestic food supply in Rotterdam)* 6.8%)	**43.8**		

Annex 9 Wastewater phosphorus outflow from Rotterdam households - Waterboard Schieland en Krimpenerwaard 2011

Hard data received from Schieland en de Krimpenerwaard, year 2011					
Zuivering	**Aandeel van Rotterdam**	**Aandeel huishoudens vs. Industrie**	**P-vracht in influent in kg/dag**	**% rendement P (removal from ww into sludge)**	**Debiet in m3/jaar**
Kralingseveer	80.45 %	80.42 %	434	78 %	31, 456, 744
Groenedijk	31.25 %	87.33 %	64	85 %	4, 682, 879
Kortenoord	13.5%	79.22 %	153	94 %	7, 762, 860

Calculations for phosphorus (P) flow in ton									
Purification plant	**Total influent wastewater in Rotterdam city/year**	**Total removal from wastewater to sludge in the city of Rotterdam**	**Total effluent in Rotterdam city**	**Household influent**	**Household removal to sludge**	**Household effluent**	**Non-househol influent**	**Non-household removal to sludge**	**Non-household effluent**
Kralingseveer	127	99		102.5	79.9		25	19	
Groenedijk	7	6	30	6.4	5.4		1	1	
Kortenoord	7.5	7.1		5.9	5.6	23.9	2	1.5	
Total Tons	142.2	113		114.8	90.9		27.4	21.7	5.7

Annex 10 Wastewater phosphorus outflow from Rotterdam households - Waterboard Hollandse Delta 2011

Hard data recived from Hollandse Delta, year 2011					
Zuivering	**Aandeel van Rotterdam**	**Aandeel huishoudens vs. Industrie**	**P-vracht in influent in kg/dag**	**% rendement P (removal from ww into sludge)**	**Debiet in m3/dag (exlusief rgenwater)**
Dokhaven	100 %	71.1 %	515	80%	55, 000
Rozenburg	100 %	93.4 %	22	67%	1, 530
Hoogvliet	71.6 %	80.5 %	99	92%	9, 850
Ridderkerk	10 %	82.3 %	116	91%	7, 700

Calculations for phosphorus (P) flow in ton P per year									
Zuivering	**Total influent Rotterdam**	**Total removal to sludge in Rotterdam**	**Total effluent Rotterdam**	**Household influent**	**Household Removal to sludge**	**Household effluent**	**Non-Household influent**	**Non-household removal to sludge**	**Non-household effluent**
Dokhaven	187.9	150		133.7	106.9		54	43.5	
Rozenburg	8	5.4		7.5	5		0.53	0.4	
Hoogvliet	36	33.2		29.1	26.8		7	6.5	
Ridderkerk	42	38.5		34.8	31.7		7.5	6.8	
Total	274	228	46.9	205.1	170	34.7	69.4	57	12.3

Annex 11 Solid waste phosphorus outflow from Rotterdam households

Mass flows of different waste types, amounts in tons per year based on year 2012								
Type of waste		**Percentage in total household waste (huishoudelijk restafval)\Based on**		**Total**	**SW incineration (% in total household waste)**	**Reuse**	**Compost**	**Fuel production for green energy**
Mixed household waste				**2, 057, 473**				
Organic waste (GFT afval)		**36.70 %**		**762, 567**	**755, 093**		**7, 474**	
Garden waste (grof tuinafval)				**34, 742**			**243, 194**	**10, 423**
Wood products	**Wood A & B (Houtafval A & B)**	**3.70 %**	**89, 742**	**96, 376**	**76, 127**	**77, 101**		**19, 275**
	Wood C (Houtafval C)		**6, 091**					
	Household furniture (Bruikbaar huisraad)/ assuming that out of all 108,6 tons, 50% is wood		**543**					
Old paper & Carton (oud paper en karton)		**15.3%**		**17, 415**	**308, 621**	**17, 415**		
Textiles (kleding en schoeisel)/ assuming that all is textile and distribution between cotton, wool and linen is equal		**3.4% textiles+0.8% shoes = 4.2 %**		**1, 676**	**86, 414**	**1, 676**		
		Contribution of cotton, wool and linen/ 100 % /3		**5, 587**	**28, 805**			
Sanitary paper/ assuming that sanitary paper includes both toilet and kitchen paper		**1.70 %**			**34, 977**			

Conversion to phosphorus (P) in ton, Annex 5 used for P content					
Type of waste	SW incineration (% part of total household waste)	Bioenergy plant (digestion or incineration)	Reuse	Compost	Total
GFT	122.9			1.22	124.15
Garden waste		1		2.4	3.4
Wood products	0.6	1	0.6		2.6
Household and Sanitary paper	0.8				
Cat sand	0.3				
Paper & Carton	7.4		4.2		11.6
Total textiles/ assuming equal distribution between cotton, wool and linen (100%/ 3)	11.2		2.2		13.4
Total in Tons	Lost P		Reused P in society	Reused P in agriculture	
	143.2	2.5	6.9	3.6	155.1
	145.7				

Annex 12

Table 1: Pet feed & phosphorus consumption in Rotterdam

The marked boxes refer to the animals which were selected as having the highest probability of being kept as pets in Rotterdam households

	Netherlands	**Rotterdam**				
	Pet number	Pet number (Calculated as: fraction of Rotterdam households from NL total = 0.04122)	Total pet food consumption [kg/year] (Calculated as:Number of pets in Rotterdam*Feed consumption per pet, see Annex 12, Table 3)	P content in pet food [%]	Total pet food P consumption [tonnes P/year]	Final destination via pet excreta
Cats	2, 900, 000	120, 918[59]	3, 688	0.9	35.2	MSW (solid waste)
Dogs	1, 500, 000	41, 669	8, 964	0.7	60.5	MSW/environment and sequestration
Rabbits	940, 000	38, 748	868	0.4	3.34	MSW
Other rodents	860, 000	35, 450	93	0.4	0.36	MSW
Singing and ornamental birds	2, 000, 000	82, 442	491	0.17	0.84	MSW
Carrier pigeons	5, 000, 000	206, 104	1, 227	0.17	2.1	Environment and sequestration
Reptiles	250, 000	10, 305	27	0.3	0.1	MSW
Aquarium fishes	6, 600, 000	272, 058	119	1.4	1.6	WWTP
Pond fishes	9, 600, 000	395, 720	2, 069	1.6	32.3	Environment and sequestration
Total	29, 650, 000				136.4	
					100.4	Selected total P consumption by pets

Table 2: Average pet weight & weight factor

Average pet weight and weight factor				
Type of animal	**Total weight per pet type [ton]**	**Weight factor**	**Living weight per animal [kg fresh matter (FM)/animal]**	**Reference for weight**
Cats	10, 150	7	3.5	Several sources, but not offical: http://gemiddeldgezien.nl/meer-gemiddelden/203-gemiddelde-gewicht-kat and http://www.weetjesoverkatten.nl/eten_en_eetgewoontes.htm
Dogs	37, 035	1	24	Calculated by taking the estimated population of registered breed dogs based on the cummulative population build up using the breed dog registrations of the Dutch Breed Dog Society (Raad van beheer, So see table below
Rabbits	24, 158	9	2.6	Jongbloed, A. W. and P. A. Kemme (2005). De uitscheiding van stikstof en fosfor door varkens, kippen, kalkoenen, pelsdieren, eenden, konijnen en parelhoeders in 2002 en 2006. Wageningen, Animal Sciences Group.
Other rodents	258	82	0.3	Rats ("Tamme ratten") were taken as average of hamsters, guinea pigs, gerbils, mice and rats (according to http://dutchcommunity.com/2012/10/03/top-10-favourite-pets-in-the-netherlands/), according to the website of the Nederlandse Knaagdierfokkers Vereniging (http://www.kleineknaagdieren.nl/ratten/voortplanting/index.php) > "Volwassen mannen wegen tussen de 300 en 800 gram, de vrouwen tussen 250 en 400 gram.". 300 grams was taken as the average between male and female, at the low side.
Singing and ornamental birds	1, 367	36	0.7	Similar to Postduiven
Carrier pigeons	3, 417	36	0.7	Third of the weight of a chicken which is 2.05 according to Jongbloed, A. W. and P. A. Kemme (2005). De uitscheiding van stikstof en fosfor door varkens, kippen, kalkoenen, pelsdieren, eenden, konijnen en parelhoeders in 2002 en 2006. Wageningen, Animal Sciences Group.
Reptiles	75	82	0.3	Similar to Knaagdieren, assumed to be the average of spiders, snakes, turtles, etc
Aquarium fishes	330	494	0.1	Assumption: the size of humble goldfish or guppies. Accoring to http://dutchcommunity.com/2012/10/03/top-10-favourite-pets-in-the-netherlands : "These range from humble goldfish and guppies, to a selection of more exotic, tropical fish". Weight of guppie: http://www.wnf.nl/nl/bibliotheek/?act=dierenbieb.details&dierid=142, weight of natural goldfish, up to 3 kg: http://www.wnf.nl/nl/bibliotheek/?act=dierenbieb.details&dierid=77.
Pond fishes	5, 760	41	0.6	Assumption: the size of a koi carp. Accoring to http://dutchcommunity.com/2012/10/03/top-10-favourite-pets-in-the-netherlands : "Favourite pond fish include goldfish, koi carp and sturgeon". Favourite pond fish include goldfish, koi carp and sturgeon. According to http://kietakoi.nl/het-voeren-van-koi the average weight of a koi karper at average length of 35 cm is 600 grams
Total weight	60, 807			

Table 3: Pet feed & phosphorus consumption per pet

Pet feed fresh matter (FM) and phosphorus (P) consumption per pet based on weight redistribution

Dutch name	**English name**	**Feed consumption fraction based on fraction of weight on total weight of total pet population (Calculated as : total feed per pet type, see Annex 12/ C total weight, see Annex 12, Table 2)**	**Feed consumption total [ton/year] (Calculated as Feed consumption fraction* Total domestic supply, see table below)**	**Feed consumption per pet [ton/year]**	**Feed consumption per pet [kg/pet/year]**	**Feed P consumption per pet [kg/pet/year]**
Katten	Cats	0.2	88, 439	0.03	30.5	0.3
Honden	Dogs	0.6	322, 692	0.22	215.1	1.5
Konijnen	Rabbits	0.04	21, 049	0.022	22.4	0.1
Knaagdieren	Other rodents	0.004	2, 248	0.003	2.6	0.01
Zang- en siervogels	Singing and ornamental birds	0.02	11, 908	0.01	5.9	0.01
Postduiven	Carrier pigeons	0.06	29, 770	0.01	5.9	0.0102
Reptielen	Reptiles	0.001	653	0.003	2.6	0.01
Aquariumvissen	Aquarium fishes	0.005	2, 875	0.0004	0.4	0.006
Vijvervissen	Pond fishes	0.1	50, 188	0.005	5.2	0.08
Total		1	529, 823			

Annex 13 Food waste to different destinations

Rotterdam final total food P losses for all destinations [ton P/year]							
Unavoidable	**Collect MSW**	**Collected biowaste**	**Sewerage**	**Pets**	**Wild animals**	**Other**	**Total**
Peels and stumps	3.6	1.4	0	0.11	0.11	0.16	5.4
Cheese wax crusts	0.014	0	0	0.000	0	0	0.014
Eggshells	2.7	0.5	0	0.000	0	0	3.3
Coffee-ground	14.2	3.2	0	0.000	0	0	17.4
Thee stains	0.7	0.2	0	0.000	0	0	0.9
Meat and fish	41.9	2.9	0	1	0.5	1.43	47.8
Fatts	0	0	0.1	0.001	0.002	0.002	0.1
Other	2.314	0	0	0.08	0.08	0.08	2.5
Total unavoidable	**65.4**	**8.4**	**0.1**	**1.14**	**0.7**	**1.7**	**77.4**
Avoidable							
Meat	3.2	0.12	0	0.07	0.04	0.106	3.5
Fish	0.1	0	0	0.002	0.001	0.003	0.11
Cheese	1.6	0.01	0	0.05	0.05	0.053	1.8
Dairy	2.6	0.002	1.5	0.04	0	0.042	4.2
Eggs	0.3	0.02	0	0.003	0.003	0.014	0.3
Vegetables	1.3	0.14	0	0.03	0.03	0.05	1.6
Fruit	0.6	0.1	0	0.02	0.02	0.02	0.8
Potatos	0.96	0.4	0	0.05	0.4	0.04	1.8
Bread	7.1	0.3	0	0.3	1.9	0.2	9.9
Rice	1.2	0.09	0	0.05	0.3	0.033	1.7
Noodles	1.2	0.05	0	0.05	0.34	0.03	1.7
Candy and snacks	0.5	0	0	0.009	0.06	0.006	0.6
Sandwich spreads	0.2	0	0	0.004	0.03	0.003	0.2
Sauces and fatt	0.4	0	0.02	0.005	0.007	0.014	0.5
Soups	0.004	0	0.06	0.001	0	0.003	0.07
Beverages	0.005	0	0.02	0	0	0.001	0.026
Other	1.3	0.05	0	0.04	0.04	0.04	1.5
Total avoidable	**22.6**	**1.3**	**1.6**	**0.7**	**3.3**	**0.7**	**30.2**
Total unavoidable and avoidable	**88.1**	**9.7**	**1.7**	**1.9**	**3.9**	**2.3**	**107.7**

Source: van Westerhoven, M. and F. Steenhuisen (2010). Bepaling voedselverliezen bij huishoudens en bedrijfscatering in Nederland. Amsterdam, CREM; The following table is a result of extra calculations which were made for that, but which due to exhausative information load was decided to left out from this paper .

Annex 14 Rotterdam solid waste data 2011

Source: The waste department of the Municipality of Rotterdam (2011). Gemeentelijk Afval 2012, Hoeveelheden, 0599-Rotterdam

GEMEENTELIJK AFVAL 2012, HOEVEELHEDEN	
0599 - Rotterdam	
Vraag 1 - Afval van huishoudens - HAALSYSTEEM	
	Hoeveelheid (in ton)
Afvalcomponent	**2011**
Huishoudelijk restafval	205,747.3
Grof huish. restafval	22,138.2
Verbouwingsrestafval	5,236.2
GFT-afval	747.4
Oud papier en karton	17,415.0
Verpakkingsglas	6,535.0
Kleding en schoeisel	1,676.0
KCA (huis-aan-huis)	314.0
Metalen verpakkingen	
Drankenkartons	
Kunststof verpakkingen	29.2
Overige kunststoffen	317.3
Luiers	
Afgedankte apparaten	2,720.0
Grof tuinafval	3,474.2
Bruikbaar huisraad	108.6
Vloerbedekking	
Vlakglas	254.5
Metalen	1,986.1
Houtafval (A- en B-hout)	8,974.2
Houtafval (C-hout)	609.1
Schoon puin	7,699.0
Dakbedekking	182.0
Asbesthoudend afval	73.5
Autobanden	72.7
Schone grond	2,886.8
Piepschuim	
Matrassen	
Gips	764.3
Gasflessen	
Overige	17.1
Totaal (exclusief -1)	289,978

Annex 15 Balance sheet of household & non-household in- & outflows of phosphorus

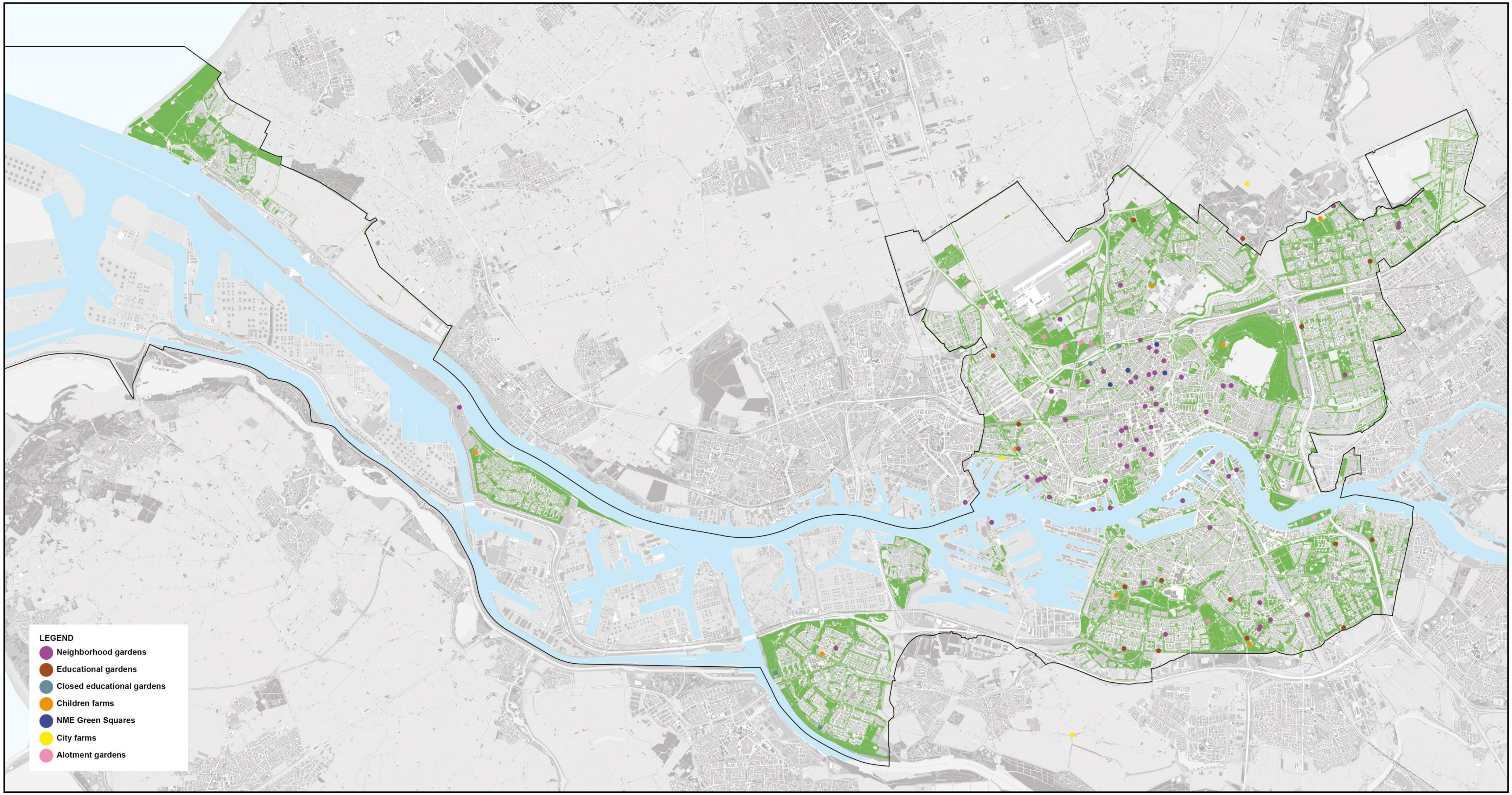
	Total domestic inflow of phosphorus		Inflow of phosphorus			Outflow of phosphorus				Final destination
	Flow type	**Amount**	**Non-household (NHH) phosphorus consumption**	**Assumption & Source for non-HH**	**Household (HH) consumption**	**Type of flow**	**Households (HH) outflows**	**Assumption & Source for non-HH**	**Non-household (NHH) & Retail outflows**	
Kitchen	**Food domestically supplied and going directly to households and non-households/ what is left from organic retail waste (641.35-43.7995)**	597.6	151.2	Based on Report on the relations between manufacturers and retailers in the food sector, households buy 74.7% of the domestically supplied food	446.4	Food consumption on mouth level \ Based on the calculations which were made for this study in line with the Dutch National Food consumption Surveys, 71% of the P is consumed at home, the rest not at home	234.3		93.4	Wastewater
						Organic waste composted	1.2			Composting
						Organic waste to incineration	122.9		Calculated by STAN	Incineration
						Home composted food and Food waste fed to animals	8.2			Composting
						Food waste to animals	5.8		Part of total human excreta	
						Human excreta	289.6			Wastewater
						Household Food waste via sink stone	2.3		Unknow/calculated as part of total wastewater P	Incineration
	Household and sanitary paper	1.13	0.2	85% in households	0.9	Household and sanitary paper to toilet	0.12	Inflow=outflow, assumed that all ends up in wastewater	0.2	Wastewater
	Detergents supply	59.5	19.8	50% in non-household	39.7	Detergents consumed	39.7	Inflow=outflow	19.8	Wastewater
						Household and sanitary paper in municipal solid waste	0.8			Incineration
						Retail organic waste			43.8	
	Total HH food outflow	*366.3*								
	Total NHH food outflow	Calculated by Stan								
Garden						Garden waste collected separately	1.009			Bioenergy plant (digestion or incineration)
	Stock	Calculated by STAN				Garden waste collected separately	2.4			Composting
						Total	*3.4*			
Other non-food in households	**Paper and carton**	18.2	9.1	50% to households	9.1	Paper and carton in municipal solid waste	7.4	Inflow=outflow	9.1	Incineration
						Paper and carton collected separately	4.2			Reuse
	Total paper and carton					*Total*	*11.6*			
	Wood	6.2	3.1	50% to households	3.1	Wood in municipal solid waste	0.6	Inflow=outflow	3.1	Incineration
						Wood collected separately	1.4			Bioenergy plant (digestion or incineration)
						Wood collected separately	0.6			Reuse
	Total					*Total*	2.6			
	Textiles	14.8	2.9	Most of the working clothes used in industries, businesses are thrown away in households. 80% of total consumption made by households	11.8	Textiles in municipal solid waste	11.2	Inflow=outflow	2.9	Incineration
						Textiles collected separately	2.2			Reuse
	Total						*13.4*			
Pets	**Pet food**	100.4		Most of the pet food goes to households, the fraction to other than households is probably quite small, therefore it was not taken into account in this study	100.4	Dog excretea	61.4			Environment & sequestration
						Cat and other pet excretea	44.7			Incineration & environment/sequestration
						Total	*106.2*			
Non-food			*15.1*		*124.4*		*137.1*		15.1	

Annex 16 Comparison of urban agriculture farms in Rotterdam

Urban farm	1. De Enk	2. De Buytenhof	3. Voedseltuin	4. Pluktuin	5.Moestuinman	6.Ghandhithuin	7.BuurtLab	8.Tussentuin	9.Uit je Eigen Stad	10.Carnissetuin	11.Dakakker
Location/Address	*Enk 134*	*Rijsdijk 98*	*Keilestraat 7-9*	*RFC Weg 14-16*	*Oudedijk 277*	*Gordelweg 131*	*Oudedijk 277*	*Gaffelstraat 70-88*	*Marconistraat 39*	*Carnissesingel 208*	*Schiekade 189*
Indicated UA type	*Institutional garden*	*Commercial-social peri-urban farm*	*Social community garden*	*Community garden*	*Community garden*	*Social community garden*	*Institutional garden*	*Community garden*	*Commercial farm*	*Social community garden*	*Roof garden*
People involved	School children, volunteers, some people working with contracts	Volunteers, some people working with contracts	Volunteers, some people with contracts	Volunteers	Children, volunteers	Volunteers, some people with contracts	Children, volunteers	Volunteers	Volunteers, some people with contracts	Volunteers, some people with contracts	Some people with contracts, volunteers
Financial profit	Small profit only for people with contracts\money gained mainly from government support or other funding	Very commercial, high financial profit is there compared to other farms	Small profit only for people with contracts\money gained mainly from government support or other funding	No financial profit	Not much financial profit (the project manager only)	Small profit only for people with contracts\money gained mainly from government support or other funding	Not much financial profit (the project manager only)	No financial profit	Very commercial, high financial profit is there compared to other farms	Small profit only for people with contracts\money gained mainly from government support or other funding	Commercial. Profit for people with contracts.
Land ownership	Municipality	Privately	Municipality former vacant land	Municipality former vacant land	Municipality former vacant land	Municipality	Municipality former vacant land	Municipality former vacant land	Social housing corporation, former vacant land	Municipality	Rooftop owned by the architecture company
Food selling\ its end location	No food is sold, given to people who work in the garden	Sold to several restaurants and farmers shops within the city and outskirts of it. Sometimes given to people who work in the garden	No food is sold, given to people who work in the garden as well as delivered to Foodbank	No food is sold, given to people who work in the garden	No food is sold, given to people who work in the garden	No food is sold, given to people who work in the garden as well as delivered to Foodbank	No food is sold, given to people who work in the garden	No food is sold, given to people who work in the garden	Sold to several restaurants and farmers shops within the city and outskirts of it. Sometimes given to people who work in the garden	No food is sold, given to people who work in the garden as well as delivered to Foodbank	Sold to several restaurants within the city and given to people who work in the garden
Soil health (Based on verbal explanation\no technical measuremtns were taken)	Considered to be healthy	Considered to be healthy	Former polluted vacant land which has been improved	Former polluted vacant land which has been improved	Former polluted vacant land which has been improved	Considered to be healthy	Former polluted vacant land which has been improved	Former polluted vacant land which has been improved	Former polluted vacant land which has been improved	Considered to be healthy	It was claimed that rooftop gardening is relatively difficult in general. In case of Dakakker the ground which was built was considered

											to work out well.
Organic waste management on sites (planting\manure in some cases)	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (wood) is transported from Hoeksche Waard.	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (planting) is transported from nearby farm - van de Materlinckweg Some organic parts are eaten by pigs and manure is used as fertiliser directly on site.	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (planting) is transported from the waste department of the Municipality of Rotterdam and Landschapsonderhand.	The organic waste (plants) is composted (in heaps) and re-used directly on site.	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (planting) is transported from nearby children's farm – De Kraal.	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (manure) is transported from nearby children's farm – Kinderparadijs.	The organic waste (plants) is composted (in heaps) and re-used directly on site.	The organic waste (plants) is composted (in heaps) and re-used directly on site.	Stores its plant waste which later is transported to an organic farm in Vlaardingen once a year where it gets composted and then delivered back to Uit je Eigen Stad	The organic waste (plants) is composted (in heaps) and re-used directly on site. Extra organic waste (planting) is transported from nearby children's farm - Kinderboerderij De Molenwei. Sometimes the organic waste is exported also to Proefpark de Punt, Al Gazhalischool.	The organic waste (plants) is composted (in heaps) and re-used directly on site.
Type of water used at site	Rain water + canal water	Rain water + canal water	Rain water and ground water as extra when rainwater in not enough	Rain water + canal water	Rain water and ground water as extra when rainwater in not enough	Mostly groundwater	Rain water and ground water as extra when rainwater in not enough	Rain water and ground water as extra when rainwater in not enough	Mostly groundwater	Rain water + canal water	Rain water and ground water as extra when rainwater in not enough
Energy	Non-sustainable energy provider	Non-sustainable energy provider	Non-sustainable energy provider	Sustainable energy sources\own solar panels. Extra electricity provided from nearby buildings	No energy needed\used at site	Sustainable energy provider\Contract with Green Choice	No energy needed\used at site	No energy needed\used at site	Non-sustainable energy provider	Non-sustainable energy provider	No energy needed in garden itself, rooftop garden house has contract with non-sustainable energy provider

Annex 17 Green surface in Rotterdam & present spots of urban agriculture



Annex 18 Original & by STAN re-calculated flow values

Flow	Flow name	Mass flow	± Mass flow	Mass flow (calculated)	± Mass flow (calculated)
F19	Cat and other animal excreta	44.7 t/a		44.7 t/a	
F69	Commercial compost			3.6 t/a	
F63	Commercial solid waste			131.8 t/a	18.7 t/a
F9	Communal wastewater	416.7 t/a		416.7 t/a	
F74	Company\organisation (NHH) food waste			66.3 t/a	16.14 t/a
F47	Detergents consumed (HH)	39.7 t/a	2.9 t/a	39.8 t/a	2.1 t/a
F65	Detergents consumed (NHH)	19.8 t/a	1.5 t/a	19.9 t/a	1.05 t/a
F2	Detergents supply	59.5 t/a	11.9 t/a	59.7 t/a	2.3 t/a
F41	Detergents supply (HH)	39.7 t/a	2.9 t/a	39.8 t/a	2.1 t/a
F42	Detergents supply (NHH)	19.8 t/a	1.5 t/a	19.9 t/a	1.05 t/a
F32	Digestate and ashes			2.5 t/a	
F22	Dog excreta	61.4 t/a		61.5 t/a	
F1	Domestic food supply	641.4 t/a	32.4 t/a	605.7 t/a	18.7 t/a
F50	Food consumed (HH)	234.3 t/a	21.4 t/a	260.8 t/a	8.6 t/a
F72	Food consumed (NHH)	93.4 t/a	9.6 t/a	93.5 t/a	8.45 t/a
F39	Food supply (HH)	446.4 t/a	47.6 t/a	395.5 t/a	8.6 t/a
F40	Food supply (NHH)	151.2 t/a	15.9 t/a	159.8 t/a	14.6 t/a
F76	Food waste fed to animals	5.8 t/a	0.09 t/a	5.8 t/a	0.09 t/a
F48	Food wastes to sinkstone	2.3 t/a	0.14 t/a	2.34 t/a	0.14 t/a
F58	Garden waste to compost	2.4 t/a		2.4 t/a	
F46	Garden wastes for bioenergy	1 t/a		1.01 t/a	
F13	HH Effluent to surface water	34.7 t/a		34.7 t/a	
F15	HH Effluent to surface water	23.9 t/a		23.9 t/a	
F12	HH Sludge digested for biogas	170.4 t/a		170.4 t/a	
F14	HH Sludge digested for biogas	90.9 t/a		90.9 t/a	
F77	Home composted food waste	2.3 t/a	0.1 t/a	2.3 t/a	0.09 t/a
F45	Household & sanitary paper supply (HH)	1 t/a	0.1 t/a	1 t/a	0.013 t/a
F43	Household & sanitary paper supply (NHH)	0.17 t/a	0.014 t/a	0.2 t/a	0.014 t/a
F64	Household and sanitary paper (NHH)	0.17 t/a	0.014 t/a	0.2 t/a	0.014 t/a
F5	Household and sanitary paper supply	1.13 t/a	0.2 t/a	1.13 t/a	0.02 t/a
F18	Household and sanitary paper to incineration	0.8 t/a		0.8 t/a	
F52	Human excreta (poo and pee)	289.6 t/a	43.4 t/a	354.4 t/a	2.3 t/a
F31	Incineration ashes			187.7 t/a	
F67	NHH effluent to surface water	5.7 t/a		5.7 t/a	
F68	NHH effluent to surface water	12.3 t/a		12.3 t/a	
F38	NHH non-food solid waste			15.13 t/a	0.7 t/a
F60	NHH sludge digested for biogas	21.7 t/a		21.7 t/a	
F66	NHH sludge digested for biogas	57.1 t/a		57.12 t/a	
F82	Organic waste			3.6 t/a	
F61	Organic waste to compost	1.2 t/a		1.2 t/a	
F16	Organic waste to incineration	122.9 t/a		122.9 t/a	
F51	Paper & carton (HH)	9.09 t/a	0.9 t/a	9.1 t/a	0.9 t/a
F49	Paper & carton supply (NHH)	9.1 t/a	0.6 t/a	9.1 t/a	0.6 t/a

F70	**Paper and Carton recycle/reuse**	**4.2 t/a**		**4.1796 t/a**	
F4	**Paper and carton supply**	**18.2 t/a**	**3.05 t/a**	**18.2 t/a**	**1.04 t/a**
F20	**Paper and carton to incineration**	**7.4 t/a**		**7.4 t/a**	
F90	**Pet food consumed**	**100.4 t/a**	**6.3 t/a**	**100.4 t/a**	**0.09 t/a**
F3	**Pet food supply**	**100.4 t/a**	**6.3 t/a**	**100.4 t/a**	**0.09 t/a**
F75	**Recycling and reuse in society**			**6.9 t/a**	
F62	**Retail organic waste**	**43.8 t/a**	**13.9 t/a**	**50.4 t/a**	**13.06 t/a**
F44	**Sanitary paper to toilet**	**0.12 t/a**	**0.013 t/a**	**0.12 t/a**	**0.013 t/a**
F7	**Textiles supply**	**14.8 t/a**	**2.2 t/a**	**14.8 t/a**	**0.9 t/a**
F56	**Textiles supply (HH)**	**11.8 t/a**	**0.9 t/a**	**11.8 t/a**	**0.8 t/a**
F59	**Textiles supply (NHH)**	**2.9 t/a**	**0.2 t/a**	**2.9 t/a**	**0.2 t/a**
F21	**Textiles to incineration**	**11.2 t/a**		**11.2 t/a**	
F73	**Textiles to recycle/reuse**	**2.2 t/a**		**2.2 t/a**	
F11	**Wastewater HD**	**274.5 t/a**		**274.5 t/a**	
F10	**Wastewater SK**	**142.2 t/a**		**142.2 t/a**	
F83	**Wood & garden waste**			**2.45 t/a**	
F24	**Wood for bioenergy**	**1.4 t/a**		**1.45 t/a**	
F6	**Wood supply**	**6.2 t/a**	**0.9 t/a**	**6.16 t/a**	**0.3 t/a**
F54	**Wood supply (HH)**	**3.1 t/a**	**0.2 t/a**	**3.08 t/a**	**0.23 t/a**
F53	**Wood supply (NHH)**	**3.1 t/a**	**0.2 t/a**	**3.08 t/a**	**0.23 t/a**
F17	**Wood to incineration**	**0.6 t/a**		**0.6 t/a**	
F71	**Wood to recycling and reuse**	**0.6 t/a**		**0.6 t/a**	
F78	**Wood, paper, textiles**			**6.9 t/a**	