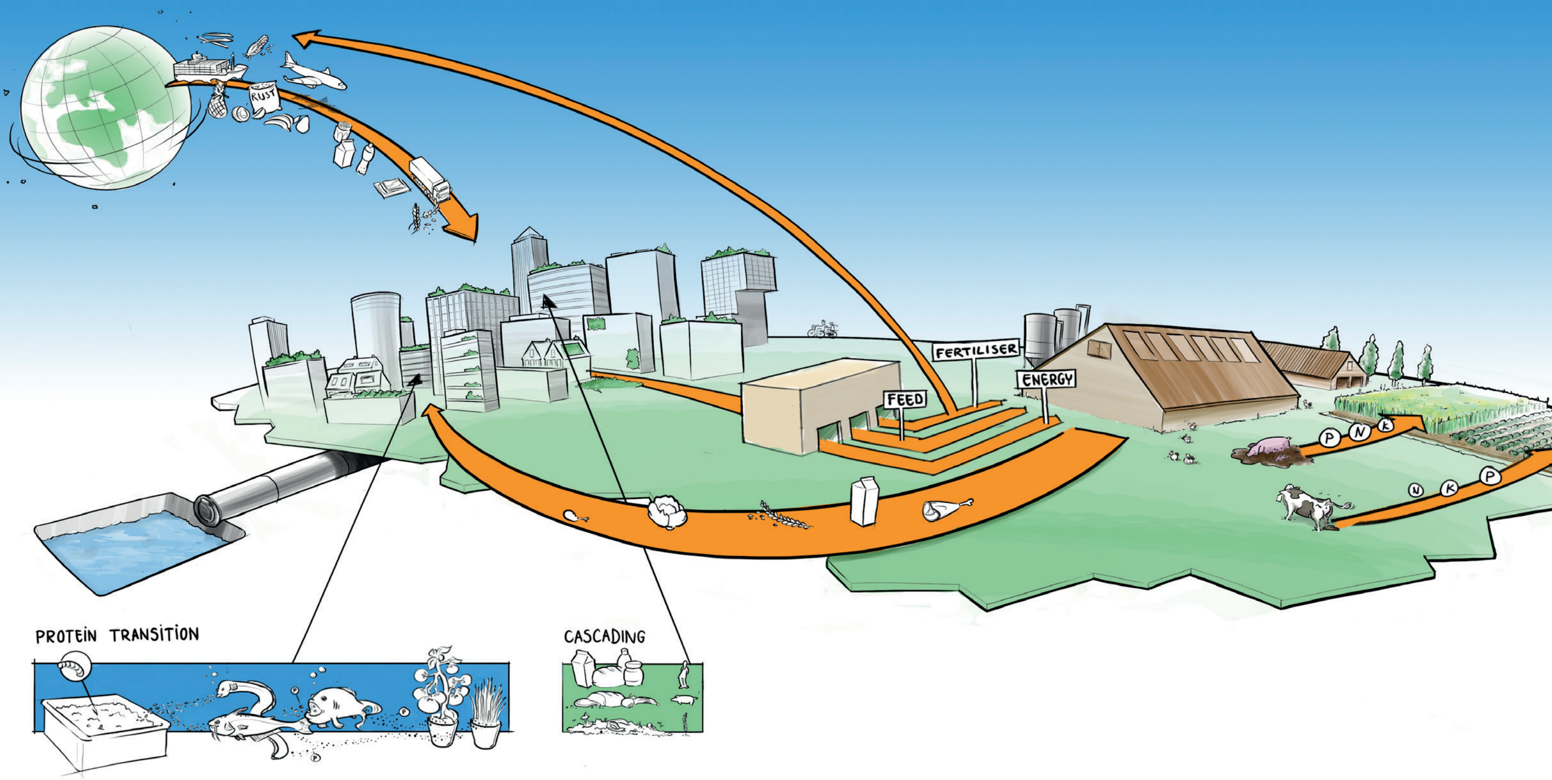

Closing the life cycle of phosphorus in an urban food system: the case Almere (NL)

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WAGENINGEN UNIVERSITY & RESEARCH

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W. van Dijk[1], J.E. Jansma[1], W. Sukkel[1], H. van Reuler[2], T. Vermeulen[3] & A.J. Visser[1]

1 Wageningen University & Research, Praktijkonderzoek AGV
2 Wageningen University & Research, Praktijkonderzoek BBF
3 Wageningen University & Research, Glastuinbouw

This study was carried out by Wageningen University & Research and was commissioned and financed by the Dutch Ministry of Economic Affairs within the context of the KB research program Metropolitan Solutions, research theme KB-25-006-003.

Wageningen Plant Research is the collaboration of Wageningen University and the foundation Stichting Wageningen Research.

Wageningen, January 2017

Report 725

Van Dijk, W., J.E. Jansma, W. Sukkel, H. van Reuler, T. Vermeulen & A.J. Visser, 2017. Closing the life cycle of phosphorus in an urban food system: the case Almere (NL). Wageningen Plant Research, Report 725, 44 pp.

Nutrient recycling in current food systems is relatively low. This study explores the possibilities of closing the phosphorus cycle for a local food system for the urban region Almere. The phosphorus flows within the food system (primary production on farms, processing industry, retail, households and waste sector) are quantified.

Keywords: Food system, phosphorus, recycling

Chamber of Commerce no. 09098104 te Arnhem
VAT NL no. 8065.11.618.B01

Wageningen Plant Research Report 725

Contents

Preface

Wageningen UR wants to be leading in metropolitan applied and scientific research on the newly defined 17 UN Global Goals for sustainable development. Because the urban world plays an important role in uncovering these goals, it recently launched the Metropolitan Solutions program. This program is positioned in various organisational units of the university and will cover a time frame from 2016 to 2018. Transdisciplinary research in which several disciplines and local knowledge are combined, is a keyword. Its Metropolitan Solutions approach holds four themes: (1) Liveable and healthy cities, (2) Resilient, climate-proof cities, (3) Resource efficient cities, and (4) Food secure cities. This rapport is the result of desk study carried out within this Metropolitan Solutions Program under the heading of the themes 3 and 4. This desk study centres on the possibility to develop a circular system in an urban context based on the phosphorus flow. It is just a start of a wider program which focuses on the co-creation of tools and policies to meet a circular urban food system with regard to phosphorus.

According to the UN, global urbanization is especially caused by the rise of medium-sized cities, rather than megacities. This is one reason we decided to focus on the city of Almere, the 7th largest in the Netherlands. Another reason to select this city is that Almere will organise the 2022 Floriade World Expo. This Almere Floriade shares one central theme: the challenges of feeding an urbanising world, i.e. how to Feed the City of the future. In the realm of this World Expo, Almere and its regional partners recently established an institute, The Flevo Campus, to encourage innovation, research and education in this same field: Feeding the city. This makes Almere the ideal starting point for such a study and the foreseen next steps of the program it is part of.

The study was supervised by a committee representing different expertise of Wageningen Plant Research. Besides the authors additional members were Jan Hassink and Rommie van der Weide. We thank them for their feedback during our work and for commenting the report. We also acknowledge Izak Vermeij (Wageningen Livestock Research) and Michiel van Eupen (Wageningen Environmental Research) for providing data with regard to animal production and for designing maps which depicts the impact of the different scenarios, respectively.

The authors

Summary

In order to explore the possibilities of a local food system and its effects on the nutrient cycle, a desk study was executed for the urban region Almere, a Dutch city located in the Flevo Polder with about 200,000 inhabitants. This desk study takes this urban perspective as starting point in the search of measures to maintain future food productivity whilst decreasing the demand (and dependence) of external resources. The study focussed on phosphorus (P) as this element is essential for food and feed production while the resources are finite and, it is technically feasible to recover it from the urban waste flows.

Three scenarios were distinguished each different in the extent to which the food is produced locally (Table S1). The first scenario, “Current”, refers to the current situation in which only a small part of the food, estimated at 5% for all food products, is produced and processed locally. In this scenario the reuse from waste is limited and occurs via compost (e.g. kitchen waste) and digestate. In the second scenario, “Hybrid”, the food is as far as possible produced locally except for products that cannot be grown locally (e.g. coffee, tea, exotic fruits). Also a part of the animal feed ingredients (e.g. soybean meal) are still imported. Within the Hybrid scenario two sub-scenarios are distinguished: (a) with a limited P reuse, only via compost/digestate (as in scenario Current) and (b) with a maximal (up to 90%) recovery of P from waste. Finally, in the third scenario, “Self-Sufficient”, all feed ingredients are also grown locally. Only food products that cannot be grown locally are still imported. P recycling from waste is maximal (90%).

Table S1. The three scenarios that are compared in this study.

Scenario	Local food production	Food processing	P reuse from waste
Current	Limited, 5%	Limited, 5%	Compost/digestate[1]
Hybrid a	Max except for exotic products and partly animal feed	Locally	Compost/digestate[1]
Hybrid b	Max except for exotic products and partly animal feed	Locally	Maximal reuse (90%)
Self-Sufficient	Max except for exotic products	Locally	Maximal reuse (90%)

1 mainly via organic waste (e.g. kitchen waste) that is collected separately

Starting point in this study was the intake of food of Almere, from that point stepwise the area demand and P flows were calculated. The food intake was derived from national data of the intake of food and the population structure of Almere. For each food product group representative model food products were chosen (e.g. bread for cereal products) and these model food products were linked to primary products that are produced on farms (e.g. bread linked to wheat). Subsequently, for each food product group the needed amount of primary product can be calculated assuming a certain percentage of wastage throughout the chain (30%). Based on crop yield and animal production data the area demand for food and feed production was derived. The required amount of P for crop growth was set equal to the P removal with harvested products.

In the scenario Current, the area demand is about 1,000 ha. In the scenario Hybrid the required area increases to about 20,000 ha of which about 85% is needed for the production of feeds. In the Self-Sufficient scenario the area demand increases further to about 27,000 ha. The major part of the area in the scenario Self-Sufficient is needed for feed production (nearly 90%). The major part of the

needed area for the production of animal products is necessary for the production of dairy products (almost 60%). With regard to the required area for the production of plant products for food about 65% of the area is needed for cereals, 15% for sugar beet, 10% for fruits and about 10% for potatoes and vegetables.
The 27,000 ha area demand corresponds with a per capita land use of 1,400 m^2 per year in Almere. This figure is relatively low compared to similar studies from The Netherlands and abroad. This low figure is due to the fact that not all food products are grown locally (so still land abroad is needed) and due to the high production levels in the primary sector in the Netherlands and in the Flevo Polder in particular, which are among the highest in the Netherlands.

In all three scenarios the P in the primary products produced on the farm and the imported food products predominantly ends up in the waste sector. In the Current and Hybrid A scenario recycling from the waste sector is limited to about 20 and 25% of the P entering the waste sector, respectively. The remainder, about 130 and 195 ton P, respectively, is not recycled and is lost for the food system (Table S2). This loss is compensated by the import of feeds and manure/fertilisers. When in the Hybrid scenario the recycling from the waste sector is increased to 90% (scenario Hybrid B), the extra recycled P substitutes the imported manure/fertilisers and the non-recycled P decreases to about 20 ton P. When all feeds are produced locally and recycling from waste is maximal (scenario Self-Sufficient), a nearly circular system is looming. A relatively small import of manure/fertilisers (about 25 ton P) is still necessary in order to compensate for the non-recycled P from the waste sector (20 ton P) and a small net export of food products (about 5 ton P).

Table S2. Import and export of P (1,000 kg) in the three scenarios.*

Scenario	Import (*1,000 kg P)			Export (*1,000 kg P)				
	Feed	Manure	Food	Total	Food/ feed	Recycled waste P[1]	Non recycled waste P	Total
Current	5		149	154	1	25	128	154
Hybrid A	106	97	19	222	26		195	222
Hybrid B	106		19	125	26	79	20	125
Self-Sufficient		27	19	46	26		20	46

Ad 1) Includes compost, digestate, other recycled P fertiliser products and biomass

The study demonstrates that, at least technically, a circular local food system based on P is possible, However this circular food system requires fundamental changes in how the food chain (from farm to fork) is organised including waste management. Because P is mainly used for food and feed production and therefore ends up in different waste streams in the food cycle, a decreased use of P (e.g. efficient use, less wastage of food) combined with recycling from waste streams is crucial for future food systems whether organized locally or not.

1 Introduction

The sustainability of the current food system is questionable in the light of challenges like peak oil, climate change, loss of biodiversity, loss of soil fertility, nutrient emissions, the use of fresh water, and waste. On the one hand, it is estimated that our food system is responsible for 25% of the global greenhouse gas emissions (Westhoek et al, 2013). In addition, the food system is the largest contributor to the loss of natural resources, like biodiversity, and water (Westhoek et al, 2013). Furthermore, it is estimated that around 18% of our household food is wasted (Van Westerhoven, 2013; WRAP, 2013). On the other hand our global food system is vulnerable to changing environmental conditions (climate change, scarcity of water and a decreased soil fertility) and demographic conditions (diets changing to more protein consumption, urbanisation) (UNEP, 2016). A growing world population with a changing preference in diet will require more food and protein production, and thus an increasing demand for land, fresh water and fertilisers. Therefore, our current food system holds a triple challenge. It has to reduce its impact on the loss of natural resources, it has to cope with a changing climate and at the same it has to feed a growing urban population which increasingly consumes protein richer diets. This challenge fuels the thinking about (and acting in) new ways of food security; specifically, food security with a more urban and regional geography (Soninno, 2014). It is argued that the perspective of a city region oriented food system "[…] is the most appropriate level of scale to develop and implement an integrated and comprehensive solution for a future proof urban food system" (Wiskerke, 2015: 15). Over the last two decades urban-regional food-related policies gain momentum. Following in the footsteps of harbingers such as Toronto, Brighton-Hove, London, and New York, many cities have put regional food squarely in the middle of their policy agendas (Cohen and Reynolds, 2014; Sonnino, 2014). In 2015 more than 40 world cities, initiated by the city of Milan, signed the Urban Food Policy Pact that directs to the support and exploration of urban food systems, policies and practices (Dubbeling et al, 2015). This urban food or city region perspective is new, but might it help to overcome the triple challenge of our food system?

This study takes this city region perspective as starting point in the search of measures to maintain future food productivity whilst decreasing the demand (and dependence) of external resources. It explores the potential of closing the life cycle of nutrients in our food system with the focus on the element phosphorus (P). The route of P in this study is taken from an urban (regional) perspective. Figure 1 depicts the pathway of P in our current food system. Almost all mined P is being used in our food system as fertiliser of food and feed crops, and all P consumed with food leaves the human body with faeces and urine which ends up in the sewer (Cordell and White, 2014). At this point P mostly leaves the food system again. Could this P be reused locally, thus contributing to a local circular food system? This question leads to a bigger question, i.e. how does a circular urban-regional food system looks like? A system which is predominately based on local food production, processing and procurement, and a local recovery and reuse of nutrients.

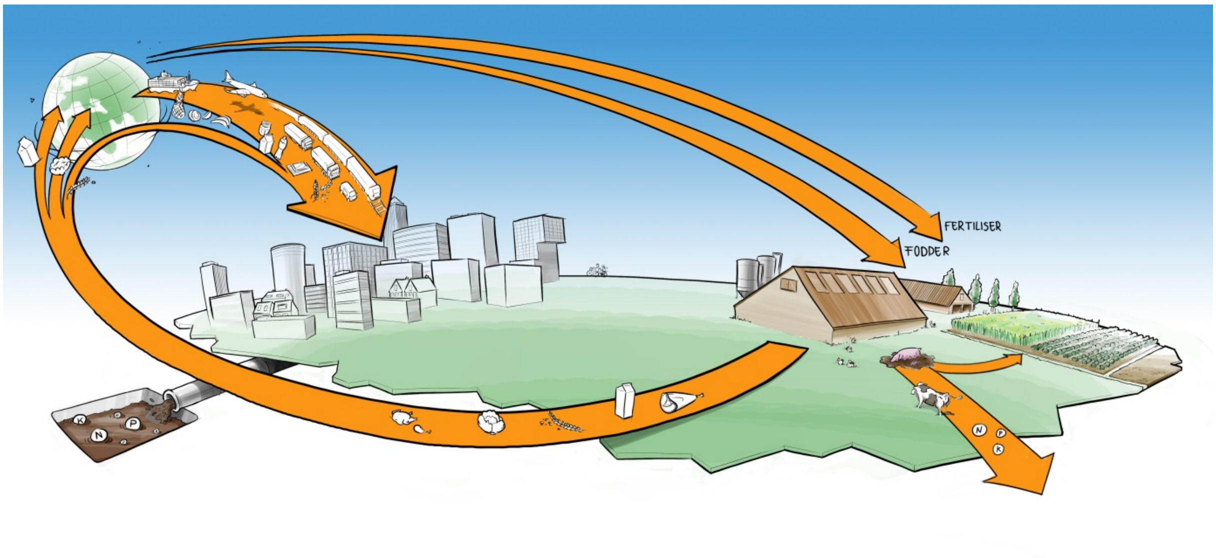


Figure 1. An outline of the disconnection between agriculture and the city. Agriculture produces food for the global market, and imports feed and fertilisers. Urban waste leaves the local system as well as a part of the animal manure.

Why did we choose P? P is essential to all life, it is essential to growth and thus to food production (Cordell et al, 2011; Cooper et al, 2011). Throughout human history, (human and animal) excrements, natural resources (flooding and burning, and later Guano) and recycling (water, (animal) bones, compost) were the only additional source of P for food production. P deficit was one of the reasons of the (much) lower food producing capacity of agriculture throughout human history compared to today. It is estimated that the food producing capacity of the British Isles in the middle ages was about 5 million people, instead of the 55 million today (Ashley et al, 2011). Over the past 50-100 years, P, as phosphate fertilizer derived from mined rock, has been one of the essential elements to an improved global food production and food security. Today around 90% of the mined phosphate rock is used for agricultural and food production (Neset and Cordell, 2011). However, these reserves are finite and there's no alternative. Estimation of expected global reserves of rock phosphate alter between 100 and several 100 years, but most of the producing countries will have depleted their reserves within 100 years (Cooper et al, 2011). In addition to the size of the P rock reserves the extractability plays an important role, less accessible P will lead to higher inputs to extract and thus higher costs and more waste (Cordell and White, 2014). The debate about the P stock has also a geo-political component, i.e. the vast majority of the reserves (70-90%) belong to one single country: Morocco (Cooper et al, 2011). Opposite to the expected P scarcity is the inefficiency, loss, spill and leakage of it throughout the food system from mining to consumption. Only one-fifth of the mined P finds its way to the global consumer (Cordell and White, 2014). One of the side effects of this loss is the local eutrophication of surface water around the world.

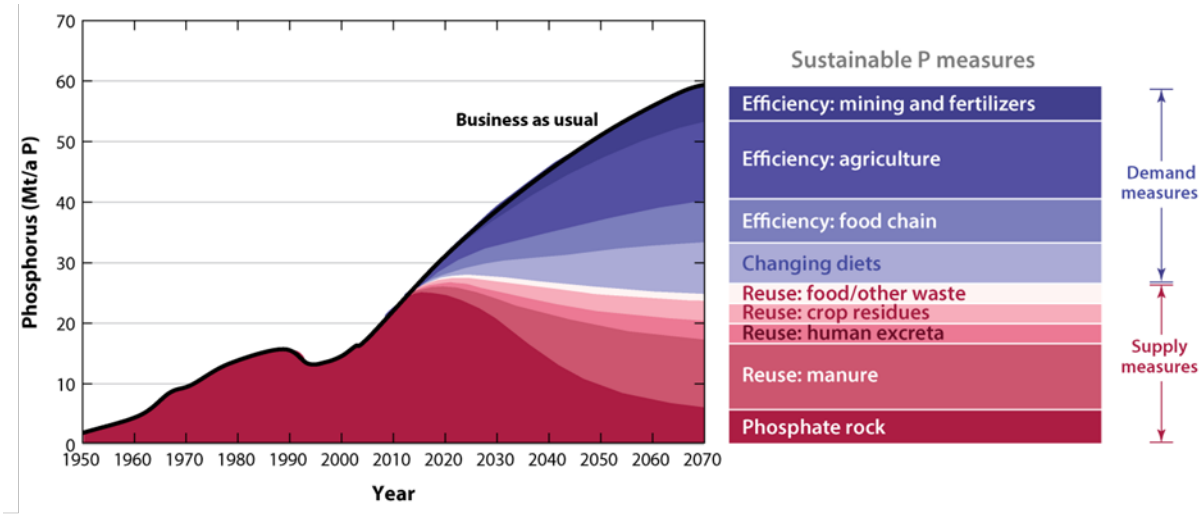


Figure 2. Measures for reducing the future use of phosphate rock (Source: Cordell and White, 2014).

So the debate of the future of P (in our food system) has more than one side, or as Cordell et al (2011: 756) puts it: "Whilst the exact timeline of peak phosphorus is uncertain, what is clear is that unless we intentionally change the way we source and use phosphorus throughout the food production and consumption system, we will end up in a 'hard-landing' situation with increased phosphorus scarcity and phosphorus pollution, further fertilizer price fluctuations and increasing costs and energy consumption". There will be no one fits all solution to the complex multi-faced aspects of P scarcity and pollution. Cordell and White (2014), referring to earlier work of Cordell, suggest an integrated approach of measures at the demand and supply side of P and at all stages of our food system (Figure 2). They also propose that optimal measures may vary between regions. A greater diversity in P sources supports a transition to a more resilient food system (Neset and Cordell, 2011). In Europe, with no rock reserves, high population density and high concentration of livestock, and thus a surplus of phosphorus in manure and waste, the measures may lay in efficiency, recovery and reuse. Currently, P reuse in food production systems is low due to wastage in the food production chain (primary production, transport, processing industry, retail and households) and a low reuse of nutrients from (especially human waste and excrements in) sewage water. In the Netherlands around 80% of the P (app. 12,000 ton P per year or 50-60% of the P fertilizer use in NL) in municipal waste water ends up in sludge (Van der Grinten et al., 2015). Sludge leaves the system and is predominately incinerated, the waste product (ash) finds its way in for example road construction. A small percentage of the P in waste water is recovered, mostly as struvite. Van der Grinten et al. (2015) estimated that in 2014 about 360 ton P is recovered in The Netherlands, but it is expected that this number will increase the coming years.

Aim and case

This study is conducted to explore the potential of a local circular food system, in terms of P flows (P is the main focus of this study, but it could also be carried out for N and K). The aim of this study is to develop a tool which reconnoitres local P flows in urban regions under different circumstances (scenarios). Based on the diet of a city region this tool should calculate the required area for food production and quantify the nutrient flows between city and (local) agriculture.

In this study the urban region Almere is the case (Figure 3). Almere is a sub urban city about 30 km east of Amsterdam. In its original design food played a significant role. The city is situated in the Flevopolder, which was planned in the late 50-early 60 to harbour modern, rational, high productive agriculture. The poly-nuclear design of the city reflects the ideas of the Ebenezer Howard design of the garden city. Today, Almere is a city with approximately 200,000 inhabitants. Although it has food in its DNA, Almere has hardly any relation with its agricultural fringe. Like any other modern western city, its food comes from everywhere and not necessarily out of the region. The waste from the sewage system of the city is mainly incinerated. The city has separated recycle systems for household paper, plastics and glass and also for household organic waste. The latter is collected and composted on a plant in the region (part of this compost is offered for free to the citizens of Almere). Likewise, the agriculture in the Flevopolder has hardly any connection with the city of Almere. Flevopolder agriculture produces for the world market, its fertilizers and animal feed are (mainly) imported from elsewhere, and part of its manure is exported again (Figure 1). This makes Almere an interesting case for a reconnaissance of a reconnection between the city and its region from a food perspective. Moreover, the Almere Floriade World Expo in 2022 and the recent establishment of the urban food oriented institute, the Flevo Campus: Feeding the City, puts (local) food high at the policy agenda of the city and the region. Already in 2009 Almere launched the ambition to produce 10% of its future food basked locally (Almere 2009).

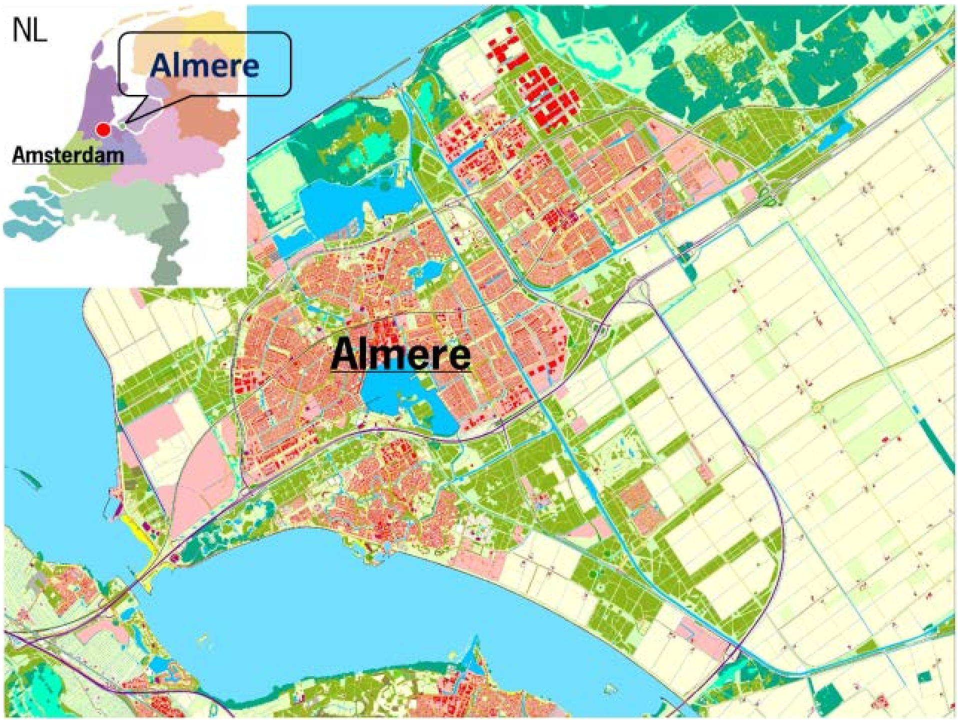


Figure 3. The city of Almere is located 30 km East of Amsterdam in the Flevopolder.

Content of report

We start this report with describing the three scenarios (Current, Hybrid and Self Sufficient), each with different levels of local food production and P recovery/reuse. Chapter 3 describes the methodology used to calculate the required area of food production in the three scenarios and thus to quantify the P flow in the food system. Starting point in this study is the intake of food in Almere. The next chapter presents the results of the desk study. It shows that a nearly circular local food system in Self-sufficient is possible in Almere and that it corresponds with a food footprint of 1,400 m2 per inhabitant of Almere and a 90% reuse of P. In the final chapter we conclude that although this circular food system technically is feasible, it will require fundamental changes in how the food system (from farm to waste) is organised.

2 Scenarios

This study distinguishes three different scenarios. The first scenario, “Current”, refers to the current situation in which only a small part (estimated at 5% for all food products) of the food is produced and processed locally (Figure 1). The other 95% of the food products are imported. In this scenario the reuse from waste occurs via compost (e.g. kitchen waste) and digestate (residue of waste in the food chain that is (co)digested for energy production).

In the second scenario, “Hybrid”, the food is as far as possible produced locally except for products that cannot be grown locally (e.g. coffee, tea, tropical fruits). In scenario Hybrid a part of the animal feed ingredients (e.g. soybean meal) will still be imported. Within the Hybrid scenario two sub-scenarios are distinguished: (a) P reuse only by compost/digestate (as in scenario Current) and (b) a maximal reuse of P from waste. It is assumed that in Hybrid B a maximum of 90% of the P in waste(water) is recovered (De Ruijter et al., 2015).

Finally, in the scenario “Self-Sufficient” all feed ingredients are grown locally. The food products that cannot be grown locally are still imported. P recycling from waste is maximal (Figure 4). Table 1 shows the main differences between the subsequent scenario’s.

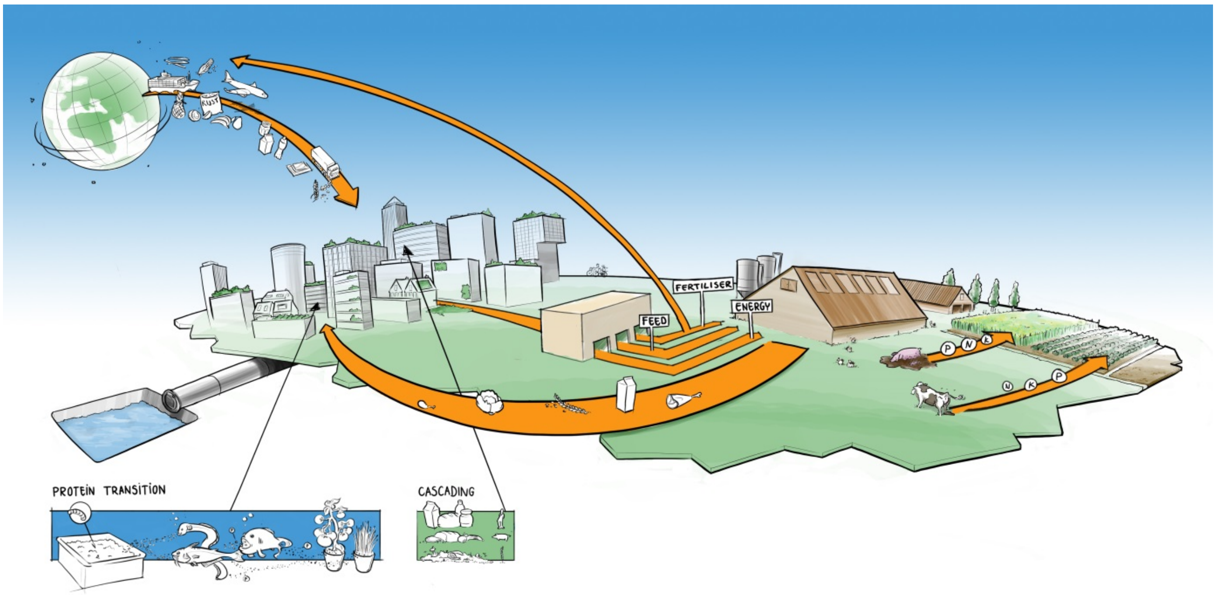


Figure 4. An outline of a future local circular food system. Except for subtropical products the food is produced locally (on farms as well as in the city) and recycling of waste is maximal making the import of feeds and fertilisers not necessary anymore.

In all three scenarios the human diets were the same and we used the current primary production data of the Flevopolder (KWIN, 2015 for arable and vegetable crops and livestock), these are (per ha) amongst the highest in the Netherlands (CBS, 2016). The Netherlands realises one of the highest yields of crops per ha in the world (FAOSTAT, 2016).

Table 1. The three scenarios that are compared in this study.

Scenario	Local food production	Food processing	P reuse from waste
Current	Limited, 5%	Limited, 5%	Compost/digestate[1]
Hybrid A	Max except for exotic products and partly animal feed	Locally	Compost/digestate[1]
Hybrid B	Max except for exotic products and partly animal feed	Locally	Maximal reuse (90%)
Self-Sufficient	Max except for exotic products	Locally	Maximal reuse (90%)

1 mainly via organic waste (e.g. kitchen waste) that is collected separately

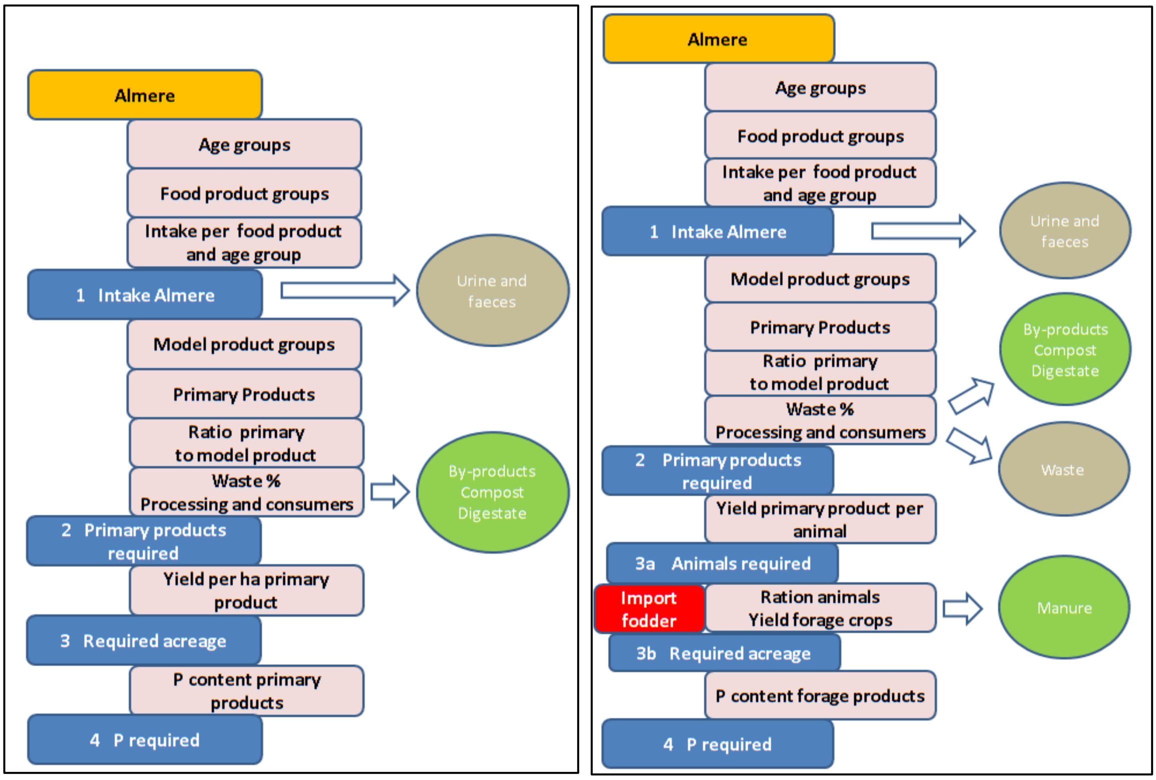
The next chapter elucidates on the different steps to calculate the P flow and land demand in the scenario's.

3 Methodology

Figure 5 describes the methodology used to calculate the required area of food production and to quantify the P flow. Starting point was the intake of food in Almere (upper part of the figure, orange box). From this point we stepwise calculated the required P (bottom part of the figure, blue box) to meet this intake of food. A distinction was made between P flows associated with the production of plant products (left part in figure 5) and animal products (right part in figure 5).

In the following steps we describe the calculating process (and the choices made):

1. Starting point in this study was the food intake of different age groups and gender in the Netherlands (N = 3,819) as part of the Dutch National Food Consumption Survey in the period 2007-2010 (Van Rossum et al, 2011). Based on these national data the intake (per age group and per gender) per food product group of the population of Almere was estimated.
2. Subsequently, for each food product group (e.g. cereal products, milk products) representative model products were chosen (e.g. bread, milk, cheese). Then, each model product was linked to a primary product that is produced on a farm (e.g. bread to wheat, cheese to milk). Via the ratio of primary product to model product (e.g. 0.8 kg of wheat for one kg of bread, 10 litre of milk for 1 kg of cheese) and the percentage wastage (see section wastage), the required amount of primary product at the farm to meet the intake was calculated. We assumed that for all scenarios the wastage and the by-products of the plant production (produced in the whole chain) completely return to the food system through compost, digestate, fertiliser and animal feed. This in contrast to waste and by-products for the production and processing of animal products, here for scenarios Current and Hybrid A a part will end up as non-recycled waste and leaves the food system (e.g. dead animals, slaughter waste cat 1 & 2). The same applies to the waste water (e.g. urine, faeces) for these two scenarios. For scenarios Hybrid B and Self-Sufficient it was assumed that the main part of the P in these waste streams is recycled.
3. The required area of plant based products was calculated by dividing the amount of required primary products by the yield per hectare. In case of the animal products, firstly, the number of animal places per year was calculated (step 3a) based on the production of primary product per animal (e.g. X litre of milk (to meet the demand of milk based products) leads to Y heads of dairy with a Z litre of milk production per head). Subsequently, based on the feed rations of the animals and the forage crop production level per hectare, the needed area to feed this number of livestock was calculated (step 3b). The feed ingredients that are currently not grown in the Netherlands (e.g. soy bean meal) were imported in the scenario Hybrid or substituted by locally grown feed ingredients in the scenario Self-Sufficient (see also Scenarios). For all scenarios the manure is used for crop production taking into account the maximum allowed P rates on agricultural land (see step 4). The surplus is exported.
4. The required amount of P for the crop growth was set equal to the P removal with agricultural products in order to maintain the soil fertility. These P supply levels are more or less comparable with the legal maximum allowed P application levels (www.rvo.nl). Losses through run off and leaching in the field were not taken into account. On a national level this amounts to about 2 kg P per ha agricultural area per year (National data emissions, 2016).



Plant products **Animal products**

Figure 5. Schematic outline of the methodology of the calculation of the required area for food production and quantification of the P flows for plant products (left) and animal products (right).

In this study an extra area demand for pet food is excluded.

In the following part we explain stepwise the different elements of this calculation following Figure 5 from top to bottom, the blue boxes: (Food) Intake Almere, Primary products required, Required acreage and animals, and Required P, respectively.

Intake Almere

This study used the Dutch National Food Consumption Survey (Van Rossum et al, 2011) as source for the food intake in Almere. This survey analysed the daily intake of children and adults in the Netherlands aged 7 to 69 years in the period 2007-2010. The intake per age group of this survey was transferred to the age groups of Almere as elaborated in the Sociale Atlas Almere (2013). Because the distinguished age groups in the National survey and those in Almere at some points differ, they had to be adjusted (see also Appendix 1). The combination of the data of the national survey and the population of Almere resulted in the total food intake of the 195,191 inhabitants of Almere in 2013 (Table 2).

Table 2. Annual food intake per food product group of the population of Almere based on the Dutch National Food Consumption Survey 2007-2010 and Sociale Atlas Almere 2013 (total number of inhabitants 195,191).

Food product groep[1]	Main products	Intake Almere		
		Total	Per inhabitant	
		(1000 kg)	(kg/annum)	(g/day)
Potatoes and other tubers	Potato	5,730	29.4	80
Vegetables	fruit vegetables, cabbage, salads	7,487	38.4	105
Fruits, nuts and olives	Fruit	6,184	31.7	87
Cereals and cereal products	Bread	13,817	70.8	194
Dairy products	Milk, cheese and yoghurt	23,866	122.3	335
Eggs and egg products		1,732[3]	8.9	24
Meat and meat products	Pig, poultry, beef	6,590	33.8	92
Fish and shellfish		615[2]	3.2	9
Fats and oils	Margarine, oils	1,631	8.4	23
Sugar and confectionery	Sugar, sweets, chocolate	2,876	14.7	40
Cakes		2,567	13.2	36
Condiments and sauces		1,577	8.1	22
Non-alcoholic beverages	Fruit juices, soft drinks, coffee, tea, waters	103,463	530.1	1452
Alcoholic beverages	Beer, wine	3,444	17.6	48
Total	Solid (including milk, fats and oils)	75,678	388.0	1048
	Drinks	106,907	548.0	1501

Ad 1: derived from: Van Rossum et al, 2011

Ad 2: derived from: Davegos and Zaalmink, 2014

Ad 3: derived from: Productschap voor Pluimvee & Eieren (PPE), 2012

Some products like fish and fresh eggs were set at zero in Van Rossum et al (2011). Apparently, the registered intake per day of these products in the distinguished age groups was too low to allow to calculate an integrated total intake per day. Consequently, this study used other sources to estimate the intake of these food product groups. According to Productschap Pluimvee en Eieren (PPE, 2012) in 2012 the average egg consumption in the Netherlands was 195 per year per person. Assuming an average egg weight of 65 gram (including the shell), an annual consumption of almost 13 kg can be estimated. This includes the eggs used in industrially processed foods like bakery products. The annual consumption of fish was estimated on 4.5 kg per person (Dagevos and Zaalmink, 2014). These figures, for eggs as well as for fish, refer to consumption instead of intake. To estimate the latter the consumption was decreased with the wastage (a percentage of 30% was taken for the whole food chain, see also section wastage). This gave an annual intake of 8.9 kg eggs and 3.2 kg fish.

Primary products required

Within each food product group (as described by Van Rossum et al, 2011) a “model product” was selected. The reason to focus on model products was to reduce the volume of products in our calculation. This model product represents the food product group within this study, i.e. is the main product of that group (e.g. bread in the cereal and cereal products group). Each model product was linked to a primary product, a product which actually is produced at the farm (e.g. wheat is the primary product of bread).

Subsequently, each unit of model product correspondents with a certain amount of primary product. Table 3 shows the selected model products, their share in the food product group, the primary products and the ratio between primary and model product. For example for vegetables we distinguished three subgroups: leaf vegetables (32% of total vegetable intake), cabbage crops (31%

of total vegetable intake) and fruit vegetables (37% of total vegetable intake). As model product for these three groups we chose iceberg lettuce, cauliflower and tomato, respectively.
Sugar is processed in different food product groups. Therefore, we calculated with the estimated total annual intake of added sugars.
For some food product groups the total share of the model products was less than 1 (e.g. fruits, nuts and olives, fats and oils, non-alcoholic and alcoholic beverages). This applies to food products from which the primary products are partly to not grown in the Netherlands (e.g. tropical fruits, coffee, tea, wine).

More details on Table 3 are given in Appendix 2.

Table 3. Used model products for the food product groups in the Dutch National Food Consumption Survey 2007-2010 (Van Rossum et al, 2011) and the share n of the model product in the food product group, primary products and ratio primary product and model product. The table is elucidated in the text.

Food product groups[1]	Model products	Share of model product in food product group (fraction)	Primary product	Ratio primary product vs model product
Potatoes and other tubers	Potato	1.00	Potato	1.00
Vegetables –leaf vegetables-	Iceberg lettuce	0.32	Iceberg lettuce	1.00
Vegetables -cabbage crops-	Cauliflower	0.31	Cauliflower	1.00
Vegetables -fruit vegetables-	Tomato	0.37	Tomato	1.00
Fruits, nuts and olives	Apple	0.40	Apple	1.00
Cereal and cereal products	Bread	1.00	Wheat	0.80
Sugar	Sugar	1.00	Sugar beet	6.30[2]
Cakes	Cakes	1.00	Wheat	0.40
Fat and oils	Rape seed oil	0.15	Rape seed	2.50[3]
Dairy products	Milk + yoghurt	0.85	Milk	1.00
	Cheese	0.15	Milk	10.00
Meat and meat products	Cattle meat	0.20	Cattle meat, carcass	1.67[4]
	Pig meat	0.50	Pig meat, carcass	1.25[4]
	Poultry meat	0.30	Poultry meat, carcass	1.14[4]
Eggs	Eggs	1.00	Eggs	1.00
Alcoholic beverages	Beer	0.70	Barley	0.20
Non-alcoholic beverages	Fruit juices[5]	0.04	Apple	1.43
	Soft drinks[6]	0.11	Apple	0.14

Ad 1 derived from: Van Rossum et al., 2011
Ad 2 Based on beet sugar content of 17.5 % and a sugar recovery of 91%
Ad 3 Based on an oil content of 40%
Ad 4 Ratio carcass weight to consumable meat weight (see also Appendix 4, Table A4)
Ad 5 Excluding orange juice
Ad 6 Excluding cola and comparable soft drinks

Wastage
Food wastage occurs throughout the whole food chain. The food wastage (evitable and inevitable) in households was estimated on 18% (Van Westerhoven, 2013). This equals the WRAP study of 2012 (WRAP, 2013). The wastage and losses in other parts of the food chain is estimated at 15-20% (depending on the type of product) during primary production (farms) and 13% in the processing industry and retail (LEI factsheet, not dated). In this study losses of production at the farm were not

included because the yield levels in KWIN (2015) refer to the amount of product leaving the farm. It was assumed that losses at the farm will be reused at the farm (e.g. return to the field). For the wastage in the whole food chain from the farm gate to the intake by consumers (transport, processing, retail and households) it was assumed that 30% (10% during transport and processing and about 20% in households) is lost. As data for different food product groups were not available, this value was used for all products (plant as well as animal products). For the processing of concentrates in the feed industry a wastage of feed ingredients of 10% was assumed.
Not all the wastage leaves the system (important for the P flow calculation). In this study we assumed that all plant product waste of households is returned to agriculture via compost, because in Almere 100% of consumers' organic waste (incl. waste from gardens) is composted. For solid animal products (meat products, cheese and eggs) from households, we also assumed that 100% will return to agriculture via compost or digestate. For the liquid animal products (e.g. milk, yoghurt) it is assumed that this wastage ends up in the sewage system.

By-products
In the food production chain from primary product till consumption, by-products are being produced, like beet pulp, sugar factory lime, cheese whey and slaughter by-products. With regard to the use of these products the following assumptions were made:

- All plant by-products are returned to agriculture via feed (e.g. beet pulp) or fertilisers (digestate and compost). The produced beet pulp that is not used for local feeds is exported from the system.
- As cheese whey is not used as an ingredient for livestock feeds it is exported from the system.
- In the meat processing industry there are four types of by-products: food grade products, and category 1, 2 and 3 products. In this study it is assumed that the food grade products (mainly fat and organs) are exported, category 3 ends up in the pet food industry and category 1 and 2 are leaving the food system (destroyed). Appendix 3 elucidates the by-products of the meat processing industry.

Required area and animals required
To quantify the required amount of primary products which equals the intake of the model products, we need to know: crop yields (food and feed crops), animal production, waste and loss in the food production chain (and the reuse of by products in the food chain).

Crop production
The production of plant products (food and feed) is based on the average yield levels in the Flevopolder, which are amongst the highest in the Netherlands (CBS, 2016). In the Netherlands tomato is a greenhouse crop, yield data are not bound to the location of production. The crop data are given Appendix 4.

Production of animal products
The animal production data are derived from the KWIN Veehouderij (2015) and are summarized in Appendix 4.

With regard to meat production the following assumptions are made:

- Meat production data normally are expressed in carcass weight while this study refers to meat product intake. The conversion from meat intake to carcass weight is based on the ratio as given in Appendix 4. We use the ratio carcass to living weight to estimate the weight of living animals (necessary to calculate the P flows from the farm). Rule of thumb is that 40-65% of the living weight ends up in consumable meat.
- For beef meat we first used the meat production from milking cows and, subsequently, the meat production of veal calves (calves that are not necessary to maintain the dairy cattle). Finally, the remaining beef demand is produced via beef cattle.
- The required pork production, is based on the meat production per meat pig place. This value includes the additional meat from slaughtered sews. The number of sews is based on the average number of piglets per annum per sew.
- For poultry meat first the meat production for laying hens necessary to meet the egg demand (see hereunder) is calculated. The remaining poultry meat demand is produced via raising broilers.

The feed rations optimisation per animal place are compiled by Wageningen Livestock Research (with the feed optimisation programme Bestmix) and consist of a mix of roughages and concentrates. These rations are used in the scenarios Current and Hybrid and are given in Appendix 4. It is assumed that all roughages are being produced locally. The ingredients for the concentrates are as much as possible grown/supplied locally in the scenarios Hybrid and Current. This refers especially to the ingredients wheat, barley, grain maize, oil seed rape, molasses and beet pulp. For cattle, pigs and poultry the locally grown feeds contribute to 47%, 86% and 70% of the total amount of concentrates. The imported feed ingredients refer especially to soy bean meal, palm kernel meal and sunflower meal. In the scenario Self-sufficient the imported feed ingredients are totally substituted by locally grown feed crops. The soy meal is substituted by a mixture of lupine, peas and field beans. The assumed yield level of the seed legumes is given in Appendix 5. The palm and sunflower meal, is substituted by rape seed meal. It must be emphasized that for the scenario Self-Sufficient no (feed) ration optimisation is done (as was done for the scenarios Current and Hybrid). Therefore, the results can only be seen as a first indication.

P required
To estimate the P flows, the P content of feeds, primary products, food products and by-products of the processing industry are needed. The used values are given in Appendix 5.

4 Results

4.1 Required area

Table 4a and 4b show the area that is required for the production of the subsequent food product groups (and in total) and feed crop production, respectively, per scenario in Almere. In scenario **Current** we chose to limit the percentage regional products in the daily intake at 5%, this leads to about 1,000 ha production (52 m^2 per inhabitant). In the scenario **Hybrid** the required area increases to about 20,000 ha, of which about 85% is needed for the production of feeds (more than one third of the total area required is needed for meadows to produce grass). In the **Self-Sufficient** scenario the required area increases further to about 27,000 ha. To put this area in perspective, the southern part of the Flevopolder in which Almere (and the village Zeewolde) is situated, covers 43,000 ha. The extra area compared to the area needed in the hybrid scenario is required for the growing of feed crops to substitute the import of feed ingredients (especially protein rich ingredients as soy meal). In this scenario the required area for food production is about 1,400 m^2 per capita per year. If the area required for the production of tea, coffee, cacao, tropical fruits and wine (which are still imported) is taken into account an extra area of about 200-300 ha will be needed giving a total area for food production of about 1,600-1,700 m^2/year per resident. The required area for the imported products is based on data derived from Rood et al. (2004).

The major part of the area in the scenario **Self-Sufficient** is needed for feed production (nearly 90%). The major part of the needed area for the production of animal products is necessary for the dairy products. With regard to the required area for the production of plant products for food about 65% of the area is needed for cereals, 15% for sugar beet, 10% for fruits and about 10% for potatoes and vegetables.

Table 4a. Required area for food production (ha) per scenario in Almere (195,191 inhabitants).

Product	Area (ha)		
	Current	Hybrid	Self-Sufficient
Plant products			
Potato	8	153	153
Vegetables, field grown	6	130	130
Vegetables, tomato	0	8	8
Fruit	14	280	280
Wheat	94	1,876	1,876
Barley	5	103	103
Sugar beet	25	495	495
Subtotal (ha)	*152*	*3,044*	*3,044*
Animal products			
Milk	536	10,720	14,269
Eggs	30	606	1,138
Meat, veal calves	38	766	1,501
Meat, beef cattle	88	1,753	2,368
Meat, pigs	137	2,743	3,538
Meat, poultry	38	757	1,415
Subtotal (ha)	*867*	*17,346*	*24,229*
Total (ha)	*1,020*	*20,390*	*27,273*
Total (m^2/inhabitant)	*52*	*1,045*	*1,397*

Table 4b. Required area for feed crop production (ha) per scenario in Almere (195,191 inhabitants).

Feed crop	Current	Hybrid	Self-Sufficient
Grass	390	7,799	7,799
Silage maize	73	1,463	1,463
Wheat	90	1,802	1,967
Barley	44	884	884
Grain maize	92	1,839	1,971
Rape seed	176	3,515	7,805
Seed Legumes	2	44	2,339
Total	*867*	*17,346*	*24,229*

4.2 P flows

In the local food system three subsystems are distinguished: Agriculture, City (processing industry, retail, households) and Waste (Figure 6). In the subsystem **Agriculture** we distinguish export of produced food (net production, F1) to the city, import of feeds (F2) and an import or export of manure/fertilisers (F3). Additionally, there's a small flow to the waste system via dead animals (F5) and a flow back from waste (F4) that refers to recycled P that is used for fertilisation (compost, digestate or other recycled P fertiliser products) or feed (e.g. aquatic biomass grown on side-streams).

In the subsystem **City** food from the local agriculture (net production, F1) and imported food from elsewhere (F7) enters the system. The net production of the local agriculture (plant products, milk, eggs and living animals) and the imported food will partly be processed and finally consumed. A flow is returning to agriculture representing by-products of the processing industry that are used for feeds (e.g. beet pulp) and fertilisers (F6). Additionally, there's an export flow of by-products of the processing industry (e.g. cheese whey) and by-products from the meat processing industry (e.g. organs and fat) that are not locally used as food resource (F8). These products could be used again in the local food industry, but due to the complexity of allocating them to certain food products we assumed them as being exported from the local food system.

The major part of the P inflow leaves the city sub system to the **Waste** system (e.g. household wastage, waste water and cat 1&2 by-products of the meat industry; F9). Depending on the scenario this P is partly to maximal recycled via compost, digestate, recycled P fertiliser products (e.g. struvite, recycled P from burned ashes) or biomass that is used in the local agriculture (F4) or exported to be used elsewhere (F10). The non-recycled P leaves the (local) food system (F11).

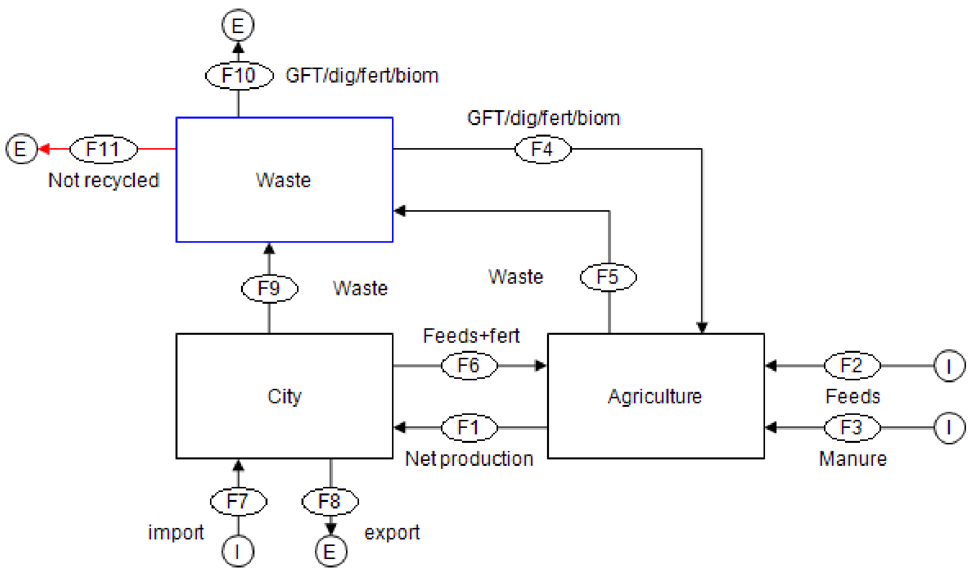


Figure 6. P flow scheme of the local food system (squares refer to the three subsystem and arrows refer to internal flows and import and export flows; flows are explained in the text).

Table 5 illustrates the P flow (with harvested products) within the subsystem agriculture in the subsequent scenarios. For plant products produced in agriculture all P taken up in the harvested products (except for loss during harvest and processing at the farm) is going to the city. For the P taken up in feed crops only a part ends up in animals and animal products that are exported to the city. The remaining part mainly ends up in manure that is returned to the agricultural land. Additionally, a small flow is leaving agriculture to waste via dead animals. The manure is an internal flow within the subsystem Agriculture and is not visible in the Figure 5 unless imported or exported.

In Appendix 5 the P flows per crop are given. For the animal products it applies to the P taken up in feed crops needed for the animal production.

Table 5. P removal from agricultural land with harvested product (1000 kg P) per scenario in Almere (195,191 inhabitants).

Product	P removal with harvested product (*1000 kg P)		
	Current	Hybrid	Self-Sufficient
Plant products			
Potato	0.2	4	4
Vegetables, field grown	0.1	2	2
Vegetables, tomato	0,1	1	1
Fruit	0.1	1	1
Wheat	2.9	59	59
Barley	0.1	2	2
Sugar beet	0.9	18	18
Subtotal (ha)	4.4	87	87
Animal products[1]			
Milk	19.6	391	479
Eggs	0.9	18	29
Meat, veal calves	1.0	21	39
Meat, beef cattle	3.3	66	81
Meat, pigs	3.7	74	90
Meat, poultry	1.1	23	36
Subtotal	29.7	593	754
Total	34.0	681	841

1 P taken up in harvested feed crops

Figure 7A-D present the P flows in the (local) food system for each of the three scenarios.

In the scenario **Current** (Figure 7A) only a small part of the food products (5%) is produced locally resulting in large import of food products. About 20% of the waste is reused via mostly household compost. About 25% of the compost is used in the local agriculture and the remainder is exported to be used elsewhere. About 80% of the P entering the waste system is not recycled.

In the **Hybrid** scenario two sub-scenarios are distinguished. In the first one (Figure 7B) the food is produced as much as possible locally except for exotic food products that cannot be grown locally. Additionally, a part of the feed ingredients is still imported (e.g. soy meal). Recycling of waste P is limited (via GFT and digestate). The latter is comparable with the Current scenario. The amount of P in GFT/digestate and the amount of non-recylced P is higher in the Hybrid scenario due to the fact that the processing of primary products to food products is now done locally resulting in higher amounts of waste. In this scenario the amount of P in GFT/digestate is completely re-used in the local agriculture. In addition, extra manure P is imported in order to compensate for the outflow of P in the net production which leaves the agriculture subsystem.
Figure 7C depicts the outcome for the Hybrid B scenario which assumes a maximal recycling of waste P. This recycling can be done by producing fertilisers or biomass (e.g. aquatic side or waste streams) from wastage and sewage sludge. It is assumed that maximal 90% of the P in waste can be recycled. In this situation import of manure is not necessary anymore. Not all recycled waste P can be used in the local agriculture in order not to exceed the permitted P application levels. The remainder is exported from the system.

Figure 7D presents the results of the **Self-Sufficient** scenario. Compared to the Hybrid scenario all feed ingredients are produced locally. In this scenario also a maximal recycling from waste P is assumed. This results in a more or less closed system. Because the P recycling from waste is less than 100% (i.e. 90%) and there is a small net export (i.e. whey and by products from meat processing), a relatively small import of P in manure/fertiliser still is necessary in order to maintain P soil fertility.

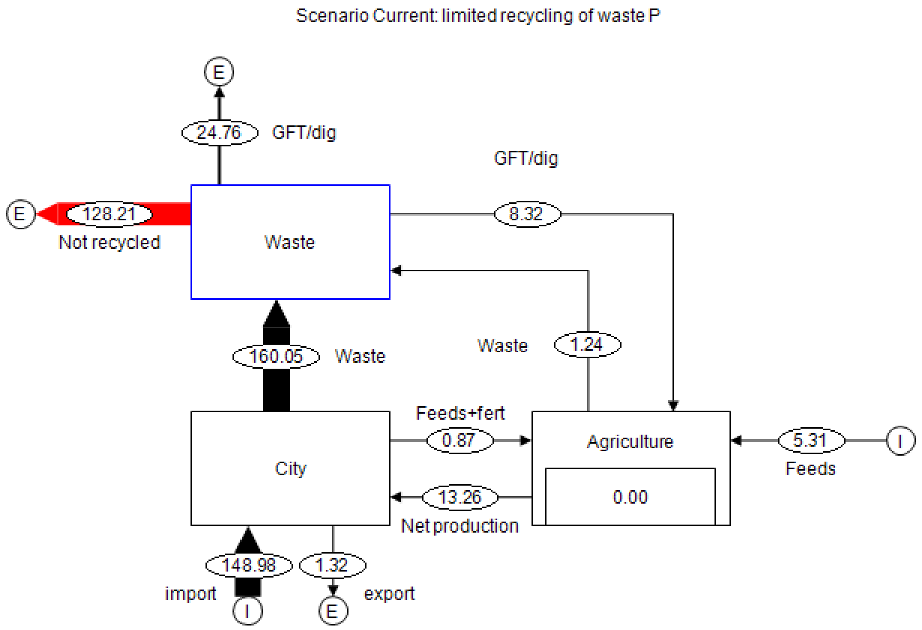


*Figure 7A. P flows (*1000 kg P) of the local food system for scenario Current with limited recycling of waste P (only recycling via GFT and digestate).*

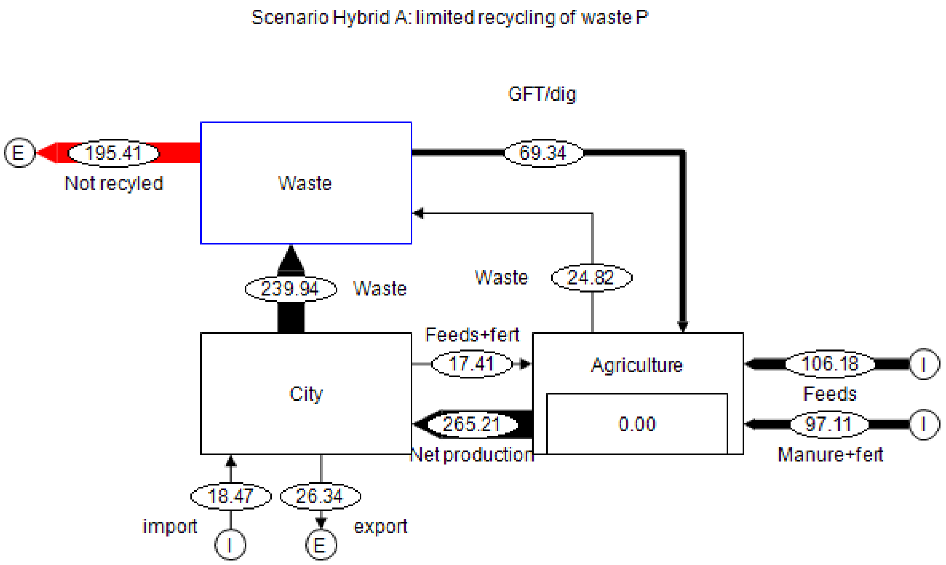


*Figure 7B. P flows (*1000 kg P) of the local food system for scenario Hybrid A with limited recycling of waste P (only recycling via GFT and digestate).*

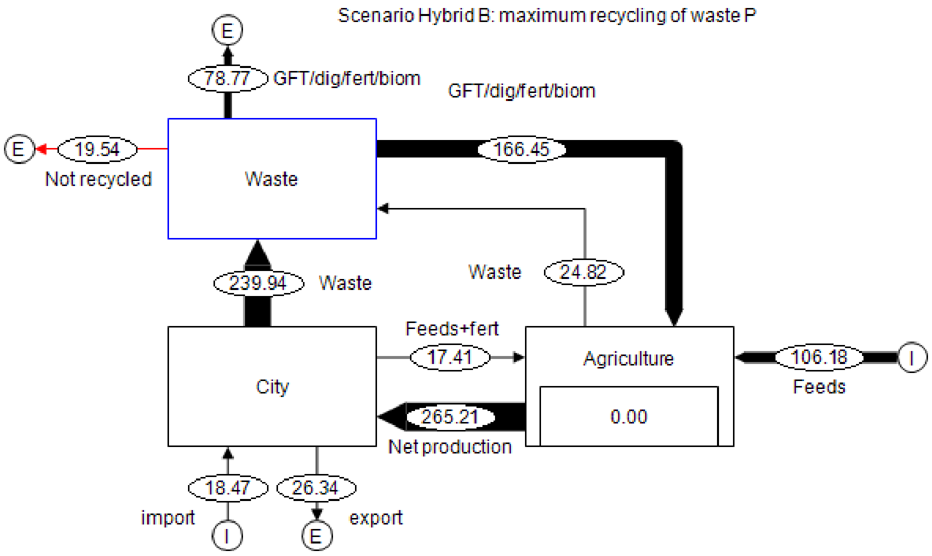


Figure 7C. *P flows (*1000 kg P) of the local food system for scenario Hybrid B with maximal recycling of waste P (via GFT, digestate, fertilisers, food or feed biomass).*

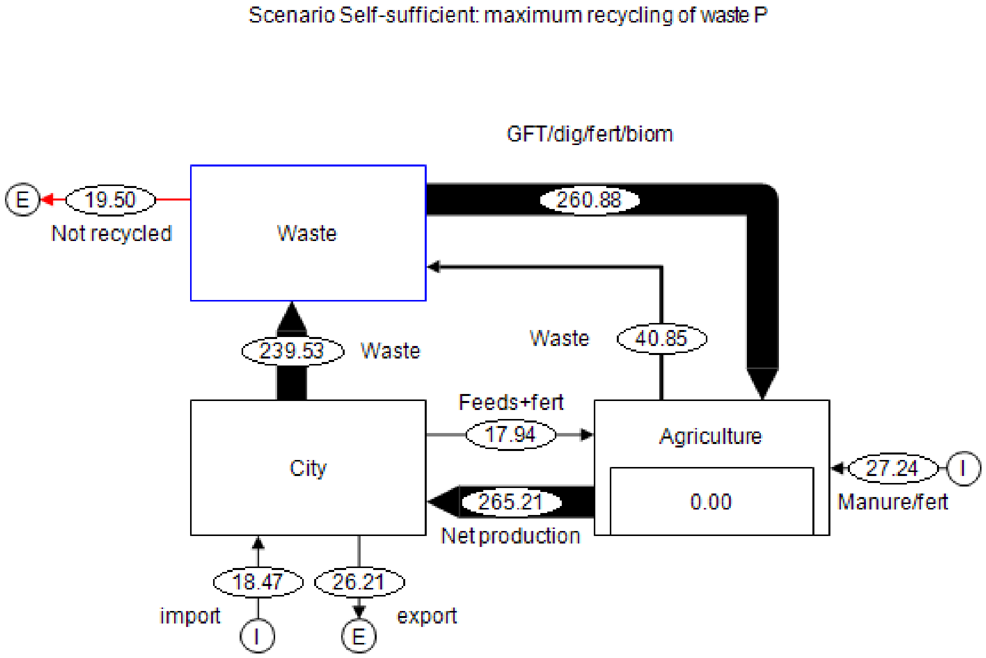


Figure 7D. *P flows (*1000 kg P) of the local food system for scenario Self-Sufficient with maximal recycling of waste P (via GFT, digestate, fertilisers, food or feed biomass).*

Table 6 summarizes the import and export of P at the level of the local food system in the three scenarios. In scenario Current almost all P is imported through food, and it leaves (the urban food system) via the sewer system as non-recycled waste. In scenario Hybrid the total P import and export is higher than in current, due to the assumption that all food is locally produced and processed. This leads to more local food production and processing thus to more P in the local food system. In the scenario Current mainly processed food enters the system, leaving the P waste in food processing outside the local food system in Almere. A higher re-use of P from the urban system (harvested out of the urban sewer) conducts in scenario Hybrid B a lower import of P (via manure). In the scenario Self-Sufficient a maximum internal flow of P is aimed at, but because it is assumed that maximal 90% of P can be recycled from the sewage, a fully circular system is not feasible. Some import of P with manure/fertilisers, besides the import of P through exotic food products like coffee, is still necessary to balance the export and (inevitable) waste. The export in both Hybrid A and B and Self-Sufficient concerns predominantly the whey from milk processing (cheese industry) and non-consumed by products from the meat processing industry like organs.

Table 6. Import and export of P (1,000 kg) in the three scenarios.*

Scenario	Import (*1,000 kg P)			Export (*1,000 kg P)				
	Feed	Manure	Food	Total	Food/ feed	Recycled waste P[1]	Non recycled waste P	Total
Current	5		149	154	1	25	128	154
Hybrid A	106	97	19	222	26		195	222
Hybrid B	106		19	125	26	79	20	125
Self-Sufficient		27	19	46	26		20	46

Ad 1) Includes compost, digestate, other recycled P fertiliser products and biomass

In short, the results show that when recycling of waste P is restricted to mainly reuse of wastage from household and processing (scenarios Current and Hybrid a), a relatively large amount of P leaves the food system unused. This non-recycled P mainly refers to P in the waste water of the sewer. This loss of P from the food system is mainly compensated by the import of P in feeds, manure and mined rock. In order to change this linearity, circularity is created in which a maximal of P is recovered and re-used in (a local) food and feed production (Scenarios Hybris b and Self-Sufficient).

5 Discussion and conclusions

The aim of this study is to develop a tool which explores local P flows in urban regional food systems. The question behind this aim is whether it is feasible to design of a circular local system, in terms of P flows in food and feed. This study connects P flows in waste with P flows in our food. The starting point was the food intake of a city region, i.e. Almere with approximately 200,000 inhabitants. From this point we stepwise (Figure 4) quantified the required area of food and feed crops to meet the estimated food consumption in Almere. When the flow of food and feed crops from field to fork is quantified, the nutrient flows from (local) agriculture to city and vice versa can be estimated too. Three types of scenarios with different assumptions, i.e Current (5% local production), Hybrid (max. local production and processing of food and partly local feed for livestock) and Self-sufficient (max. local production and processing of food and feed) where taken into account (see also table 1). The results show for scenario Self-Sufficient that a maximal local production of food in combination with a maximal P recycling (of 90%) from waste streams results in an almost circular system with regard to P. In this situation in Almere only about 46,000 kg P (or even 20,000 kg P when the by-products are also used internally) have to be imported instead of the about 154,000 kg in the scenario Current. That is a reduction of at least two third of the amount to feed a city.

It can be concluded that a combination of local food production and reuse of P from waste can result in a more or less circular food system with regard to P. Two basic assumptions are fundamental to this conclusion. The <u>first</u> is that 90% of P from waste (sewer, household and industry) could be recycled and reused in agriculture. This refers to a potential recovery percentage based on estimations of de Ruijter et al. (2015). In practice this figure is not yet realistic. However, several waste water treatment plants do recover a part of the P via struvite. In addition, two Dutch companies that incinerate sewage sludge (SNB and HVC) and a fertiliser company (Ecofoss) have agreed to recycle P from ashes to be used for fertiliser production. A question this study does not touch up on is the way P is harvested in the local context. Besides the chemical options (struvite, recovery from ashes) also biological recovery by growing aquatic biomass on waste streams (e.g. microalgae, duck weed) is a possible pathway. Additionally, reuse of P may also force a change of our sanitation and water system, e.g. source separation of urine and faeces and precipitation water in the sewage system, and a decrease in the use of household water, in order to minimise the water content of the sewage water. Water is the carrier of waste in the sewer, but the removal of water is energy consuming. The contamination with hormones and medicine residues may complicate the P recovery from the waste system. Currently, in the Netherlands a number of pilots with separate collection of urine and faeces are executed.
The question is at what level of organisation this recycling of P is most effective in a local context, in terms of environmental, economic and social impact. It is not the scope of this study to determine which processing nor scale of P recycling is the most effective or desirable. In this study we assume that P from waste is as effective in agriculture as P fertilisers from mined rock, that there are no technical, environmental and, policy thresholds to reuse P, that there are no legal restrictions and that prices are equal to other P sources. But is it in the local context and under which conditions? Moreover these conditions can change swiftly due to changes in the geo-political reality. So it is important to look for a greater diversity in P sources in our food system, but also like Cordell and White (2014) emphasize to go for other measures which can reduce the future use of phosphate rock.

The <u>second</u> assumption is that the required food can be locally produced, processed, distributed and purchased, again in an economic, environmental and socially sound way. A locally based food system, with only 15% import of food, as suggested is this study, is far from reality in the Netherlands. Some Dutch cities aim at 10% percentage of local products in the urban food basket, but this is still far from the figures in this study. Moreover, in the current food system an opposite process is taking place. This is an ongoing process of brands to centralise the processing and distribution at national and even international level. This is rendered in how consumers purchase their food; locally produced food is hardly available in their main route of collecting food, i.e. at the supermarkets. So a change to a more local oriented food system needs a fundamental change of the way food is produced, collected, processed, distributed and purchased.

Beside the recycling of P from waste (water), which is essential for closing the P cycle, there are more ways to contribute to a more sustainable P use in our food system (Cordell and White, 2014). A change to a diet with less dairy and meat, and more plant based ingredients will reduce the amount of required P in the food system. This study underlines the impact of livestock, about 85-90% of the area in the Hybrid and Self-Sufficient scenario is needed for feed production. The major part of this area is necessary for the production of dairy. The lesser land to feed the local population is needed the lesser land to fertilise. Westhoek et al (2013) estimate that a combination of halving the meat- and dairy consumptions, reduction of the wastage of food, improvement of animal welfare and a more efficient food production in the Netherlands could lead to 30% lower use of land for food production. A change of diet to more plant based ingredients also reduces greenhouse gas emissions and claims on other natural resources of our food system (Neset and Cordell, 2011). Other options are a more efficient mining process, and to increase efficiency (and decrease losses) in agriculture (Neset and Cordell, 2011), e.g. increase P fertiliser efficiency of crops or decrease P excretion by animals by decreased P levels in feeds.

An interesting next step in this research is to explore the effect of different types of diets, feeds and other options to reduce the land and P use. For example, an alternative for the substitution of protein-rich imported feeds by locally grown seed legumes and rape seed can possibly also be realized by the production of aquatic biomass as duck weed or microalgae. Roughly, the protein production per unit area is expected to be 4-5 times higher than for seed legumes (Spruijt et al., 2016). This means a lower area demand while the production does not necessarily compete with terrestrial crop production. Moreover, when the aquatic biomass is grown on waste water this will also contribute to an improved recycling of nutrients. It must however be emphasized that at the moment the production of aquatic biomass on waste water or side streams is tested in an couple of pilots, but that further improvement is necessary for large scale application. A further exploration in this direction was beyond the scope of this study.

We have to elaborate on some assumptions in this analysis:

- It is assumed that Dutch wheat has a sufficient quality for the making of bread and cakes but this may not always be the case due to growing conditions.
- Another assumption is that three model vegetable products are distinguished: iceberg lettuce, cabbage (cauliflower) and tomato, but they cover not all of the vegetables consumed. Increasing the number of model products would increase the accuracy, however, vegetable production has only a small impact on the total area demand and P-flows.
- In this study we assume that it is possible to substitute imported oils by rape seed oil. However, as mentioned before, due to the relatively high production level of rape seed (meal) for animal feed, this has no effect on the required area. The required rape seed meal in animal feeds (in Hybrid and Self-Sufficient) leaves more than enough oil as by-product.
- We assumed that all the food is consumed by the inhabitants of Almere, living within the city borders and that all the waste find its way in the Almere (sewer) system. In reality the system is not closed like that, people commute. We also left non-food industrial use and waste of P in Almere out of our calculation.
- In our calculations the area demand for the production of pet food is excluded which is not the reality. We assumed that category 3 by-products of the meat industry is used in pet food. However, these by-products are not sufficient to meet the demand of all the domestic animals. In this study only cats and dogs were taken into account, but there is a wider diversity in types of domestic animals (chicken, doves, horses etc) and also a diversity in pet food ingredients. Household animals ask also a considerable proportion of plant products corresponding with 55 and 125 m^2 per annum for a cat and a dog, respectively (Leenstra & Vellinga, 2011). For Almere this would result in an area demand for plant products for pet food of about 400 ha.
- In the Self-Sufficient scenario the import of soy meal is substituted by locally grown legumes. However, no feed ration optimisation has been done with these local legumes which may have different feeding qualities (compared to soy). Therefore, the results must be seen as an indication of the area demand.

- In the calculations the area demand for seed material (e.g. seeds, seed potatoes) was not taken into account. It is expected that the area demand for seed material is relatively small.

The food consumption is the key figure in this study. It determines the amount of P that is circulated through the food system. This study used the food intake figures from a national survey which is assumed to be representative for the population in the Netherlands with regard to age, gender, level of education, and region of residence and population density (Van Rossum et al, 2011). Results from this survey show that the consumption of fruit, vegetables, fish and fibre in the Netherlands are (far) below the recommended consumption level, i.e. 200 grams of vegetables and 200 grams of fruits a day (Gezondheidsraad, 2015). However, the intake of these products at the recommended level will not affect the outcome of this study dramatically as the demand for land for these products is relatively low. Meat and dairy consumption are the area demanding factors. Based on the national survey, the meat intake is 34 kg per person per year. Verhoog et al. (2015) estimates a meat consumption in 2013 of app. 77 kg per person per year based on carcass weight: porc 38 kg, poultry 22 kg and beef 16 kg. Using our ratio carcass to meat, this 77 kg leads to a consumption of approximately 59 kg (30+19+9.5 kg) meat product per person per year, roughly still 25 kg higher than the intake data (34 kg) in the national survey. However, the figures of Verhoog et al. (2015) are based on the meat consumption instead of intake. So, if 30% wastage in the food chain (processing and household) is assumed, an intake of about 40 kg can be calculated which is about only 5 kg higher than the data from the national survey. The Dutch dairy consumption in the national survey is comparable with other figures: 107 kg per person per year in 2010 (zuivelonline, 2016).

The national survey assumes a daily intake of app. 1,048 grams solid food per day (388 kg/365 days). How does our figures compare with others? In a Melbourne study the typical Australian diet consists of 1,210 grams of solid food (incl. dairy products) eaten per day (Sheridan et al., 2016). Compared to the Australian diet, the Dutch diet consists of less fruit, meat, sugar and fish and more dairy and cereals. Dankaert et al. (2013) mention a daily intake of about 1,220 gram of solid food per day for Flanders. Compared to our data the intake of meat, vegetables and fruits is higher in Flanders while the intake of dairy products is lower.

At the time this desk study was conducted a new national food consumption survey was published, covering the first two years of a new (2012-2016) survey period (Van Rossum et al, 2016). Compared to the period 2007-2010 a decrease of more than 10% in consumption was observed in the food product groups of ‘Potatoes’, ‘Fats and oils’, ‘Alcoholic beverages’ and ‘Dairy products’. The product groups of ‘Meat’ and ‘Cakes and biscuits’ showed a tendency to a small decrease in consumption (Van Rossum et al, 2016). The consumption of non-alcoholic beverages, condiments and sauces, and fruit, nuts and olives increased (up to 20%) in the same period. The consumption of the other food product groups nearly stayed the same. These new consumption figures will affect the outcome of this desk study, in particular the reduction of meat (app. -5%) and dairy (app. -10%) consumption. A reduction in the consumption of these products reduces the area demand and also the P flow in the food system notably. In future, the database used in this desk study can be adjusted to these new figures.

This study estimates an area demand of about 1,050-1,400 m^2 per capita land use per year (Hybrid and Self-Sufficient scenario). For the Netherlands (17 million inhabitants) this would mean an area demand of about 2,4 million ha while the current agricultural area is about 1.9 million ha indicating that with the current diet and cropping systems there’s not enough area to feed all the people.
In literature the figures of the food footprint differ between 400-800 m^2 to 3,2 ha per capita (Table 7). Van Kernebeek et al. (2015) comes with the lowest figures, i.e. 400-800 m^2 per capita land use per year. The base of their calculations was a diet fixed at a daily per capita requirement of 2000 kcal, 57 gr protein and 90 gr of sugar. The animal protein in this diet consisted mainly of milk, and beef was consumed as a co-product of milk production. It is unclear how far wastage in the whole food chain was included in their calculations. The figures of Van Kernebeek et al (2015) show that an austere diet can influence the land use efficiency dramatically. Danckaert et al. (2013) estimated in their study for the Flanders region an area demand of 1,280 m^2. In their calculations all food was produced locally (so, coffee was substituted by chicory, no import of tropical fruits), but no wastage in the processing

industry and households was taken into account. Rood et al. (2004) comes with 3,100 m^2 per inhabitant (in the year 2000), in this figure the area for agricultural infrastructure, pet foods, wine, rubber, and exotic food products (e.g. coffee, rice, tea) is included. Terluin et al. (2013) explored different scenarios for an autarky situation (no import and export) in the Netherlands. They concluded that it is possible to feed 17 million inhabitants on the current 1.9 million ha agricultural area. Depending on the scenario the area demand ranged from 500-1,000 m^2 per inhabitant. To realize this, a significant change of diet is necessary (a diet with less meat and cereal products, more potatoes and mainly chicken meat). Sheridan et al. (2016) estimate an area demand in Australia of 3.2 ha per person. This relatively high figure is due to Australia's extensive systems for beef and lamb production. In our study the area needed is relatively low compared to the other studies. This is partly due to the fact that not all food products are grown locally (e.g. tropical fruits, coffee, tea) and the high production levels of crop and animal production in the Netherlands and the Flevo Polder, which is among the highest in the Netherlands (CBS, 2016).

Table 7. The food footprint (m^2 per inhabitant) as found in different studies.

Study	Area demand (m^2/inhabitant)
Van Kernebeek et al. (2015), The Netherlands	400-800
Terluin et al (2013), The Netherlands	500-1000
Dankaert et al. (2013), Flanders	1280
Van Dijk, Jansma & Visser (2017), The Netherlands	**1400**
Rood et al. (2004), The Netherlands	3100
Sheridan et al. (2016), Australia	32000

The aim of this study was to develop a tool to calculate the P flow in urban regional food systems. Compared to other comparable studies (Danckaert et al., 2013, Terluin et al, 2013 and Van Kernebeek et al, 2015) the tool uses the real intake of food based on an average Dutch diet and not a pre-fixed diet with limited number of ingredients. The tool also includes the wastage within the total food chain, which not all studies do. The database on which the tool is based, is not finished yet. We recommend to add different types of diets to the data base, for instance diets with less dairy and or meat intake. With these different diets the restrictions of a (local) food systems could be explored, like the studies of Van Kernebeek et al. (2015) and Terluin et al. (2013). Another useful addition to the tool would be the flows of the other macronutrients nitrogen and potassium. These nutrients have in general the same route as P within the food system, but especially nitrogen is more dynamic due to gaseous emissions and biologically fixation. Also addition of other environmental parameters, like climate parameters (the use of energy or fossil fuels, food miles and greenhouse gas emissions), would be useful.

This study focuses on a change to a circular food system in a local context. A change to such a local food system will have other side effects. Synergies of such a circular food system are a potential decrease of transport (and its related nuisances like air pollution , traffic etc.), an increase of local employment in agriculture and food processing and a direct connection between society and food production (transparency). The study also underlines the complexity of a change to a local food system. A fundamental change is needed in food production. A change in type and area of crops will affect the infrastructure, organisation and economy of the agriculture. Current local agriculture in Almere predominantly focuses on crops like (seed) potato, sugar beet, onion, carrot and flower bulbs, which are the financially interesting crops. In the local food system (scenario Hybrid or Self-Sufficient) the major part (up to 85%) of the area is needed for feed production, mainly grass, silage maize, wheat and rape seed (and in scenario Self-Sufficient legumes). With regard to sound crop rotations the contribution of rape seed and sugar beet to the total arable area (plant products + arable feed crops, excluding grass) in scenario Self-sufficient, of about 40%, is too high. This should not exceed 25%. A part of the rape seed (for animal feed) can possibly be substituted by seed legumes. However, this will be limited as the contribution of seed legumes should not exceed 25% and in the scenario Self-sufficient the contribution of seed legumes is already 10-15%. If grassland is included in the crop rotation, this would improve the situation. In the current situation, feed crops are economically less attractive due to the low prices in animal feed industry. A change to a local system on the urban side will be complex too. Here, a fundamental change of the infrastructure of food is needed. As mentioned before, the current system of centralised collection, processing and distribution of food (at national or even international base) have to change to a local decentralised equivalent. It is beyond the scope of this study how a decentralised equivalent could work, what its characteristics are and whether it is sound in economic, social and environmental terms.

Final conclusion

This desk study developed a tool which calculates the P flow in urban regional food systems. The study demonstrates that, at least technically, a circular local food system based on P is possible corresponding with a food footprint of 1,400 m^2 per resident of Almere. However this circular food system requires fundamental changes in how the food chain (from farm to fork) is organised including waste management. With regard to agricultural land use this will require an increase in area for feed crop production. Because P is mainly used for food and feed production and therefore ends up in different waste streams in the food cycle, a decreased use of P (e.g. efficient use, less wastage of food) combined with recycling from waste streams is crucial for future food systems whether organized locally or not. The recycling of P from waste and the use of recycled P products in the food chain (e.g. as fertiliser, feed) needs further innovation and research. This also applies to integration of food production in the city including hydroponics and alternative biomass production (e.g. aquatic biomass, insects). The needed fundamental change of both the food and waste system raises the question if a fully local organisation of P streams is the most feasible option to reduce the dependence to P mined rock. A maximal recycling of P does not necessarily require a local food system, as long as the recycled P products are used elsewhere in a sustainable way. Research is needed to explore and compare local food production with the other options to reduce this P dependency but also to put local food systems in a broader spectrum than just in terms of P dependency.

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Annex 1 Age groups Almere

Age groups in Dutch National Food Consumption Survey 2007-2010 (van Rossum et al, 2011):

1. 7 to 8 year-old children;
2. 9 to 13 year-old boys;
3. 9 to 13 year-old girls;
4. 14 to 18 year-old boys;
5. 14 to 18 year-old girls;
6. 19 to 30 year-old men;
7. 19 to 30 year-old women;
8. 31 to 50 year-old men;
9. 31 to 50 year-old women;
10. 51 to 69 year-old men;
11. 51 to 69 year-old women.

Age groups (number per group) in Almere based on the social atlas of Almere, 2013 (Almere, 2013).

Age group	Man	Woman	Sum
<15	20,571	19,819	40,390
15-20	6,829	6,381	13,210
20-29	13,148	13,241	26,389
30-49	29,170	31,041	60,211
50>	27,195	27,796	54,991
Sum	**96,913**	**98,278**	**195,191**

In this study it is chosen to adjust the age groups in Almere (Almere, 2013) to those used in Van Rossum et al (2011) as below:

Almere, 2013		Van Rossum et al, 2011
<15	=	7-9
15-20 man	=	14-18 man
15-20 woman	=	14-18 woman
20-29 man	=	19-30 man
20-29 woman	=	19-30 woman
30-49 man	=	31-50 man
30-49 woman	=	31-50 woman
50> man	=	51-69 man
50> woman	=	51-69 woman

Annex 2 Model products and primary products for the food product groups

In Table A1 the used model products and primary products for the different food product groups are given.

Table A1. Used model products for the food product groups in the Dutch National Food Consumption Survey 2007-2010 (Van Rossum et al, 2011) and the share n of the model product in the food product group, primary products and ratio primary product and model product

Food product groups[1]	Model products	Share of model product in food product group (fraction)	Primary product	Ratio primary product vs model product
Potatoes and other tubers	Potato	1.00	Potato	1.00
Vegetables –leaf vegetables-	Iceberg lettuce	0.32	Iceberg lettuce	1.00
Vegetables -cabbage crops-	Cauliflower	0.31	Cauliflower	1.00
Vegetables -fruit vegetables-	Tomato	0.37	Tomato	1.00
Fruits, nuts and olives	Apple	0.40	Apple	1.00
Cereal and cereal products	Bread	1.00	Wheat	0.80
Sugar	Sugar	1.00	Sugar beet	6.30[2]
Cakes	Cakes	1.00	Wheat	0.40
Fat and oils	Rape seed oil	0.15	Rape seed	2.50[3]
Dairy products	Milk + yoghurt	0.85	Milk	1.00
	Cheese	0.15	Milk	10.00
Meat and meat products	Cattle meat	0.20	Cattle meat, carcass	1.67[4]
	Pig meat	0.50	Pig meat, carcass	1.25[4]
	Poultry meat	0.30	Poultry meat, carcass	1.14[4]
Eggs	Eggs	1.00	Eggs	1.00
Alcoholic beverages	Beer	0.70	Barley	0.20
Non-alcoholic beverages	Fruit juices[5]	0.04	Apple	1.43
	Soft drinks[6]	0.11	Apple	0.14

Ad 1 derived from: Van Rossum et al., 2011

Ad 2 Based on beet sugar content of 17.5 % and a sugar recovery of 91%

Ad 3 Based on an oil content of 40%

Ad 4 Ratio carcass weight to consumable meat weight (see also table 4)

Ad 5 Excluding orange juice

Ad 6 Excluding cola and comparable soft drinks

In addition to table A1:

- Within the food product group "Fruits, nuts and olives", it is assumed that not all of the model products can be connected to a primary product that is grown locally. Based on Van der Sluis et al. (2013) it is assumed that 40% of "Fruits, nuts and olives" is grown locally and 60% is imported (primarily: tropical fruits and nuts). Apple is taken as model crop (and primary product) for the group of "Fruits, nuts and olives".

- With regard to the product group "Fats and oils", in the Netherlands currently about 15% of total use is rape seed oil and 85% is imported (primarily: palm oil, olive oil, soy oil etc) (Voedingscentrum, 2016). We assumed that imported oils can be substituted by rape seed oil.
- In this study we do not allocate extra area for the production of rape seed oil (for human consumption). Rape seed is already grown as ingredient for animal feeds (see Table 5). The protein rich residue (rape seed meal) is used for animal feed, the oil is sort of a by-product. The total oil production resulting from the rape seed area needed for feed production is far higher than the rape seed oil consumption, in fact it is twice as high as the total fat and oil consumption (including imported fats and oils). Therefore, no extra area is needed for the oil production.
- This study uses three model crops in the group of "Vegetables": iceberg lettuce representing leaf vegetables, cauliflower representing cabbage crops and tomato representing horticulture fruit vegetables.
- It is assumed that the whole category of "Cereals and cereal products" is allocated to bread, the major consumed cereal containing product in the Netherlands. A value of 0.8 kg wheat per kg bread is used to calculate the amount of required wheat. For cakes also wheat was taken as primary product (0.4 kg wheat per kg cake). The eggs used in the cakes are already accounted for in the "Eggs" product group.
- Sugar is an ingredient that is part of several food product groups. To estimate the intake of added sugars (in cakes, sweets, drinks etc) this study uses Sluik et al. (2014). Sluik et al. (2014) gives a value of 71 gram/person/day resulting in an annual intake of 26 kg sugar. Based on this number the required area of sugar beet is calculated assuming a beet sugar concentration of 17.5% and a sugar recovery of 91% (i.e. 6.3 kg of sugar beet for 1 kg of sugar).
- Within the food product group "Milk products" the model products milk and cheese are distinguished. The contribution of milk and cheese to the total intake of milk products is estimated at 85% and 15%, respectively. The model product milk includes (drink-)yoghurts, custards, etc. To produce one unit of cheese, 10 units of milk are needed.
- For the meat products a distinction is made between beef, pig and poultry assuming a contribution to the total meat intake of 20%, 50% and 30%, respectively (based on Verhoog et al., 2015). The Dutch consumption of mutton, lamb, goat and others is negligible.
- This study assumes that the "Alcoholic beverages group" consists of 70% of beer. The barley demand for beer production is estimated at 0.2 kg per kg beer. The other 30% in this food product group is mainly allocated to wine and is assumed to be imported.
- The "Non-alcoholic beverages group" consist of fruit juices (7%), cola (8%), other soft drinks (11%), coffee/tea (41%) and different types of 'water' (33%). It is estimated that fruit juices consist of 45% orange juice and 55% apple and other juices (Nederlandse Vereniging Frisdranken, Waters, Sappen, 2013; www.frisdrank.nl). This study assumes that the fruit juices excluding orange juices and the soft drinks excluding cola, contain apples as main ingredient. It is estimated that 0.7 kg apple juice equals 1 kg apples and that the soft drinks contain 10% apple juice. It is assumed that orange juice, cola, coffee and tea are imported.
- We assume that the food product groups "Sugar and confectionery", "Fish and shellfish" and "Condiments and sauces" are imported except for the added sugar in it. The latter is accounted for in the total sugar consumption (see above).

Annex 3 By-products of the meat processing industry

Table A2 shows the by-products of the meat processing industry.

- The food grade “by-products” predominantly refer to organs and fats. Currently, they are mainly exported (organ consumption is not common in the Netherlands). In this study it is also assumed that this type of by-product is exported.
- The Category 1 & 2 products are not allowed to be used in the food chain and are processed and are finally destroyed. The nutrients end up in waste or in cement. The same applies to dead animals due to accidents or diseases.
- The Category 3 products are allowed to be used in the food chain. Currently, the major part is used as ingredient for pet food.
- In the Netherlands the number of dogs and cats is about 1.5 and 2.6 million, respectively (Feiten & Cijfers Gezelschapsdierensector, 2015). In the case of Almere this would mean about 17,000 dogs and 30,000 cats. Based on a daily meat demand of about 20-30 gram per kg body weight for dogs and 30-40 gram per kg body weight for cats (www.voerwijzer.com) and an average weight of 20 kg (dogs) and 3.5 kg (cats) an annual intake of 150-200 and 40-50 kg meat per animal is estimated. This corresponds with a total intake of 3.7-5.2 million kg meat per annum while the production of Category 3 material is 3.9 million kg (number of slaughtered animals x slaughter weight x fraction Cat 3). Therefore, it is assumed that all Category 3 material ends up in pet food, thus leaving the system. Because, after consumption by pets, the nutrients end up in waste or are excreted on places where reuse is not feasible.

Table A2. Relative contribution of meat and by-products in the Dutch meat processing industry (fraction of slaughter weight) (Smit et al, 2015; based on information VION).

	Meat	By products		
		Food grade	Cat 1 & 2	Cat 3
Cattle	0.38	0.16	0.20	0.26
Pigs	0.62	0.15	0.04	0.19
Poultry	0.66	0.08	0	0.26

Annex 4 Primary products

Crop production

Table A3. Yield level crops (KWIN Akkerbouw 2015 and KWIN Veehouderij 2015) and P removal with harvested product (based on yield and P content harvest product (see Appendix 5)).

Crop	Yield (ton/ha/annum)	P removal with harvested product (kg P/ha/annum)
Potato	54	26
Iceberg lettuce[1]	77	17
Cauliflower[2]	39	12
Tomato[3]	480	125
Apple[4]	50	5
Sugar beet	92	36
Oilseed rape	3.7	24
Winter wheat	9.2	31
Barley	6.7	23
Grain maize	8.8	31
Lupine	6.0	13
Peas	5.0	21
Field beans	3.5	34
Grass (grazed+silage)	10.5	42
Silage maize	16	32

1 2 cultivations per annum

2 1.5 cultivations per annum

3 Personal communication Tycho Vermeulen

4 Average of 10 varieties, based on Heijerman-Peppelman & Roelofs (2010)

Animal products

The animal production data are shown in Table 6 and are derived from the KWIN Veehouderij (2015). The used rations are given in Table A5.

Table A4. Production animal products per animal place (KWIN Veehouderij 2015) and ratio carcass to meat product, ratio carcass to living weight and ratio meat to living weight (Smit et al., 2015).

	Production/animal place/annum			Ratio meat to carcass	Ratio carcass to living weight	Ratio meat to living weight
	Milk (kg)	Eggs (kg)	Meat (carcass) (kg)			
Milking cows	8,500		99	0.60	0.64	0.38
Veal			332	0.60	0.64	0.38
Beef			277	0.60	0.64	0.38
Pork			277[1]	0.80	0.78	0.62
Broilers			11.4	0.88	0.75	0.66
Lay hens		17.1	0.8	0.88	0.75	0.66

1 production per animal place and including additional meat from sews

Table A5. Rations per animal type (kg/animal place/annum) in current and hybrid scenario. In scenario Self-sufficient the imported part is assumed to be produced in the region too.

	Milking cows	Veal calves	Beef cattle	Meat pigs[1]	Broilers[2]	Lay hens[3]
Roughages						
Grass	7,291		5,506			
Silage maize	2,197	595				
Concentrates						
Total	2,671	1,148	1,825	962	47	30
Locally supplied						
Wheat	321	138	219	269	16	10
Barley	80	34	55	202		
Grain maize	401	172	274	221	14	9
Oil seed rape meal	401	172	274	67	1	1
Legumes				5		
Dried beet pulp	134	57	91	19		
Dried molasses	84	36	57			
Fats				20	1	1
Imported	1,252	538	855	135	15	9

1 including feed for sews and piglets

2 including feed for mother animals

2 including feed for rearing hens and mother animals

The number of dead animals is based on average values for mortality as given in KWIN Veehouderij (2015). The P flow with dead animals is calculated by multiplying the number of dead animals with the average weight and P-content of dead animals. The average weight is calculated as the average of the weight at the start and at the end of the raising period.

Table A6. Percentage mortality and average weight dead animals

	Mortality (%)	Average weight dead animal (kg)
Cows	2	550
Young calves	10	25
Veal calves	3	150
Beef cattle	2	650
Meat pigs	2.4	70
Sews	5	230
Piglets, born dead	5	1.3
Piglets	15	2.8
Broilers	3.5	1.1
Lay hens	10	1.7

Annex 5 P content products

Table A7. P content primary products and food products.

Product	P content (g/kg)	Source
Plant products		Beukenboom et al. (1996)
Potato	0.5	
Iceberg lettuce	0.2	
Cauliflower	0.3	
Tomato	0.5	
Apple	0.1	
Wheat	3.4	
Barley	3.5	
Grain maize	3.5	
Sugar beet	0.4	
Rape seed	6.6	
Lupine	3.6	
Peas	4.1	
Field beans	5.7	
Grass	4.0	
Silage maize	2.0	
Imported feeds		Van Bruggen et al. (2015)
- Cows	4.2	
- Veal calves	4.9	
- Beef cattle	4.9	
- Meat pigs	5.1	
- Broilers	4.5	
- Lay hens	4.9	
Animal products		Van Bruggen et al. (2015)
Milk	0.97	
Eggs	1.8	
Living animals		
- Cows	7.4	
- Young calves	8.0	
- Veal calves	6.8	
- Beef cattle	7.4	
- Meat pigs, sews, piglets	5.4	
- Broilers	4.4	
- Lay hens	5.5	
Food products		www.voedinsgwaarde.nl
Meat, beef	2.1	
Meat, pigs	1.9	
Meat, poultry	1.9	
Bread	2.2	
Oranges	0.3	
Cakes	1.5	
Cheese	5.5	
Condiments & sauces	0.5	
Sugar and confectionery	2.1	
Beer	0.3	
Wine	0.1	
Fruit juice, apple	0.1	
Fruit juice, orange	0.2	
Softdrinks, cola	0.2	
Coffee, as drink	0.04	

To explore the potential of nature to improve the quality of life

Wageningen University & Research
Praktijkonderzoek AGV
Edelhertweg 1
Postbus 430
8200 AK Lelystad
T | (+31)320 29 11 11 1
www.wur.nl/agv

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