Circular Agriculture in Low and Middle Income Countries

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- Circular pig breeding enterprise, China
- Aquaponic farm, Egypt
- BUNCH2SCALE: Biochar-urine technology, Bangladesh
- The Ketchup Project: Value addition of tomatoes and mangos, Kenya
- Biobuu Limited: Transforming organic waste into insect-based proteins, Tanzania
- Safi Sana: Urban organic waste management, Ghana
- Ferm O Feed: Organic fertilizer distribution, worldwide

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Glossary

ADB	Asian Development Bank
BSF	Black Soldier Fly
BUNCH2Scale	Scaling-up Biochar-Urine Nutrient Cycling for Health
CBS	Statistics Netherlands (*Centraal Bureau voor de Statistiek*)
CE	Circular Economy
CSA	Climate-Smart Agriculture
CSBs	Communal Service Blocks (Ghana)
F&BKP	Food & Business Knowledge Platform
FAO	Food and Agriculture Organization of the United Nations
LMICs	Low and Middle Income Countries
MoA	Ministry of Agriculture, Nature and Food Quality
NGOs	Non-Governmental Organizations
NWO-WOTRO	Netherlands Organisation for Scientific Research - Science for Global Development (*Nederlandse Organisatie voor Wetenschappelijk Onderzoek - Wetenschappelijk Onderzoek in de Tropen*)
PBL	Netherlands Environmental Assessment Agency (*Planbureau voor de Leefomgeving*)
RVO	Netherlands Enterprise Agency (*Rijksdienst voor Ondernemend Nederland*)
SACCO	Savings and Credit Cooperative Organizations (Kenya)
SDGs	Sustainable Development Goals
SNV	Netherlands Development Organisation (*Stichting Nederlandse Vrijwilligers*)
UN	United Nations
WUR	Wageningen University & Research

Executive Summary

Circular Agriculture is a rather new concept. It has been embraced as a concept to be further promoted and developed by the Dutch Ministry of Agriculture, Nature and Food Quality. While the current focus of the Dutch agrifood sector is on how circular agriculture could be implemented in The Netherlands, this study focusses on the question what the concept particularly could mean for the agrofood sector in low and middle income countries (LMICs). We studied the available literature on the circular economy as applied to the agricultural sector and circular agriculture. Additional information was collected from interviews and consultations via e-mails. In order to identify a diverse set of cases that could help inform the understanding of how circular agriculture could work in practice, we adopted a network approach, collaborating with partners from the network of Food & Business Knowledge Platform, NWO-WOTRO, AgriProFocus, Wageningen Centre for Development Innovation and others involved in the organisation of World Food Day 2019 in the Netherlands.

The realisation of the need for change towards circularity is the result of critical reflections about the current global food system. One of the key challenges in the coming decades is to produce enough safe and nutritious food for future generations without exceeding the planetary boundaries even more. Many authors, who write about circular agriculture, are inspired by the concept of circular economy and apply it to the food system, defining principles for its application. The aim of a circular system is to use no more acreage or resources than strictly necessary. This can among others be achieved by closing resource loops. In circular agriculture, waste is seen as a raw material to produce new valuable products, including crops, food, feed and energy. Another characteristic of the concept is the need to reduce resource consumption and discharges into the environment. Each author focusses on a particular professional area or a particular part of the food system. The resulting principles do not so much contradict, but rather complement each other. Most of the principles concentrate on environmental aspects of sustainability, while the social and economic aspects remain implicit. We observed that most concepts have a rather technical approach. In many concepts, ideas on social aspects such as inclusiveness, equity and gender are not very well developed.

Several agricultural production systems can be captured under the heading of circular agriculture, including agroecology. However, some of these agricultural systems – agro-ecology in a strict sense and many traditional agricultural production systems – have much older roots and are based directly on mimicking ecological processes, without the ‘detour’ via circular economy and industrial ecology. The words ‘local’ and ‘locality’ play an important role in these ‘traditional’ systems, as do local or indigenous knowledge, culture and organisation. Some see these systems and their concepts as in sharp opposition to the ones based on industrial ecology. The novelty of circularity is its application to the whole food system, including processing and consumption. In principle this way of thinking offers many options for recycling of nutrients, elements and organic waste.

To illustrate what circular solutions could look like in practice in LMICs, we gathered and examined several case studies around the world, ranging from farm level up to international level. At farm level, we studied a pig breeding enterprise in China and an aquaponics farm in Egypt, both private initiatives. At regional level, we looked into a research project which focusses on using biochar-urine in Bangladesh. Furthermore, we studied a project, called the Ketchup Project, which aims to improve the growth, production and processing of tomatoes in Kenya. Moreover, we studied the approach of Biobuu limited that produces insect-based proteins out of organic waste from the city of Dar Es Salam, Tanzania. Also, we looked into the company Safi Sana which collects urine and facial waste, organic waste from food markets, slaughterhouses and industries to produce organic fertiliser, irrigation water, biogas and electricity in Ashaiman, a town of some 190,000 inhabitants in Ghana. At international level, we studied the company Ferm O Feed. This company purchases animal and vegetable by-products from 20 selected Dutch farms and transforms this into organic fertilizer. This fertilizer is being sold to more than 65 countries.

Based on the case studies, we found that often the companies sold various products, and the income of these products seems to make the business case economically feasible in most cases. Social benefits of circular agriculture include improved living conditions (less smell and pollution) and the creation of new jobs. The environmental benefits include better waste management, a reduced use of natural sources, lower CO2 emissions, less environmental pollution. Moreover, because of the use of organic fertilisers, soil quality and soil biodiversity can improve. Even though the social, economic and environmental effects presented in the cases seem plausible, they lack quantified robust evidence. Furthermore, in most cases circularity is not monitored.

How can a move take place towards circularity at larger scale? Based on the case studies, we have gathered more in-depth insight into the driving forces of circular agriculture. Environmental and health concerns play a role to start a circular agriculture innovation. For successful implementation and business growth, import factors are to have a good market strategy, entrepreneurial skills, access to an (international) knowledgeable network and being in the

position to receive funds for investment. Upscaling has started too, mainly through the extension of the projects by the companies or organisations involved. A transition to circularity in the whole food system is not (yet) taking place.

Challenges and risks related to starting up a circular agribusiness are identified both at production level and at system level. At production level; lengthy and/or costly registration processes for new products, a lack of knowledge about new products among potential clients, time-consuming processes to get the new circular model right. At the system level; closing a relatively unimportant cycle achieving minimal economic or environmental benefits, while other linear processes, including their waste streams, still continue, amongst others because pricing in the current food system does not incorporate externalities. Another system risk is that the use of organic waste may circulate toxic materials or pathogens in the food system. Besides, if circularity is promoted taking into account only technical and economic aspects like recycling of nutrients and building the business case, there may be negative social consequences for vulnerable groups.

It is recommended for governments in LMIC and their public and private partners to promote circular agriculture as a means to improve different objectives, including better environmental conditions, climate mitigation, public health and income generation at the same time. In the design of circular initiatives, the social, environmental and economic dimensions need to be addressed, with attention to an appropriate monitoring system as well, as in most concepts of circularity, those social aspects, such as inclusiveness, equity, youth and gender are not very well integrated. Moreover, it is recommended to include the private sector in the development of new initiatives. Also it is recommended to support and facilitate the development of circular initiatives as well as to learn from existing initiatives and additional pilots. This is needed to further explore the potential of the promising concept of circularity in agriculture and food in LMICs.

The study concludes that there is potential for governments in LMICs, and their public and private partners, to promote circular agriculture as part of an approach to foster the sustainability of the food system. This would help achieving various objectives at the same time, including less environmental pollution, climate mitigation, improved public health and better incomes for farmers and other entrepreneurs, and those -including youth or women- who find new employment opportunities in this circular agrifood sector.

Image source: Safi Sana

1 Introduction

1.1 Background

Circular agriculture is a rather new concept. One of its central principles is to use no more acreage or resources than strictly necessary to meet the demand for food and other agricultural products. This can be achieved by closing cycles (WUR, 2018). The Dutch Minister for Agriculture, Nature and Food Quality, Carola Schouten (MoA, 2019) has embraced circular agriculture as a concept that should be further developed and promoted. Until now, the Dutch discourse has focussed mostly on what must change in The Netherlands if the concept is to be implemented; indeed, the first implementation efforts are currently under way. However, as the food system is becoming increasingly globalised and not all resource loops can be closed nationally, there is a need to explore what circular agricultural could mean internationally. This study will focus on this issue, paying particular attention to the agrifood sector in low- and middle-income countries.

1.2 Justification for this study

Key stakeholders in the Netherlands, including the Ministry of Foreign Affairs are interested in the concept of circular agriculture and what it could mean within the framework of international cooperation in general and Food Security in particular. A fair number of publications on circular agriculture has been published. However, it seems to be quite unclear what the concept and its implementation should and could mean for low and middle income countries (LMIC). To fill this gap, the Food and Business Knowledge Platform has commissioned this study, in order to bring together knowledge and practical insights developed so far as regards this issue.

1.3 Objectives of the study

1. Make an inventory of ideas and concepts regarding circular agriculture worldwide, and briefly describe their meaning.
2. Make an inventory of possible impacts the implementation of circular agriculture will have in LMICs on different SDGs and on the agrifood business.
3. Document exemplary cases of circular agriculture in practice in LMICs at different levels.
4. List the benefits and challenges of circular agriculture for LMICs in detail.
5. Based on the findings from literature and on the evidence from the cases, list the benefits and challenges of circular agriculture for LMICs and conditions for successful implementation by the agrifood sector actors.

1.4 Description of methodology

We studied the available literature on the circular economy as applied to the agricultural sector and circular agriculture. During this study, we used sources from different countries and continents.
In order to identify a diverse set of cases that could help inform the understanding of how circular agriculture could work in practice, we adopted a network approach, collaborating with partners from the network of Food & Business Knowledge Platform, NWO-WOTRO, AgriProFocus, Wageningen Centre for Development Innovation and others involved in the organisation of World Food Day 2019 in the Netherlands.

The description of the concepts of circularity is based on the literature review. Additional information has been collected from interviews and/or consultations via e-mails. We have tried to collect cases from different regions, scales and type of intervention. These are not necessarily representative of all possible applications of 'circularity' in the agricultural & food sectors in LMICs. Our criterion for selection was the existence of new efforts to circulate materials that used to be 'waste'. Another very practical criterion was that the time we had to collect the information on the cases was limited. So the 7 cases are not necessarily representative of all possible applications of 'circularity' in the agricultural & food sector in LMICs.

We then combined insights from the analysis of the concepts and the cases in order to formulate the conclusions and recommendations you will find at the end of this study.

2 The Concept of Circular economy and agriculture

2.1 Justification: why is circularity needed?

The realisation of the need for change towards circularity is the result of critical reflections about the current global food system. Some of these are general reflections; others are more specific. We present a few of them here.

1. The current global food system has an enormous environmental impact. It is responsible for about a quarter of all greenhouse gases released by human activity, drives deforestation and loss of biodiversity, pollutes fresh and marine waters, and takes up 40% of the world's ice and desert-free land. The way we produce food is becoming the subject of controversy in high-income countries and increasingly across the world. There are mounting concerns about a range of issues such as farm size, farm profitability, animal welfare and the risk to human health of zoonotic diseases and processed foods (de Boer & van Ittersum, 2018).
2. The key challenge in the coming decades is to produce enough safe and nutritious food for future generations without running out of resources or destroying the Earth's ecosystems. Most scientific studies focus on producing more food with less impact. But they do not take into account the circularity of the food system (Jurgilevich et al., 2016).
3. The continued and increasing demand for products – still produced in a 'linear way'- puts direct pressure on resources. Furthermore, new ambitions in (among others) Europe to develop the bio-economy and to decarbonise the energy system (i.e. ending its dependence on fossil fuels as a response to climate change). puts even more strain on available non-fossil resources (Rood et al., 2017).
4. The reserves of easily extractable elements that are important for food production (e.g. phosphate, potassium) are scarce and diminishing; estimates about worldwide availability vary widely, from another 100 years to another 1,000. Therefore it is important to recycle and reuse them, if only because certain extractable reserves are concentrated in just a few countries or regions (Morocco, Western Sahara and China) (Burgo et al., 2019).
5. Todays' models of development are not inclusive and threaten life on the planet. In order to achieve the SDGs, a change is required in scientific, political and business thinking. Important parts and aspects of the cultural fabric of rural areas are disappearing and there is rising inequality: there are heavily subsidised rich farms unfairly out-competing poor unsubsidised farmers (Ellen Macarthur Foundation, 2018) and these differ substantially in their input-output relations and impact.
6. Our current agrifood system is based on supply chains, consisting of actors who each aim to gain the greatest economic benefit. Each party uses the raw materials at its disposal and processes these at the lowest costs and with the highest yield. However, individual parties still insufficiently consider the system as a whole. Regulation is also still mostly focused on parts of the system. This is a serious flaw, because the system contains many leaks, wastages, inefficiencies and other undesirable effects (MoA, 2018). In addition, these externalities are mostly not reflected in agricultural product prices.

The above points are valid for global and national food systems in lower, middle and high income countries. Circular agriculture is not an invention of the economically developed world; it does not originate in either Europe or The Netherlands. The concept of circularity was and is applied in many traditional agricultural systems all over the world, including in LMICs. See for example the Globally Important Agricultural Heritage Systems (FAO) or the more recent Cuban experiences with circular urban agriculture (Jones et al., 2011).

The opportunities to change to a more circular system can also be made more situation specific. For example, in many cities unmanaged waste is a big issue. If waste can be transformed into a raw material (compost, biogas) for agricultural or energy production, what is a nuisance and a health threat can turn into a source of income. Many smallholder farmers in LMICs have difficulty accessing agricultural inputs, and circular agriculture may offer alternative, more affordable options.

2.2 Circular Economy

According to Su et al. (2013), the concept of circular economy (CE) was first raised by two British environmental economists D. W. Pearce and R.K. Turner in 1990. They pointed out that the traditional economy had been developed with no in-built tendency to recycle; the environment had been seen and treated as a repository for waste. They identified the need to contemplate earth as a closed system, in which the economy and the environment are not connected by linear interlinkages, but by a circular relationship. To achieve a win-win situation for both economy and environment, they proposed a closed-loop of materials within the economy. The implementation of the circular economy started in Germany in 1996, with the enactment of the Closed Substance

Cycle and Waste Management Act. In 2000, Japan became the second country that issued a law to promote CE nationally.

Jurgilevich et al. (2016) start their thinking on Circular Economy in the Food System by describing their concept of a circular economy, as follows:

> "Circular economy uses theory and principles from industrial ecology. The aims of industrial ecology are to close the loop of materials and substances, and reduce both resource consumption and discharges into the environment. Industrial metabolism in industrial ecology refers particularly to the idea of industrial systems working as natural ecosystems. Circular economy is an industrial economy that is restorative by design and mirrors nature in actively enhancing and optimizing the systems. It applies several principles from nature: production out of waste, resilience through diversity, the use of renewable energy sources, systems thinking, and cascading flows of materials and energy. Circular economy means reuse, repair, refurbishing, and recycling of the existing materials and products; what was earlier considered to be waste becomes a resource. This concept is in contrast with the current model of "take-produce-consume-discard", which assumes that economic growth can be based on the abundance of resources and unlimited waste disposal."

Rood et al. (2017) use a slightly different description for the circular economy which can also be used to further reflect on the question what the concept could mean for food:

> "A circular economy promotes making optimum use and reuse of raw materials and products in the economy, in order to conserve natural resources. This means that natural resources are used again in a way which adds the most value to the economy and causes the least damage to the environment. This applies to non-renewable resources – such as fossil fuels and metals - as well as renewable resources, such as agricultural produce and wood (biotic raw materials). A circular economy aims to keep natural resources in the chain for longer and to prevent waste and hazardous emissions to soil, water and air, as much as possible. In a circular economy, fewer new natural resources are necessary. Often this also means that less energy is required, because the extraction of natural resources and product manufacturing uses large amounts of energy. Important goals in the transition to a circular economy include reducing environmental pressure, creating economic opportunities and ensuring natural resource security."

Van Berkum et al. (2019) presents the concept of circular economy briefly as:

> "The economic counterpart of the ecological circularity concept – stands against the linear economic model of 'take-produce-consume-discard' and entails three economic activities, to be referred to as the 3Rs: reuse, recycle and reduce existing (used) materials and products. What was earlier considered as waste or surplus becomes a resource that is (re-)valorised."

The three descriptions do not contradict each other. Rood acknowledges that there is always some residual damage to the environment in the form of hazardous discharges to soil, water and air. She also mentions 'natural resources security' as an aspect, which is an interesting additional justification for working towards the circular economy.

2.3 A range of concepts to define circular agriculture

This section provides a series of descriptions of the various concepts that are employed to describe circular agriculture or circular economy applied in agriculture. We start with a synthesis of these different concepts and then explain these concepts in more detail.

2.3.1 Synthesis of the different concepts

Circular agriculture (or circular economy applied to food systems) is based on ideas from the circular economy, which uses theory and principles from industrial ecology. Industrial ecology seeks to reduce resource consumption and discharges into the environment by closing the loop of (the use of) materials and substances.

Some agricultural production systems (especially agroecology in a strict sense and many traditional agricultural production systems) can be wholly or partially described as circular agriculture. But in spite of the modern terminology to describe them these systems have old roots and are based directly on mimicking ecological processes, without the 'detour' via circular economy and industrial ecology.

Many authors are inspired by the concept of the circular economy and apply it to food systems. They come up with principles that provide a framework for such an application. As each author focusses on a particular professional area or a particular part of the food system, the resulting principles do not so much contradict, but rather complement each other. Examples of such principles, mentioned in this chapter are:

- Optimise the use of all biomass in the food system. Circular agriculture wants to close the loop of materials and substances, and reduce resource use and discharges into the environment
- Optimum management of resources
- Optimum use of food, reducing food waste
- Optimum use of residue streams
- Optimise (not maximise) natural resource yields by circulating products, components and materials
- Recycle by-products from food production, processing and consumption back into the system
- Close nutrient loops and employ regenerative agriculture
- Foster effectiveness by identifying and then phasing out wasteful and detrimental practices
- Preserve and enhance natural capital by balancing renewable resource flows
- Recover value from organic nutrients
- Plant biomass is the basic building block of food and should be used by humans first
- Use animals for converting feedstock that humans cannot digest into high-value food for humans
- Establish new forms of collaboration between people and organisations
- Promote local and regional food systems in which resource loops can be closed (particularly in the context of urban and peri-urban areas).

Most of these principles concentrate on the environmental aspects of sustainability, while the social and economic aspects remain implicit. In other circular agriculture definitions, other aspects are mentioned as principles or important themes. These include the following:

- Celebrate local diversity by taking inspiration from nature and cultures
- Sustainable circular systems are adapted to local conditions, capacities and cultures
- Self-reliance and the proximity principle
- Low external input, regenerative systems
- Appropriate scale and technology
- Diversity, multifunctionality and complexity
- Stability, security and safety
- Local organisations to sustain circular systems
- Replace specialised and centralised supply chains with resilient and decentralised webs of food and energy systems that are integrated with sustainable water and waste management systems
- Planning based on the knowledge of local people who demand food
- Productive planning.

The words 'local' and 'locality' play important roles here, as do local or indigenous knowledge, culture and organisation. Some see these systems and their concepts as in sharp opposition to the ones based on industrial ecology. In a policy document produced by the Dutch Ministry of Agriculture, Nature and Food Quality 'local' is not embraced as a principle. However, cultural historical aspects of the agricultural landscape are explicitly mentioned as elements that will benefit from circular agriculture. Likewise it stresses the importance of the soil as basis for circular agriculture, as well as the importance of climate resilience and smart use of scarce resources such as water and land. It also enumerates some of the benefits for stakeholders. We present a summary of the policy document at the end of this chapter (section 2.3.10).

2.3.2 Emphasis on agricultural and animal production

Based on the general concept of circular economy, Jurgilevich et al. (2016) define **Circular economy in the food system** as follows:

- It implies reducing the amount of waste generated in the food system, re-use of food, utilization of by-products and food waste, nutrient recycling, and changes in diet toward more diverse and more efficient food patterns. Avoidance of food waste and surplus is also a consumption issue related to consumer food competences and skills. The loop of nutrients related to the food system can, principally, be closed. The loop of matter can be partly closed relating to the reuse of food, and the utilization of by-products and waste. Minimization of food surplus and waste reduces the overall matter consumption in the economy, thus decreasing the flow of matter related to the linear economy. The measures must be implemented both at the producer and consumer levels and, finally, in waste management.

De Boer & van Ittersum (2018) agree with this definition and refines it a little bit:

- Moving towards a circular food system implies searching for practices and technology that minimise the input of finite resources, encourage the use of regenerative ones, prevent the leakage of natural resources (e.g. carbon (C), nitrogen (N), phosphorus (P), water) from the food system, and stimulate the reuse and recycling of inevitable resource losses in a way that adds the highest possible value to the food system.

Based on this concept of a Circular Food System, de Boer & van Ittersum (2018) defines **three principles** for **Circular Food Production**:

1. **Plant biomass is the basic building block of food and should be used by humans first**. This principle implies a shift from highest yield of a single cop towards the highest total quantity and quality of whole crops and other vegetation (including of by-products like straw, leaves or stalks. The focus is not on the homogeneous, single crop but on the entire cropping system.
2. **By-products from food production, processing and consumption should be recycled back into the system.** Our food system leads to various by-products such as crop residues, co-products from food-processes, food waste and animals and ultimately also to human excreta. Our first priority should be to prevent human edible by-products and food waste. By-products that are not of immediate use for human consumption should be recycled back into the food system: beet pulp, slaughterhouse waste, animal and human excreta, unavoidable food waste.
3. **Use animals for what they are good at.** By recycling biomass unsuited for direct human consumption into the food system, animals can play a crucial role in feeding humanity. They convert biomass unsuitable for human consumption into high-quality, nutritious food, and recycle nutrients into the food system that would otherwise be lost to food production. Rather than consuming biomass edible by humans, such as grains, such animals convert so-called ‘low-opportunity-cost feeds’ (e.g. crop residues, co-products from the food industry, inevitable food losses & waste, and grass resources) into valuable food, manure and other products.

See for more information on these principles Annex 5.

2.3.3 Emphasis on the two ends of agricultural production chains

Biomass is not only used for food production but also – and increasingly - for medicines, in the chemical industry (e.g. bioplastics), construction (e.g. biomaterials), for energy generation and mobility (e.g. biofuels). More large-scale production will be necessary to create more biomass. (Rood et al., 2017) defines three requirements for a circular food system:

1. **Optimum management of resources**. Natural resources must be effectively and efficiently used and managed. Such resources include soil, water and biodiversity, but also minerals. Increased demand for biomass requires space. In the circular economy it is important to make efficient use of the scarce space available. Efficient use of minerals is another important aspect. There are considerable benefits to be gained from a more efficient management of minerals, such as nitrogen, phosphate and trace elements. With the exception of nitrogen, these elements are mined. Residue streams are created in the food industry, hospitality, retail sectors and in homes, as a result of which a large proportion of the minerals is lost (also in the air). The minerals which people consume in food mostly end up in sewers.
2. **Optimum use of food**. Reducing food waste is an important starting point in this context. A third of the food produced worldwide goes to waste. In the processing of food, residue streams are created that are not used for human consumption but fermented for energy, for example. These residue streams often contain valuable proteins, minerals and fibres. Ways should be found to use them as much as possible for human consumption. In addition, the reversal of a trend towards ever-increasing consumption of highly processed food forms part of promoting a circular food production system, as well as improved nutrition. A shift in the human diet (from animal-derived towards more vegetable-based proteins) would also fit into a circular food production system, because this requires fewer natural resources.
3. **Optimum use of residue streams**, such as tomato stalks, beet pulp and stale bread. This will result in the lowest possible loss of biomass. In an economically developed country like The Netherlands, many residue streams are already used. However, some residue streams could be put to better or more ‘high-value’ use. This means looking for the highest economic value with the least damage to the environment. Rood et al. (2017) mentions two tools for high-value reuse: the value pyramid and Moerman’s ladder. Obstacles for reuse of residue streams should be overcome. These include the

virtual absence of a market for residue streams and existing legislation, e.g. on food safety. For these, tailor-made solutions should be found. (see 'implementation pathways' in chapter 4, for examples of this).

2.3.4 Food System Approach linked to Circular Agriculture

Van Berkum et al. (2018) take the food system as starting point for thinking about the concept of circularity. They define food systems as follows:

- Food systems comprise all the processes associated with food production and food utilisation: growing, harvesting, packing, processing, transporting, marketing, consuming and disposing of food remains (including fish). All these activities require inputs and result in products and/or services, income and access to food, as well as environmental impacts. A food system operates in and is influenced by social, political, cultural, technological, economic and natural environments. The food systems approach describes the different elements in our food system and the relationships between them. It looks on the one hand at all the activities relating to the production, processing, distribution and utilisation of food, and on the other hand at the outcomes of these activities in terms of food security (including nutrition), socio-economics (income, employment) and the environment (biodiversity, climate).

This concept is used by van Berkum et al. (2019) to clarify further the concept of circular agriculture. Firstly they define circular agriculture:

- Circular agriculture is an ecological concept that is based on the principle of optimising the use of all biomass. Circular agriculture is aimed at closing the loop of materials and substances, and reducing both resource use and discharges into the environment.

Both circular agriculture and the food systems approach link in a very tangible way to a number of global challenges: climate change and water scarcity; urbanisation and shifting diets; productivity, hunger and malnutrition; deforestation & decreasing biodiversity. These challenges manifest themselves in ways and intensities that differ from one part of the world to the next. Solutions are to be found in a combination of technological and socio-economic innovations, preferably in a participatory process involving as many stakeholders as possible. These solutions call for a systemic, holistic approach. Combining the food systems approach and circular agriculture could provide useful solutions for the promotion of sustainable agriculture. The authors conclude:

- Tackling the global challenges summarised in the SDGs requires a food system approach: a focus on increasing production in order to combat hunger and poverty does not solve the problem, while promoting production efficiency often increases ecological stress instead of reducing it.
- Interventions that intend to change behaviour in order to contribute to achieving SDGs must be socially, economically *and* environmentally sustainable: a systems approach will look for solutions that benefit all three sustainability dimensions simultaneously.
- Circular agriculture is a useful means to contribute to improved natural resource efficiency, since the focus of this concept is mainly directed towards enhancing environmental sustainability. The food system approach highlights the importance of the socio-economic context, and helps to shed light on the trade-offs between intervention strategies and system outcomes on all three sustainability dimensions.

2.3.5 Circular agriculture and forestry in relation to a bio-economy in Europe

The bio-economy is often confused with the circular economy; it is another conceptual term used in the context of resource efficiency. The bio-economy focuses on the production and use of renewable biological resources and their conversion into value added products, such as food, feed, bio-based materials and bio-energy. Agriculture and forestry (and also aquaculture, fisheries and other marine biomass) are at the heart of this concept. Both the circular economy and the bio-economy require innovation and new business models. But unlike the circular economy, the bio-economy is not sustainable by default and can be linear or circular in nature depending on the choices made and the approaches taken. At an EIP-AGRI Workshop (2015) the concept of circular economy was applied to agriculture and forestry within a European context and yielded these ideas as a result:

- The preservation and enhancement of natural capital by balancing renewable resource flows
- Optimising (not maximising) natural resource yields by circulating products, components and materials
- Fostering effectiveness by identifying and then phasing out wasteful and detrimental practices
- Establish new forms of collaboration between people and organisations

2.3.6 Cities and circular economy for food

The Ellen Macarthur Foundation (2018) emphasizes the following in relation to the concept of the circular economy of food:

- A circular economy of food emphasizes the regeneration of natural capital by closing nutrient loops, as well as the potential for cascading additional value from organic nutrients as they metabolise on their journey back to the biosphere, or to be used for energy recovery.

The theory offered by the Ellen MacArthur Foundation (2018) is that shifting to a circular economy of food could lead to more economic prosperity, contribute to natural system re-building and lead to better health outcomes.

The authors state that the debate over the last decades on the need to transform the food system has focused almost exclusively on the agricultural system. However, it is clear that downstream actors, residing mainly in towns and cities are crucially important in the quest to achieve the desired food system outcome: the right food in the right place at the right time. These actors can catalyse systemic change in the urban food system and could play an important role in closing nutrient loops and reversing natural system degradation. The foundation sees a global food system in crisis and a big potential for cities to contribute towards solutions in the shape of a circular food system. But many questions have to be addressed in order to understand the potential of circular food systems in an urban context and the extent to which this could contribute to feeding the global population in a healthy way and add value to the economy.

The Ellen Macarthur Foundation (2018) names three circular economy levers that could be applied to the urban food system and subsequently contribute to a lower carbon footprint:

1. **Closing nutrient loops and employing regenerative agriculture**. Regenerative agriculture views the farm as one part of a larger ecosystem. The central concern here is the preservation of soil health. By returning organic matter to the soil in the form of composted by-products, food waste or digestates from treatment plants, organic content in topsoil increases and soil structure improves. The potential for carbon sequestration through regenerative agriculture is very significant.
2. **Recovering value from organic nutrients**. Left to rot, for example in landfills, organic matter will release methane, a potent greenhouse gas. Better management of discarded biomass can reverse this contribution, not only by reducing landfill emissions, but also by displacing carbon emitted from other processes and sources. Options are: (1) energy recovery from organic matter by the controlled production of biogas, and (2) bio refineries that convert food waste into highly nutritious feed for animals (for example insects).
3. **Urban and peri-urban agriculture.** Producing food closer to where it is consumed can reduce the carbon footprint. Long-distance food transport, which accounts for 11% of food-related emissions will be greatly reduced. The amount of food packaging, which accounts for 80% of food-related emissions, will also be reduced. Similarly, the return of nutrients to the area where food is produced will also require less transport and related energy demand and carbon emissions. Examples are: locating farms on urban roofs, harvesting water falling on the roof and the use of hydroponic systems.

2.3.7 Local diversity and community thinking

The idea of the circular economy has inspired authors to think of designing a system that can meet long-term needs (Duncan & Pascucci, 2016). The term “circular economy” has been proposed to describe an economy that is designed to be restorative and regenerative; one that aims to maintain products, components, and materials at their highest utility and value at all times. When it comes to food production, there is a risk that the term gets hijacked, diluted, and employed as a form of “green washing.” To avoid this, the authors see a need to develop clear design principles that address the deep-seated problems of how we grow, produce, and consume food. Short of providing a complete definition of circularity in food systems, the authors state that designing a circular economy means designing food production systems that do more than recycle their constitute parts. What is needed are design processes that are restorative and build greater resilience and flexibility into the system. They define three principles:

1. **Waste is food.** This means that a product has to be designed in such a way that the use of hazardous and toxic materials is eliminated (in one word: “eco-effectively”). In an ideal situation, a circular design treats materials as nutrients for the metabolisms, keeping their properties pure, and adding value(s) derived from the knowledge and labour applied for their usage. Organic agriculture, agroecology, and permaculture are all examples of agronomic approaches that consider the natural cycles of these elements and aim to avoid using them in any kind of fossil forms. Also incorporated in a circular design of the product is a plan for how residual components will be used by other actors or processes.

2. **Use renewable energy**. This principle is meant to inspire a rethink of the type of energy used in the food production process.
3. **Celebrate diversity.** This means understanding the effect that the metabolism of materials has on local diversity and how we can integrate community thinking and cultural diversity into the design process. It implies using larger varieties of species and using local varieties that have adapted to the microclimatic conditions. In socio-economic terms, celebrating diversity is connected to fair practices along the food supply chain, including a careful assessment of competition between use of land for food or non-food crops. More in general this implies a conscious assessment of any competing issue related to use of natural resources that may hamper food security. Celebrating diversity as a principle must also address questions such as ownership of natural resources. Within circular design, the management of natural resources should be possible through the commons and public goods, providing opportunities for local people and communities to lead and monitor these processes.

The authors observe that there is limited application of these principles in food production. As a concept, the strength of circularity in food systems lies in the way it demands structural changes. In practice, deep social and scientific engagement and discussions at all levels of a society are required if its strength is to be maintained.

2.3.8 Circular systems based on social and ecological systems thinking

Jones et al. (2010) state the following:

> "An alternative to the current linear paradigm is to develop productive systems that minimise external inputs, pollution and waste (as well as risk, dependency and costs) by adopting a circular metabolism. There are two principles here, both reflecting the natural world. The first is that natural systems are based on cycles, for example water, nitrogen and carbon. Secondly, there is very little waste in (undisturbed) natural systems. The "waste" from one species is food for another, or is converted into a useful form by natural processes and cycles.
>
> The archetype of a sustainable system is a closed life cycle, like that of an organism. It is ready to grow and develop, to build up structures in a balanced way and perpetuate them, and that's what sustainability is all about. Closing the cycle creates a stable, autonomous structure that is self-maintaining, self-renewing and self-sufficient. In order to do that, you need to satisfy as much as possible the "zero-entropy" or "zero-waste" ideal. The zero-waste or zero-entropy model of the organism and sustainable systems does allow for growth and development, but in a balanced way, as opposed to the unbalanced, infinite growth of the dominant (linear) model. This immediately disposes of the myth that the alternative to the dominant model is to have no development or growth at all. Sustainable circular systems minimise fossil fuel use and greenhouse gas emissions. Such systems develop reuse and recycling systems at the local level and avoid chemicals, materials and items that are difficult to reuse or recycle (sustainably) or that are toxic."

According to Jones et al. (2010), these sustainable systems are very different to those in the industrial, globalised, fossil fuel world view. The way that these systems are implemented, at times integrated with conventional systems, varies enormously. However, common themes are:

a. self-reliance and the proximity principle[1]
b. low external input, regenerative systems
c. appropriate scale and technology
d. diversity, multifunctionality and complexity
e. stability, security and safety
f. high levels of reuse and recycling so that a large proportion of resources and "wastes" remain in the system or locality
g. local organisations to sustain circular systems

To all this, Pimbert (2015) adds that in circular production systems, specialized and centralized supply chains are replaced with resilient and decentralised webs of food and energy systems that are integrated with sustainable water and waste management systems. Circular systems can be developed at different scales, by using functional biodiversity, ecological clustering of industries, recycling, or by re-localising production and consumption.

[1] Under this principle, a large proportion of the goods consumed both in and out of the home are produced using low external input techniques and renewable energy. What remains of these goods would then be reused or recycled. The products that cannot be supplied by local producers are sourced within the district or province or through fair trade initiatives.

These rural and urban systems are often characterized by agroecological approaches, eco-design, a focus on “doing more with less”, widespread recycling/reuse and moves towards making both production processes and supply chains as local as possible, thus avoiding (long-distance) transport. Circular systems aim to reduce carbon and ecological footprints whilst maintaining a good quality of life through a controlled process of de-growth in consumption and production based on the ‘8 Rs’: Re-evaluate, Re-conceptualize, Restructure, Redistribute, Re-localize, Reduce, Reuse, Recycle. For Pimbert (2015), this means that the concept he elaborates is fundamentally different from mainstream development pathways.

2.3.9 Circular economy, agriculture and planning

Burgo et al. (2019) consider the concept of a circular economy as a sustainable alternative for the development of agriculture. The authors do not come up with a clear-cut definition of circular agriculture or circular food systems but link the concept of the circular economy to sustainability. They promote a model that includes economic, environmental and social dimensions necessary to achieve sustainable development throughout the cycle of production, distribution, change and consumption. They emphasize a more holistic approach based on flows of energy, materials, water and soil, as well as the reduction in emissions of carbon dioxide and other greenhouse gases, which are potentially harmful to human health. Sustainability is inconsistent with the non-sustainable linear model. They mention important social demands that relate to food, such as health. Ecological requirements are e.g. the preservation of natural resources, in correspondence with the needs and opportunities of rural communities. The authors from Cuba and Ecuador come up with a model where planning, organisation and implementation form the basis for the introduction of a circular economy in the agricultural sector:

> **Productive planning** is based on the knowledge of the local people who demand food with an assessment of possible surpluses according to productive possibilities and capacities. This information then helps to define how much land should be prepared for cultivation. Taking into account the variety of the products, the sowing is then planned and an estimate of the harvest is made.
> **Productive organisation** involves the agroecological processes, emphasizing all the tasks of cultivation and care for the soil. This implies taking into account the organization of the energy flows; material cycles, sequence and diversity in the agro-ecosystem. All elements for the organization of the work are also established. These include working schedules, ways of organizing the labour force and the distribution of inputs for work.
> **Productive application** includes among others: the carrying capacity (in terms of propagation, planting, harvesting), natural integration within a balanced environment (soil fertility, appropriate pest control, the integration of agro-diversified ecosystems and self-sustained technologies) and the control and regulation of the process. Finally, the land must be prepared for the next harvest.

This description seems to focus mostly on local production. It does not take into consideration the whole food system. However, the connection to sustainability brings in social aspects that tend to receive less attention. The proposal is oriented towards planning and may run counter to the idea of a market economy, even though it should be noted that a country like Cuba has made important achievements as regards circular agriculture (see Annex 3).

2.3.10 Circular Agriculture in a national policy document

In a recent policy document on circular agriculture, the Dutch government mentions the following characteristics (MoA, 2018):

- “In a circular agriculture system, arable farming, livestock farming and horticulture primarily use raw materials from each other’s supply chains and waste flows from the food industry and food supply chains. These circular chains can be structured in various ways: within a company, a region, the Netherlands or across national borders. The motto is: do it locally if you can, and regionally or internationally if you have to. Residues from the agricultural sector and the food supply chain (crop residues, food residues, process waste, manure, compost) are re-used or re-processed into new (auxiliary) products. Circular enterprises use as little energy as possible, and the energy they do use is renewable as much as possible. Cattle are fed primarily with grass, feed crops or crop residues from the farm where they are kept or from the immediate vicinity, as well as with residues from the food industry. This will strengthen land dependency – the link between business operations and the land available for agriculture – and allow entrepreneurs to take better account of the cultural historical value of the landscape. Soil management works towards applying processed animal manure while steadily reducing artificial fertilisers. That way arable land and pastures receive high-quality organic fertiliser based on crop residues or manure.

- This will ensure that the currently still significant role for artificial fertiliser keeps diminishing. Putting an end to the use of artificial fertiliser based on scarce fossil raw materials (phosphate, potassium, natural gas) will also further reduce greenhouse gas emissions from the production of artificial fertiliser. The soil forms the basis for circular agriculture. Soil management is a reciprocal process: human activity removes minerals and water from the soil for production and feeds the soil with organic materials, water and nutrients to maintain growing power. Good soil quality requires a balanced and responsible use of fertiliser and plant protection products, sophisticated farming plans and processing with machines that are geared to the cultivation capacity of the soil. As a result, not only will the soil contribute to higher yields, it can also serve as a buffer for extreme weather conditions. Soil that contains a high level of organic matter can absorb water much more efficiently and is more resistant to drought. Moreover, such soil can retain more nitrogen and minerals, hosts a more diverse range of soil life and contributes to healthy crops."

These characteristics of circular agriculture are further elaborated for different subsectors like livestock farming, crop farming, horticulture, nature and agriculture, regional scale and fisheries. The vision on circular agriculture also comprises components that are not immediately tied in with technicalities. These include a vision on agricultural entrepreneurship, valuing food (by consumers) and international aspects.

Agricultural entrepreneurship
There are several ways to implement a circular approach in agricultural entrepreneurship. Entrepreneurs may apply environmental or animal welfare standards in their production processes that go beyond the regulatory requirements. They may also form new partnerships, organising themselves in new ways. Young people may be given extra attention when they are poised to take over a business. The shift in thinking – from lowest possible cost price towards minimum possible use of raw materials - will require banks to reconsider their financing role.

Valuing food
Consumers need to know that the production of the food they eat has a major impact on the environment. This requires new thinking and purchasing behaviour. The majority of consumers still choose low price and high convenience food and this needs to change, as well as their food wastage. Finally, the public profile of farmers and cultivators in the vicinity of a town or city needs to be improved.

International aspects
Markets are international and circular systems can and do extend across national borders. Government action could address this, by promoting sustainability and climate resilience in international agrifood investments, placing a favourable leverage effect on international environmental and nature-related goals and on biodiversity. The idea is to bring in Dutch expertise and innovation, where relevant, in order to help tackle specific problems such as salinisation, drought and erosion. Dutch expertise can also be brought in to sustain further efforts in the areas of innovation, training and knowledge dissemination with regard to the process of change towards circular agriculture. Finally, laws and regulations within the EU framework may be reconsidered, while circular agriculture could be used as an important strategy to achieve SDG2.

3 What is new in comparison with comparable concepts

This chapter compares the concept of circular agriculture with a number of other key concepts regularly referred to in the discourse about sustainable agriculture.

3.1 Agroecology

Agroecology was mentioned in scientific literature as early as the 1920s. It first found expression in family farmers' practices, social movements and national public policies and more recently in the discourse of international (UN) institutions. Agroecology is an integrated approach that applies social and ecological concepts to design and manage food and agricultural systems.

Agroecology is fundamentally different from other sustainable development approaches as it is based on bottom-up processes, it is based on the co-creation of knowledge, combining traditional, practical and local knowledge with science. This approach empowers communities and producers as key agents of change.

The FAO recognises 10 elements of agroecology, that are interlinked and interdepend. A report on regional FAO seminars about these elements concludes the following (FAO, 2017):

- Common characteristics of agro ecological systems are diversity, synergies, efficiency, resilience, recycling, co-creation and sharing of knowledge.
- Context features include human and social values and culture and food traditions.
- Enabling environment consists of responsible governance at different levels, plus a circular and solidarity economy.

Seen in this way it would appear that agroecology is closely related to circular agriculture and/or circular economy in food systems, although agroecology has a stronger emphasis on the social aspects, such as co-creation, sharing of knowledge and human and social values.

3.2 Climate Smart Agriculture

The FAO (2013) defines climate-smart agriculture (CSA) as follows: it contributes to the achievement of sustainable development goals (SDGs). It integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars:

- sustainably increasing agricultural productivity (food availability) and farmers' incomes
- adapting and building resilience to climate change (adaptive capacity and resilience)
- reducing and/or removing greenhouse gas emissions (mitigation potential)

CSA wants to develop the technical, policy and investment conditions that are necessary to achieve sustainable agricultural development for food security under the challenging conditions of climate change. Coordination across agricultural sectors (e.g. crops, livestock, forestry and fisheries), and with other sectors (energy, water) is essential. CSA takes into consideration the social, economic, and environmental context. It is, as a result, an integrated approach that is responsive to specific local conditions. In recognition of the fact that achieving food security goals and enhancing resilience requires the involvement of the poorest and most vulnerable, CSA engages women and other marginalised groups.

Both circular agriculture and CSA are integrated approaches. They focus on minimising greenhouse gas emissions, while CSA also pays attention to the landscape in which agriculture is taking place. Other differences include these points:

- CSA focuses primarily on the production side of the value chain. When the concept was developed, it did not take into account food processing and consumption; this is gradually changing.
- Although CSA has been built on the concept of sustainability, it does not emphasize the need to close nutrient cycles.
- There is even a risk that CSA could be applied in a way that is environmentally unfriendly. Along with environmentally friendly agroforestry and intercropping practices, CSA can also encompass the promotion of herbicide-tolerant crops, the (over)use of insecticides and fungicides, energy-intensive livestock factory farming, and large scale industrial monocultures and biofuel plantations (Pimbert, 2015).

3.3 Sustainable food and agriculture

The FAO has defined 5 principles of Sustainable Food and Agriculture[2]:

1. Increase productivity, employment and value addition in food systems
2. Protect and enhance natural resources
3. Improve livelihoods and foster inclusive economic growth
4. Enhance the resilience of people, communities and ecosystems
5. Adapt governance to new challenges

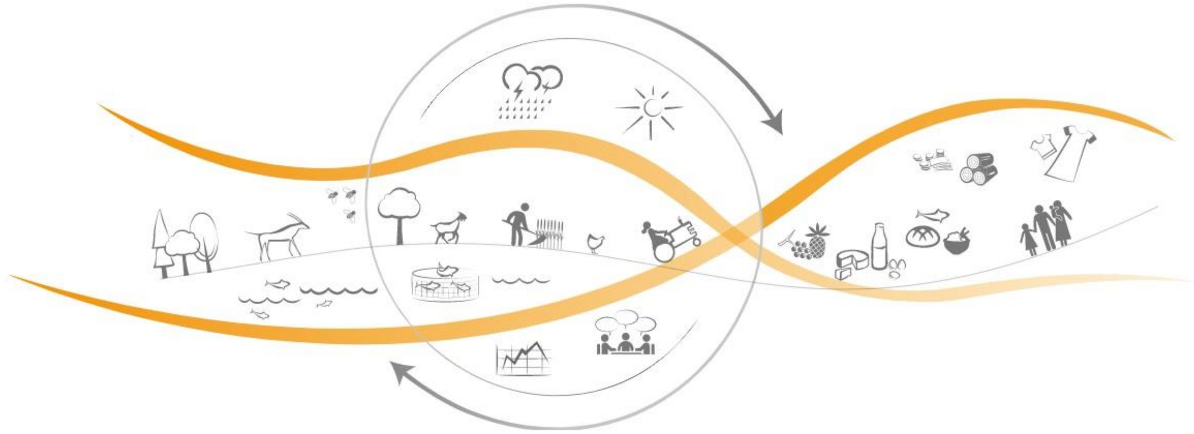

Figure 1. The 5 principles of Sustainable Food and Agriculture (FAO)

"Sustainable agriculture" was addressed by US Congress when it passed the 1990 "Farm Bill". Under that law, "the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term[3]:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

It can be concluded that in contrast to “sustainable agriculture” the concept of circularity has a very focused result area within the domain of broader sustainability goals: there should be recycling of nutrients and waste is not waste in the sense that it can be thrown away. Waste is an input for a new cycle.

[2] Source: http://www.fao.org/sustainability/en/ accessed 12 August 2019
[3] Source: https://www.nal.usda.gov/afsic/sustainable-agriculture-definitions-and-terms#toc4

4 Cases of circular agriculture in LMICs

Moving beyond theory, this chapter presents a diverse set of case studies from different parts of the world that show interesting facets of circular agriculture. We begin with cases at farm level, then move to the municipal and national levels and we end this chapter with cases at the international level. Each case description contains information about the economic, environmental and social aspects, as we believe this will give us insight in the opportunities and challenges of circular agricultural systems within the framework of sustainable development. We have selected cases in which resources are reused and recycled, while acknowledging that non-circular agricultural models can also contribute to circular agriculture or a circular food system. For example, some business models use renewable energy or develop new forms of collaboration to avoid dependency on finite resources; other business models use big data, block-chain or mobile applications to improve efficiency.

4.1 Circular pig breeding enterprise, China

4.1.1 Summary of the case

In China's Jiangxi province, in Pingxiang City, there is a pig breeding enterprise. Established in 2004, the farm covers approximately 365 ha. The enterprise originally followed the traditional model of linear production but as the farmer was facing several challenges (explained below) he decided, in 2015, to re-design the entire one-way flow of linear production (resources–products-waste) and build a circular organic production system (pig–biogas–feed for pigs/fish or pig–biogas-bamboo). The new production system takes biogas production as its central point (Figure 2). Biogas, a high-methane fuel, and biogas slurry, an organic fertilizer, are products of the pig manure anaerobic digestion. This description is based on Zhu et al. (2019).

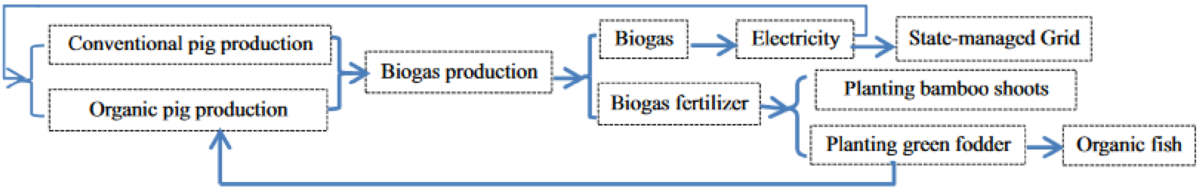

Figure 2. Schematic overview of the circular pig farm.

4.1.2 Economic aspects

At first, under the conventional system a significant portion of the farm's natural resources such as land and water were underused. To improve the situation, the farmer did some trials using biogas slurry, which can be used as an organic fertilizer for agricultural production. However, these practices resulted in unhealthy foodstuffs, like fish that turned out to be potentially poisonous or tea and herb medicine of poor quality. The farmer was also losing money due to the low margins on pig meat, a consequence of a combination of two things: the low price per kilogram conventional pig meat fetches and the high costs per kilogramme of manufactured synthetic feed. In the 2012-2013 production year, the farmer lost approximately €450,000.

In 2016, one year after the transformation into a circular system, the farm became profitable. There are several reasons for this: 1). selling organic, high quality pig meat, bamboo and fish at a premium price and 2). ending the purchase of expensive inputs such as chemical fertilizers and electricity. Replacing chemical fertilizer with organic fertilizer resulted in savings of approximately €10,500 (in 2015) and €37, 300 (in 2016). The farm is also projected to produce 430,588 kWh of generated power from biogas in 2025 (Figure 3).

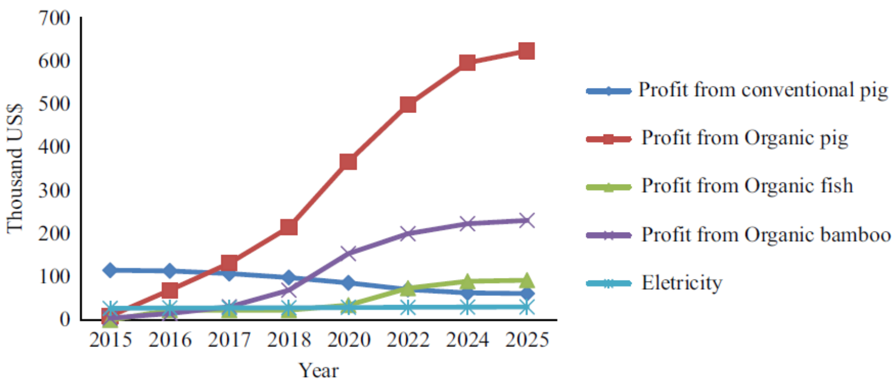

Figure 3. The projected profit from conventional and organic products.

4.1.3 Environmental aspects

Recycling energy and reusing agricultural resources has significant environmental advantages, reducing as it does the dependency on finite sources such as grid-delivered energy and artificial fertilizers. Another advantage of this production system is that the biogas slurry is used to grow crops like bamboo, which is a plant that can purify air and restore soil fertility (Mishra et al., 2014).

4.1.4 Social aspects

Due to the farm's circularity, the sanitation conditions have improved. There is now cleaner water and air, due to the anaerobic digestion of pig urine and manure, which otherwise produces bad odours and pollution. Moreover, the farmer provides his neighbours with manure for biogas production so they can produce their own energy and fertilizer in an organic way, too. Finally but crucially, the farmer also provides more full-time and part-time jobs.

4.1.5 Scale of implementation

The initiative started at farm level, but is slowly scaling up to village level as the neighbours now receive manure for their biogas digester and fertilizers from the pig farmer.

4.1.6 Implementation pathways

Around 2013, the Chinese government tightened the regulations for the pig industry and obliged farmers to reduce their negative environmental impacts. In response to these new regulations and encouraged by a grant from the government and technical support from a Chinese university, the pig breeding enterprise we feature here was able to replace its traditional production approach with a circular one.

While the adoption of a circular approach was triggered by government's concerns about the environment, its success ultimately lies with the farmer's entrepreneurial skills and his ability to make the farm economically profitable using these new production methods. This involves, among many other things, a certain perseverance in the search for additional ways to use "waste", diversifying the range of products he sells in the process. The farmer constantly explores new market opportunities as a result of his decision to take financial risks.

To scale up circular agriculture and also get the risk-averse farmers on board, the government and other players can take the following actions: (1) cover some of the initial costs through financial support - for example subsidies, (2) offer access to market information – trends, demand, movements on the organic market, (3) provide technical support, (4) offer stable prices for organic products, (5) address market failures (e.g. ensure the opportunity to sell biogas to the state-run grid).

4.2 Aquaponic farm, Egypt

4.2.1 Summary of the case

In Egypt's Giza governorate, in Sheikh Zayed City, a single farmer financed and designed his own aquaponic farm and called it Bustan Aquaponics. The farmer, who used to be a banker in London, decided to invest in an agricultural project when his wife became pregnant. He started thinking about healthy food for his child and believed that there was a lack of pesticide-free food in Egypt. This triggered him to follow a training in hydroponics abroad and then establish his farm.

He cultivates Nile tilapia, lettuce, spring onion, endive, basil, pak choi, watercress, tomatoes, beans and chili peppers. He also grows olive trees and duckweed on the sludge he collects, which, in its turn, serves as fish feed. The aquaponic farm was established in 2011 on 1000 m2 of land. It consists of two greenhouses made of fine meshed netting material. This case study is based on van der Heijden et al. (2013).

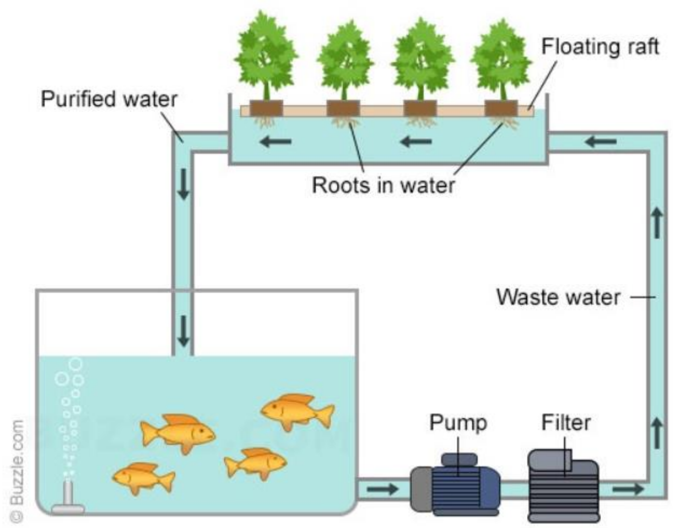

Figure 4. A systematic overview of an aquaponic system (Gardenerdy, 2019).

Aquaponics is a bio-integrated system linking recirculating aquaculture with hydroponic vegetable and herb production. Nutrient waste such as fish manure, algae and decomposing fish feed is used as liquid fertilizer for hydroponically grown plants which, in their turn, function as bio-filters, so that the water can be recirculated into the fish tanks (Figure 4). Before the water from the fish tanks enters the area where the plants are growing, it is filtered to remove big particles that can potentially clog the system.

4.2.2 Economic aspects

The economic advantage of this circular system is that vegetables and herbs can be sold at a premium price, because they are grown without pesticides and artificial fertilizers. Currently, the farm sells its produce to the general market, but the option to directly sell to consumers is being researched. The system is very space-efficient: herb and vegetable production from the total vegetable basin surface of 225 m^2 is at least equal to that of 500 to 600 m^2 of land. Another advantage of this production system is that it requires relatively little water, enabling the farmer to cultivate plants throughout the year.

4.2.3 Environmental aspects

As this farm is circular and controls pests and diseases biologically (for instance by using insect traps, natural predators and companion planting), it does not generate any (toxic) waste products that can end up in the environment. The sludge that is filtered out of the water coming from the fish tanks is used to fertilize and water the surrounding olive trees and duckweed. This farming system circulates its water so that it barely extracts water from surrounding natural sources.

4.2.4 Social aspects

In the future, the farmer would also like his farm to play an educational role; he would like to regularly have an open house on his farm for adults and (school) children, in order to inform them about the production process and give them the opportunity to plant, harvest, cook and taste “their own” vegetables.

4.2.5 Scale of implementation

At the moment, Bustan Aquaponics consists of one module, which serves as a pilot where design and operations are tested and developed. The company’s aim is to have 6 modules with an expected production of 30-40 kg of fish, 150,000 heads of lettuce, 40-50,000 bunches of chives, basil and other products. Also, the set-up of a fish hatchery to produce fingerlings and a nursery to grow seedlings is foreseen.

4.2.6 Implementation pathways

To start up an aquaponic farm of this size, heavy hydroponic infrastructure is required (Goddek et al., 2015). In this case, all the necessary materials were funded by the farmer himself (approximately US $ 50,000), pointing towards the necessity of having both the financial means and the entrepreneurial drive to create such an infrastructure (Van der Heijden et al., 2013).

Moreover, the farmer actively researches on how to optimize the farming system; he is – for instance - looking into installing a solar heating system and optimizing the insulation of the greenhouse to improve the production in the winter, as the fish operation almost comes to a stand-still due to the low temperatures (17 ℃). He is also testing other (combinations of) fish species and vegetables and fruit, e.g. strawberries.

4.3 BUNCH2SCALE: Biochar-urine technology, Bangladesh

4.3.1 Summary of the case

Since 2017, a research project, co-funded by the Netherlands Organization for Scientific research, is exploring the benefits of biochar-urine fertilizer to improve food security and nutrition among small-scale farmers, especially targeting women and young children in rural Bangladesh. For three consecutive years, training will be conducted in 1,200 households in 48 villages, organizing women into groups of 10-15.

Urine is a highly efficient fertilizer, but it is underused, due to its odour. The project tested a method to transform urine into a solid, odourless fertilizer by allowing it soak into a porous material, such as biochar. The biochar used in the pilot was produced from crop waste in soil-pit kilns. This description is based on (Waid, 2018) and (Waid et al., 2018).

4.3.2 Economic aspects

Using biochar-urine is economically an interesting option as it decreases production costs, reduces the need to buy fertilizer externally and improves soil fertility, resulting in a yield increase. As part of the project, 134 farm trials have been set up. During the trial, yields from crops produced in biochar-urine enriched soils were compared to crops grown on soil to which this fertilizer had not been applied. The results showed a yield increase of more than 100 percent.

4.3.3 Environmental aspects

Biochar-urine improves soil quality as it increases soil organic matter, biological activity and the water-holding capacity of the soil. It also contributes to climate change mitigation as it sequesters carbon and avoids the use of chemical fertilizers.

In view of ongoing climate change, this project is strengthening farmers' resilience through the increase of the soil's capacity to retain water, which diminishes the effects of a long dry period. In addition, growing a diverse range of crops reduces farmers' vulnerability to extreme weather conditions.

4.3.4 Social aspects

This project is stimulating the use of urine-biochar in homestead gardens, a female domain, without having to go to the market, a male domain in Bangladesh. The project also stimulates the consumption of a diverse range of home-grown fruits and vegetables that can enrich diets and contribute towards reducing malnutrition[4].

4.3.5 Scale of implementation

The biochar-urine technology was introduced in nine villages. Numerous small-scale farmers were involved in the project. It will gradually be expanded, in order to further test feasibility.

4.3.6 Implementation pathways

Research to pilot innovative solutions is funded by WOTRO, the Science for Global Development department of NWO (the Netherlands Organization for Scientific research). BUNCH2Scale plans to scale up biochar-based organic fertilizer production to 48 villages in rural Bangladesh. Together with local NGO field workers and research institutions, the project will evaluate the potential of this novel fertilization method.

4.4 The Ketchup Project: Value addition of tomatoes and mangos, Kenya

4.4.1 Summary of the case

In a village in Makueni county, Kenya, farmers started to collaborate with a Dutch enterprise in 2015, with the aim to produce ketchup and thus, indirectly, reduce post-harvest losses. Approximately 40% of Kenyan tomatoes goes to waste after harvest as a consequence of logistical problems and overproduction in certain times of the year. "The Ketchup Project" also known as "Sauce with a cause" supports farmers to reduce their waste by stimulating them to dry their tomatoes and transform them into ketchup. This approach is tackling two problems at the same time: first, it preserves tomatoes for a longer time thus reducing wastage; second, it generates more money throughout the year, stabilizing and improving the income of Kenyan farmers.

This project is implemented together with financing partners (RVO, DOEN), capacity building partners (SNV, FAO, Swisscontact), local partners (Kwakyai Rural SACCO, Kenya Compliance Limited, Burton & Bamber), production partners (Glasbest, Bellamy Food) and market partners (Verspilling is verrukkelijk, Tweede Jeugd, The Dutch Weedburger, One Planet Crowd). This description is based on A. Janssens (personal communication) and (MoAa, 2019).

4.4.2 Economic aspects

Traditionally, Kenyan farmers grow and harvest tomatoes twice a year. However, they can grow tomatoes throughout the year. The Ketchup Project is stimulating farmers to do just that, helping them to avoid the extremes of abundance and scarcity. Most of the tomatoes are sold on the market; a relatively small part is dried and processed into ketchup.

[4] In Bangladesh, 35% of the children are chronically undernourished.

The Ketchup Project has entered into a contract with Kwakyai Rural SACCO, which stipulates the amount of dried tomatoes to be delivered by the cooperative and purchased by the Ketchup Project.
It is the aim of The Ketchup Project to stimulate the local economy and improve the living conditions of farmer communities based on a sound business model. The price the cooperative receives per kilogram dried tomato ensures a good income for the farmers and a decent salary for the workers. As the farm cooperative keeps a certain percentage of the price they get for the dried tomatoes, it can save money to invest in projects such as paying back the dryer at the Drying Hub (see below), improve the irrigation system or enter into the certification process. The project uses a direct, transparent supply chain, which gives clarity to farmers and consumers alike. But the priority of the project remains to ensure that maximum economic benefit goes to the Kenyan farmers: the price per kilogram tomatoes they receive when selling to The Ketchup Project is approximately 7 times higher in comparison to selling fresh tomatoes to the local market.

4.4.3 Environmental aspects

To reduce the amount of food waste, a Drying Hub has been set up. This facility is drying the fresh tomatoes, so they can be transformed into ketchup. The Drying Hub is run by a selection of local people who have been trained to process the tomatoes (sorting, cleaning, cutting, drying and packaging) according to international food safety standards. The Drying Hub uses a dryer that is fuelled by agricultural organic waste such as pruning waste, mango seeds and sisal waste. The Hub does not have to pay for the organic waste; it only covers transportation costs. (Normally, a farmer has to pay to get rid of his or her waste.) Initially, the dryer worked on solar energy, but using organic waste turned out to be more energy efficient.

The Ketchup Project is also providing agricultural training (Global G.A.P. training) to the members of the farm cooperative with the goal to stimulate crop rotation, year-round production and the use of organic fertilizers and pesticides.

4.4.4 Social aspects

The Ketchup Project is targeting poorer farmers, not the relatively rich farmers who already have access to the market. Male and female farmers participate in this project; approximately 60% of the participating farmers are women and 40% are men.

Most Kenyan famers are smallholders who earn little money, owing to low and unpredictable yields. This uncertainty triggers migration of (young) people to the city, where they often cannot find proper work. The Ketchup Project aims to work on this issue by providing high-quality, local employment opportunities.

They cooperative also uses some of the extra money earned to invest in the community, for example by paying school fees, installing electricity and other investments that bring benefits to the community. The Ketchup Project does not have a say in the selection of the investment, but they can give some guidance and tips.

4.4.5 Scale of implementation

At present, The Ketchup Project is collaborating with one cooperative of about 160 farmers, a number that is expected to go up in the near future. Their Drying Hub employs 18 persons but this number will double in the coming months. The Project is in discussion with another group of farmers about the start of a second cooperative. In the future, The Ketchup Project aims to collaborate with farmers throughout Kenya and even throughout Eastern Africa: as the supply chain is relatively simple, it can be scaled up fairly easily. Besides drying tomatoes, The Ketchup Project has also started to dry mangos, in order to diversify its market. In the case of mangos the farmers earn 10 times more as compared to selling their fresh fruits directly on the market.

4.4.6 Implementation pathways

The Ketchup Project believes that entrepreneurship is essential to make change happen. As soon as they started up the Ketchup Project, a crowdfunding campaign was organised to raise money for raising awareness about the initiative and setting up the production chain. It only took three Kenyan farmers, part of a farming group with a strong community feeling, an agricultural expert and an entrepreneur to lift the enterprise off the ground. Bottling is still done in the Netherlands.

4.5 Biobuu Limited: Transforming organic waste into insect-based proteins, Tanzania

4.5.1 Summary of the case

Starting in 2014, a recycling company called The Recycler and its spin off Biobuu Limited started offering waste management and collection of recyclable material in Dar es Salaam, Tanzania. One of the services Biobuu Limited offers is to collect and process organic waste and transform it into insect-derived proteins and organic compost. This is done by a native insect called the black soldier fly (BSF). The BSF can consume 70% of its own body weight in waste every day. For every kilogramme of organic waste it consumes the insect produces nearly 50 g of protein, which can be used as a feed supplement for fish or chicken feed. After the decomposition process the leftover product can be used as organic compost. This description is based on M. Haden (personal communication, August 29, 2019) and (MoAb, 2019).

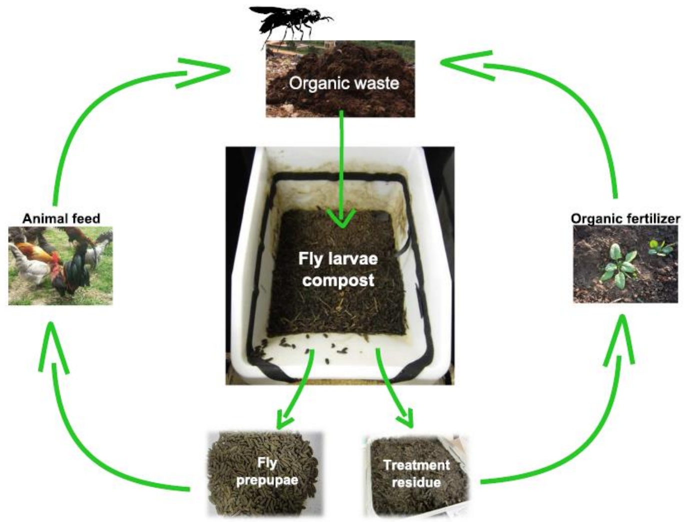

Figure 5. A graphicl representation of the circular system, showing the transformation of organic matter into animal feed and organic fertilizer (Lalander et al., 2015).

4.5.2 Economic aspects

The population of Tanzania is growing, resulting in an increase in waste materials. Most of this waste, 60%, is classified as organic. At first, Biobuu Limited looked into both biogas and composting projects. Biogas looked promising, but was only profitable if a customer or state utility wanted to pay the premium price for it. Compost heaps require a lot of land and the company was not sure whether it would be able to make it a profitable business without receiving additional subsidies. So the company started looking into the use of the black soldier fly, as part of a circular solution for food waste and food and feed production.

The source of protein for existing chicken feed is mainly soybeans or fishmeal. Soy is largely imported at high cost and most of the locally produced fishmeal is of low quality and expensive. Therefore, the production of high quality, insect-based proteins is an interesting alternative. The treatment residue, a by-product of the process, can be used as organic compost and is generating an additional revenue stream.

Biobuu Limited processes several tons of waste, and produces millions of maggots and hundreds of kilograms of dried insects and compost. By the end of 2019, the company hopes to break even and to push the production up to 1 ton of dried larvae per day.

4.5.3 Environmental aspects

Feeding chicken with insect-based feed is an environmentally friendly alternative for the current feed ingredients. It uses less land, nutrients and water. Estimates are that in one year a single acre of black soldier fly larvae can produce more protein than 3,000 acres of cattle or 130 acres of soybeans.[5] Moreover, growing fish commercially using insects as feed source may be a way to reduce overexploitation and the concomitant risk of depletion of the natural fish supply.

4.5.4 Social aspects

Sanitation and waste management in Dar es Salaam is poor, resulting in relatively high morbidity and mortality (Thomas et al., 2013). Biobuu Limited improves waste management systems, which renders the sanitation and hygiene situation better. In addition, the process of sorting, collecting, processing, drying and selling the BSF is a labour intensive process and thus provides jobs for the (local) community.

[5] https://wapo.st/bug-larvae

4.5.5 Scale of implementation

In 2013, Biobuu Limited started researching the breeding and feeding behaviour of black soldier flies. After three years, the company had gathered sufficient knowledge and raised enough funds to start the first BSF factory, in a large warehouse.

The company is currently setting up a similar factory in Kenya, and exploring opportunities across Africa. To make their model scalable, Biobuu Limited uses a low-tech, labour-intensive system. Working around the Equator means that heating the insect-breeding-room is not necessary, which cuts high energy costs. In collaboration with the Kenyan Institute for Fisheries, Biobuu Limited is researching the option to house the complete fish feed production on the company premises.

4.5.6 Implementation pathways

Since its start, Biobuu Limited has won grants that have been used to set up production facilities. The company received over one million USD in public grants, including the Blue Economy Challenge, the IDEO Amplify challenge Fund, the African Enterprise Challenge Fund, and the Bioinnovate Challenge Fund. Next year, the company will explore ways to raise private investment.
One of the challenge funds' grant conditions was that the insect-based proteins had to be sold to smallholders as well. This was to ensure that Biobuu Limited does not solely deliver to big customers. The company explores opportunities to work at different scale levels. For instance, it recently developed 'Kuku Bonge' home bins for households, which can be used to reduce household food waste while at the same time producing larvae for their chickens or fish.

4.6 Safi Sana: Urban organic waste management, Ghana

4.6.1 Summary of the case

In the slum area of Ghana's capital Accra, the Safi Sana company installed three Communal Service Blocks (CSB) in 2011. These CSB's, public toilets, are unique as they provide (paid) access to safe drinking water and clean toilets - all in one building. Daily, the urine and facial waste is collected by Safi Sana and transported, together with organic waste from food markets, slaughterhouses and industries, to its factory in Ashaiman. In the factory the waste materials are treated in a digester to produce biogas, irrigation water and organic fertilizers. Biogas is used to produce electricity, which is sold to the national grid. Safi Sana also started experimenting with growing (vegetable) seedlings using two by-products: irrigation water and organic fertilizers. This description is based on A. van den Beukel (personal communication, August 22, 2019) and Safi Sana (2019).

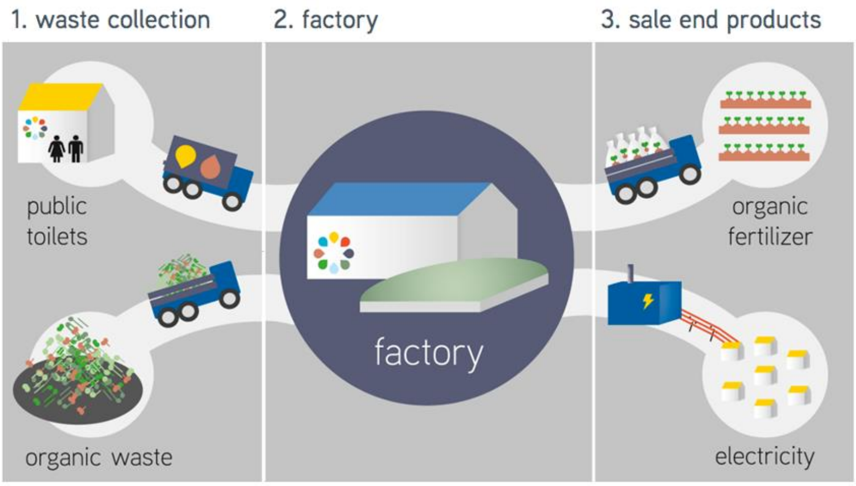

Figure 6. A schematic overview of the Safi Sana model.

4.6.2 Economic aspects

The factory in Ashaiman processes 25,000 kg of organic waste per day into biogas, water and fertilizers. Out of these three products, biogas has the highest value and thus provides a stable and reliable income to the company. Selling organic fertilizers is relatively difficult in Ghana, as they are relatively expensive in comparison to chemical fertilizers and demand fluctuates over the year. The largest cost drivers of the operation are staff and equipment maintenance. Safi Sana does not earn a lot of money with collecting waste materials, as only industries pay for this service. To create new treatment factories, fresh grants and/or investments are needed.

4.6.3 Environmental aspects

In the slum area of Accra, there is no proper waste management system, such as a sewage system. Building CSB's and collecting organic waste from markets, industries and slaughterhouses ensures that these waste materials do not pollute the environment. Moreover, using organic fertilizer improves soil fertility.

4.6.4 Social aspects

Constructing CSB's in slum areas improves the access to sanitation and hygiene services, especially for women and vulnerable groups. Management of the CSBs is in the hands of local entrepreneurs, mainly women, which is stimulating local entrepreneurship (making it a franchise company). Together with local and international NGOs, Safi Sana invests in social marketing activities to raise hygiene standards in the communities.

4.6.5 Scale of implementation

These 3 CSB's have been constructed in a slum area in Accra and the organic materials are collected from slaughterhouses, markets and industries in (the surroundings of) Accra. This is, therefore, very much an urban and neighboiurhood-level enterprise.

4.6.6 Implementation pathways

As Ghana has a stable economy, Safi Sana has chosen to implement its circular model in this country. The startup was financed by the Dutch government and the African Development Bank (ADB). The company is now exploring the possibilities of starting a similar business in Uganda or Kenya and exploring whether the government of these countries are willing to pay for the service of processing organic waste. Furthermore, research is happening into the demand for nutrients in the agricultural sector. Impact investors and even the bigger utilities / tech companies are starting to show interest.

As it is not possible to deliver energy to the grid everywhere, and as the government is not always willing to pay for sanitation services, Safi Sana is researching the option to focus more on agricultural production, using its own inputs (fertilizer and water; the company currently produces 40 L water per day). To conduct this research Safi Sana works in conjunction with WUR.

4.7 Ferm O Feed: Organic fertilizer distribution, worldwide

4.7.1 Summary of the case

Ferm O Feed is of one of the biggest manufacturers of organic fertilizers in Europe, with a factory located in Helmond, the Netherlands. The company produces 70,000 tons of organic fertilizer per year. Animal and vegetable by-products are purchased from 20 selected Dutch farms, strictly monitored for hygiene, quality and continuity. The company then sells its products to more than 65 countries. The quality and quantity of the fertilizer is consistent, as the farmers are feeding their livestock according to a known and constant diet. This description is based on P. Quadt (personal communication, September 10, 2019) (Ferm O Feed, 2019).

4.7.2 Economic aspects

Ferm O Feed exports its fertilizers all around the world, including Asia, the Middle East, Sub-Sahara Africa and North Africa. Vietnam is the biggest client. The company sells to both end-users (i.e. big farmers) and distributors who resell the fertilizers, mostly to smallholders. Products include a variety of organic fertilizers with different nutrients ratios, serving a broad market based on an integrated supply chain model.

The company states that using its organic fertilizer will result in increased soil fertility, leading to improved crop yield both in quantity and quality. Application to the field is relatively easy: the same machine that is used for the distribution of chemical fertilizers can do this job as well. Ferm O Feed has a large storage facility, ensuring that it can always meet demand.

The price of organic fertilizer per kilo produced by Ferm O Feed is relatively high in comparison to the price per kg for the standard chemical fertilizers (NPK), although the quality of the chemical fertilizers is lower due to – among others - lack of micronutrients and organic matter.

4.7.3 Environmental aspects

Ferm O Feed has a business model based on the cradle-to-cradle principle, ensuring its product is enhancing soil fertility and guaranteeing nutrient availability.

4.7.4 Social aspects

Besides selling organic fertilizers, the company provides after sales service. This means that Ferm O Feed provides training about the usage and effects of compost to distributors, extension officers and (big) farmers. The company can easily be reached through Facebook or WhatsApp for any questions related to its organic fertilizers.

4.7.5 Scale of implementation

Ferm O Feed sees a global challenge for the agricultural sector. The company aims to provide sustainable, natural, tailor-made and long-term solutions to farmers (large and small), in order to overcome the challenge of feeding the world by producing organic fertilizers in the Netherlands and exporting this to countries everywhere. The presence of a well-enforced regulation system in The Netherlands enables Ferm O Feed to be sure of the quality of its products. Furthermore, a good infrastructure ensures easy and cost-effective transport of organic materials to and from the factory. The Dutch farmers that supply the factory are relatively large, ensuring a relatively easy inflow of huge quantities of organic material. The company has said that it is open-minded about exploring other opportunities.

4.7.6 Implementation pathways

Ferm O Feed is part of the Den Ouden Group, a Dutch trading company specialised in the production and exportation of organic-based fertilizers. It uses high-quality inputs, the best technologies and agronomic knowledge to produce a sustainable, high quality fertilizer. Starting up a production facility in a developing country is still a complex challenge given infrastructure, regulatory conditions and the quality of the available organic waste streams.

Circular agriculture at the national level

Are there examples of actual implementation of circular agriculture on a national scale? Yes, there is one: Cuba. In 1989, Soviet aid to Cuba ended. Up to this point, Cuban agriculture had been highly industrialised and was dependent on food and agricultural imports including farm machinery, fuel, fertilisers and pesticides from the then Soviet Union. This type of fuel and capital-intensive farming came to an end. Cuba lost 85% of its foreign trade, including food, agricultural imports and petroleum. Already crippled by the US embargo, the country was financially devastated, with its food supply hit hardest. The Cuban people had to grow their own food almost without external inputs. Circularity became the key concept to maintain soil fertility. It is applied in urban agriculture in a variety of forms and also in rural agriculture. See for more information Annex 3.

5 Analysis of specific aspects within circular agriculture

This chapter addresses specific aspects of circular agriculture, based on findings in the cases examined and on additional information from - relatively scarce- literature. We want to emphasize that these are preliminary findings based on a limited number of cases in Low and Middle Income Countries. Circular agricultural practices are still very much in development and we hope that within a few years much more can be said about the different aspects of circular agriculture we will mention in this chapter.

5.1 Economic aspects

Almost all cases are based on a business model that turns resources that used to be organic waste and caused pollution into raw material that can be sold or used as an input for the production of a new product, or for farming. Most cases also feature the efficient use of resources such as water, land or nutrients in general, while saving cost as fewer inputs need to be purchased on the market (chemical fertilizer, energy and so on). More rational and/or innovative use of resources contributes to higher crop yields, for example in the case of the urine-biochar project.

Often different products are sold as part of one business case, such as biogas, electricity, bamboo shoots and pig meat in the case of the pig farm. Even within the product “organic fertilizer” a variety of products is marketed, and sold to different clients; this is the case with Ferm O Feed. The production system of one product may not constitute a profitable business case on its own, but it may become profitable if it is part of a waste management system together with other sources of income. Diversification also enhances the business model’s resilience, in the case of strong seasonal price fluctuations for certain products.

Smallholder farmers may not be able to benefit from such opportunities however, as creating more complex farming system is not always feasible for them. It might require in-depth knowledge of the cycli in the agroecosystem which they do not have. A hydroponics system may be more feasible to start with for smaller farms, rather than an aquaponic system. The production of high quality organic products has the potential to generate significant income in the future, when the market for organic products in low and middle income countries reaches a more mature development stage.

Before circular agriculture initiatives are implemented, good market research is essential to define the range and qualifications of new products to be sold. During implementation, the need arises to continue exploring opportunities for further diversification or adjustments.

In most cases, access to capital was available to invest in new activities, either from the initiator’s own savings or through credit or grants. Access to credit, in combination with good entrepreneurship, appears to be a key requirement for a successful start of circular agriculture at farm level and for larger-scale initiatives. Many of the cases presented here are still in the start-up phase, so little can be said about the economic sustainability and resilience of the circular business model. The only exception is currently Ferm O Feed, which is running a profitable global operation.

5.2 Environmental aspects

In various cases, organic waste or animal manure is used in different ways to produce a form of organic fertilizer. At the “entry” side this results in less environmental pollution, as less organic waste ends up in landfills where it emits greenhouse gases. Other positive effects are less eutrophication, and a reduction in nauseous odours for people in the immediate vicinity, either near a farm or in urban areas where organic waste is collected. At the “exit” side there is the product, often organic fertilizer, which has the advantage of improving soil quality, providing a richer biodiversity in the soil and an improved capacity to retain carbon. Likewise, when using organic fertilizers, less (energy-consuming) artificial fertilizer is necessary, which results in reduced emissions; this supports climate mitigation. Additionally , agricultural training helps improve farming practice relating to soil management, disease and pest management, and all this helps reducing the amount of non-specific pesticides applied, which in its turn reduces environmental pollution.

In several cases we reviewed here, one of the new products is biogas. This can be used directly as energy source or be converted into electricity, also leading to a reduction in the use of fossil fuels. Besides producing a renewable energy source, some of the projects also make use of renewable energy such as the Ketchup Project, which uses agricultural waste to fuel its dryer.

In other cases the circular system required fewer resources than the linear system. For example, in the case of using maggots for feeding chicken or fish, the result may be that fewer resources (water, land, fertilizers, pesticides) are needed to produce feed for animals. This could reduce strain on the environment. When the maggots are used as a supplement in fish feed, the pressure on natural fish stocks potentially diminishes. In a few cases we also saw the use of organic fertilizer in combination with other measures, also serving the production of organic food. In Egypt, an arid region, using as little water as possible is an extremely valuable character trade of an agricultural system.

In sum, the environmental outcomes look quite positive, but in most cases quantification is missing. The effects on water efficiency or climate mitigation haven't been measured either.

5.3 Social aspects

All initiatives play a role in enhancing the efficiency of agrifood value chains, with an expected positive effect on peoples' food security. Several cases are part of value chains delivering nutritious and/or organic foods to the consumer market. Recycling or reusing waste contributes to improved living conditions of the people living in the surroundings of an enterprise or an initiative, as a result of a reduction in nauseous smells or pollution. Effects on individual and public health can only be expected to be positive.

The production systems under discussion here also create new jobs, for example in pig breeding and in the labour-intensive model of the maggots production. The latter is an example of a waste processing activity that can be implemented as an extra source of income for rural households. Some of the projects focus on poorer segments of society or on women, such as in the Biochar-urine project. For this study we found no specifically youth-focussed initiatives, although the Ketchup Project expects to contribute to creating employment opportunities for youth.

Most initiatives were started by a project or by private entrepreneurs. They use contacts with other actors in the sector to build their business case. Individual farmers are then often the clients of the new initiative. At farm level, we found that the farmers who were in the driver's seat were individual farmers with a high level of entrepreneurship. In the urban-based case of Biobuu Limited, the Kuku Bonge home bins developed for households may create an opportunity for the local community to start managing their own organic waste and transform this into feed.

Several projects include communication strategies, to enhance after-sales contacts between a company and its end-users, or to educate consumers about sustainable agricultural practices and healthy food.

5.4 Scale of implementation

The scale at which developing circularity is usually discussed ranges from the local to the regional level, according to de Boer & van Ittersum (2018). It is interesting to note however, that in this very limited selection of cases we see implementation of circularity at a wide variety of levels: from individual farms, via villages, groups of villages, cooperatives, urban areas to the level of international trade. The Ferm O Feed case shows that it is possible to circulate resources at an international level. Nutrients imported from South America to the Netherlands as animal feed are recovered from the organic waste stream. Ferm O Feed converts the waste into high value fertilizer, which is then exported to many places in the world where nutrient deficiencies occur.

The promising conclusion is that there seems to be opportunity for introduction of circular agricultural at all levels and on all scales.

5.5 Implementation pathways

At the basis of system change there must be a deep motivation, a sense of urgency. Personal initiatives are important. In the cases we studied for this report, the driving factors in introducing and developing circular practice can be understood to a certain extent. In the two cases at farm level, environmental and health concerns were driving factors for change. On the pig breeding farm in China it was a governmental regulation that triggered the change, while in the aquaponics case it was a private concern. In these and other cases environmental concerns may have been a driving factor, but we lack information to confirm this. Frequently, the farmer's or investor's entrepreneurial propensity to grasp opportunities also plays a role. It clearly helps to have good contacts with a variety of stakeholders, including banks or universities: they can contribute expertise and knowledge, and/or funds for investment. These include grants and crowd-funding. We found that scaling up usually happens through extension of existing activities, in most cases as a company or a project.

Still, if the aim is to implement circular agriculture on a large scale, nationally or globally, much more will be needed. Insights from general academic literature on scaling apply, for example the recommendation that the design of (responsible) innovation processes needs to have future scaling up in mind (Wigboldus et al., 2016), and few authors have looked at the circular agriculture domain in particular. Analysing the pig breeding farm in China, Zhu et al. (2019) state that entrepreneurship is essential to make initiatives economically viable. According to them, the micro level should serve as the foundation for the field to move forwards. They also stress that concrete examples, in developing economies, are necessary. They see that the government is needed to scale up circular agriculture and to get risk-averse farmers on board, for instance by offering investments in initial costs, technical support, as well as intervening to stabilize prices of organic products or to address market failures.

A transition will happen when individual examples like the cases discussed here are brought together, multiplied and bring about change in the whole agricultural regime (Termeer, 2019). A transition is a change in socio-technical regime, which means it implies changes in the formal and informal structures, which determine practices of stakeholders in a certain sector. It also implies a transition with a social dimension (norms and values, policy, rules, preferences of consumers, ways of collaboration, business models, networks) and a technological dimension (business systems, ICT systems, machines, knowledge, etc) Technological and social dimensions are strongly interrelated; innovations in both dimensions take place simultaneously. For more information on transition, we refer to Annex 2.

The changes that are needed in order to make the transition towards circular agriculture could be profound. As an illustration of this the following. De Boer & van Ittersum (2018) write that the application of the concept of Circular Food Production will have implications as regards the way a society thinks about economic growth. While various authors propose technologic solutions, or particular innovation processes, de Boer & van Ittersum (2018) proposes practical solutions based on a deeper analysis of the food system:

- Economic measures: true pricing, subsidising of sustainable initiatives, and tax policies.
- Awareness raising and communication about sustainable food production and consumption patterns and the underlying paradigms and social norms and values.
- Prices for farm products: rethinking food trade and pricing, including the consumer prices and the portion of income spent on food in different parts of the world.

5.6 How to measure circularity in Food systems?

Monitoring circularity is a rather new arena. This involves using indicators, a methodology and tools to assess how well a product, organisation, region or even a country performs on circularity. In essence, the goal of a circular system, regardless of the spatial level, is to reduce raw material and energy input and consumption, because materials are reused and recycled in the system. Therefore, input and output and the value of the materials in the system are key indicators to measure circularity. Measuring circularity is important to monitor and validate the intended impacts of the circular system. Furthermore, it allows frontrunners in circular business models to identify risks (e.g. dependence on finite and externally sourced materials) and to communicate their findings and experiences to key stakeholders. It is also expected that investors and public funding agencies will increasingly demand figures from their clients or partners to justify circular models.

To monitor the transition to a circular economy in the Netherlands, PBL and CBS recently developed a national monitoring framework. Indicators are developed to measure the input and output materials of the economy, the rate of recycling, and to measure how restorative material flows are. The framework also incorporates indicators for bio-based materials, which can potentially be used to measure circularity in the food system at various spatial levels and by different actors in the supply chain. To measure circularity at an organizational level, the Ellen MacArthur Foundation is currently developing the Circularity Score, a company-level assessment tool. Nevertheless, it is expected that these high end tools will be first used by Western organisations that are frontrunners in the circular economy. From the various sources that are developing monitoring frameworks, examples of potentially relevant indicators for the food system are:

- reuse and recycling of bio-based materials into new products
- loss of material
- food waste
- pesticide and fertilizer use
- nutrient balance
- renewable energy use
- carbon emission output
- additional financial benefits from the circular business model

With regard to the cases presented in this paper, we have identified very few activities to measure the circularity of the system. Most likely this is due to the lack of standardized circularity indicators or because there is little incentive to start monitoring. Some monitoring practice is happening, though. Organic fertilizer companies, including Ferm O Feed, control the quality of the product and the absence of pathogens. The pig breeding farm measures the circular disposal of its “waste” and compares it with conventional disposal as an indicator of progress in circularity.

5.7 Opportunities and risks

Opportunities:
From the limited number of cases we can conclude that opportunities for circular agriculture are present across the whole food system.

Many LMICs cope with increasing pressures on natural and other resources, as well as the challenges related to climate change. In addition, many do not have appropriate sanitation systems, which is leading to unhealthy living conditions. Circular agriculture is an opportunity to address these societal challenges, and LMICs could benefit from the improvements in infrastructure that have already taken place.

CREM and Partners for Innovation (2018) did a scoping study on circular economy in Vietnam in which they identified several options for Dutch companies to become involved in activities to promote circularity. Examples include local production of organic fertilizers, use of stronger seed varieties to limit use of pesticides, herbicides and fertilizers, the introduction of more resource-efficient production technologies, promotion of urban farming and use of wastewater and agricultural waste streams for biomass combustion or gasification (among others). See for a short summary Annex 4.

Risks or challenges:
In assessing these initiatives, one could sense that there existed a strong need for rules and regulations that would permit innovative ways of farming. General risks include the more conventional ones, such as the time it takes (and the difficulties one encounters) when wishing to register a new company, hire staff, or prepare for registration of a new product in a new (export) market.

It may also take a long time to get the circular model right, build a network and set up the infrastructure. Marketing an unknown new product is also a challenge. In several cases we discussed grants or subsidies were given the initial phase, in order to diminish investment costs and risks. For example the re-use of organic waste and faecal materials from urban centres is a big opportunity, but it is not easy to make such initiatives profitable (or avoid running a loss), especially in circumstances where local governments do not have a proper system for urban waste management and do not spend much money – or indeed time - on it.

At the system level, a few other risks occur:

- There is the risk that a relatively unimportant cycle is closed, while other linear processes, including their waste streams, still continue. In a first production loop much artificial fertilizer may be used to produce feed for animals. When the resulting animal dung is – in a second loop - used for fertilizing soils, this part is circular, but there still remains the linear stream of artificial fertilizer from the first loop. None of this negates the usefulness of such initiatives. The case of the Ketchup Project which is ostensibly linear, helps optimising resource efficiency as a basic element, even before entrepreneurs start circulating ingredients.
- Another risk concerns the introduction of toxic materials and pathogens in the food system. This may occur, for instance, when using organic waste including the effluent from sewage systems in urban and/or rural areas for fertilisation in agricultural production systems. Residues of drugs and medicines are often found in black water and toxic elements may still be present in organic waste collected in urban areas.
- Certification schemes may be needed for circular agriculture in the future, given the experiences with the existing ones for organic and biodynamic agriculture. These schemes may well be based on rather elaborate procedures, which may be costly and go with stringent demands that are sometimes difficult to meet. While traceability is particularly important in circular value chains, it may be very challenging to realise. (J. Guijt, personal communication, September 19, 2019).
- Closing international resource loops, as is the case of Ferm O Feed, implies significant international transport. The climate effects of these have not yet been incorporated in the business models.
- If circularity is promoted taking into account only technical and economic aspects (like the recycling of nutrients and building the business case), there may be negative social consequences, especially

for small farmers, women and youth. There is always a risk that negative effects occur because not all environmental, social and economic impacts, including effects on climate, are monitored.

The cases we have described are not yet exploring the type of transition pathways proposed by de Boer & Van Ittersum (2018). The cases are a kind of 'low-hanging fruit', very valuable, but dependent on external funding for their success. It is a risk that they cannot become sustainable, given the fact that there are very few supporting rules and regulations at national and international level that would otherwise permit their further development. Food safety procedures and standards for example, may need to be revisited to facilitate the circular resource flows; the food pricing system needs adaptation, in order to reflect the externalities of resource-intensive linear production models.

A challenging discourse takes place on the question to what extent animal production can be part of circular agriculture. Any answer to this question has implications for many peasants and farmers – rich and poor - involved in animal production. De Boer & van Ittersum (2018) state that we should strive for the use of animal feed either from waste that other processes in the food system have produced or feed from vegetation (often grasslands) on soils that are not apt for growing food crops for humans. The Dutch policy document states that "cattle are fed primarily with grass, feed crops or crop residues from the farm where they are kept or from the immediate vicinity, as well as with residues from the food industry." This seems to be less ambitious - the grass may be grown on land that is also apt for crops - but could be more (politically) feasible, and have fewer negative consequences for farmers.

Further reading on recent monitoring and evaluation regarding circular agriculture: Annex 1.

Image source: Aquaponic farm, Egypt

6 Conclusions and recommendations

6.1 Conclusions

As to the concepts:

- Various publications deal with defining and conceptualising circular agriculture or the circular economy applied to the agricultural sector. Common features are the need to reduce resource consumption and discharges into the environment as well as the principle of recycling 'waste' materials as much as possible ("reuse and recycle"); i.e. waste as a raw material to produce new valuable products, including crops, food, feed, energy.
- Circular agriculture or circular economy applied to food systems are often based on ideas from the circular economy. Circular economy uses theories and principles from industrial ecology.
- Most principles that authors present in relation to circular agriculture are formulated taking into account social, economic and environmental aspects. They are not always mentioned as principles but rather as goals of circular agriculture.
- However, in some circular agriculture definitions, the words "local" and "locality" play an important role, as do local or indigenous knowledge, and socio-cultural aspects. In these definitions, the well-being of people who produce agricultural products is at the core of the concept. These concepts are supposed to be in sharp opposition to the food industry as it exists today. Promotion of alternatives to industrial food systems and Green Revolution agriculture is at the core. These definitions seem to be based on older roots, which have a relation with the concept of agroecology. The concept of circularity has been present in agroecology since 1928, but its application, undertaken in organic agriculture, permaculture and bio-dynamic agriculture, and off-course in many (but not all) traditional agricultural systems, is (still) not mainstream.
- The novelty of circularity is its application to the whole food system, including processing and consumption. Within the whole system, nutrients, elements and (organic) waste have to be recycled as much as possible.
- We observed that most concepts seem to have a rather "technical" approach. Ideas on social aspects like inclusiveness, equity and gender are not extensively developed in many concepts.

As to the cases:

We examined 7 cases of circular agriculture in LMICs. In this limited selection of cases we see implementation of circular agriculture ranging from individual farm level, via villages, groups of villages, cooperatives, cities up to the international level. The promising conclusion is that there are opportunities to introduce circular agriculture at all scales.

As to economic aspects the conclusions are the following:

- To make the business cases economically feasible, it is seen that often different products are sold, even within the product "organic fertilizers" a differentiation can be made.
- Before starting with a circular initiative, it is essential to have a good understanding of the demand for a specific product and the qualifications required.
- Both the availability of capital to invest and the existence of entrepreneurship are important to make a business case successful. Bringing the idea of circular agriculture in practice on small-scale farms in LMICs still seems a challenge.
- A part of the studied cases are rather young and received subsidies in their initial phase. In the long run they may become less profitable than anticipated once the effects of these subsidies diminish. The product price farmers earn within the different cases may also need to be monitored further; as some estimates seem to differ from what other sources say.

As to social aspects the conclusions are:

- In many cases recycling waste improved peoples' living conditions, including less smell and pollution, and livelihood opportunities, including jobs creation.
- In some cases, it is possible to process waste at household level which creates benefits at that level. Some of the projects focus on poorer segments of society and have a substantial participation of women. We have not seen any initiative specifically focussing on youth in the cases that we examined.

As to environmental aspects conclusions are:

- Circularity could result in less waste and environmental pollution.
- Organic waste and animal manure are used to produce biogas and fertilise soils, among others resulting in climate mitigation.
- As a consequence of resource recycling, there is a reduced pressure on natural resources such as land and water.
- In one case, considerable international transport is part of the business case: livestock in the Netherlands are partially fed with imported feed and the manure is processed and then exported as organic fertilizer all over the world. The use of fossil fuel, and therewith the emission of greenhouse gasses, may contribute to climate change.

As to impact:

- The social, economic and environmental effects presented in the cases seem plausible but lack quantified robust evidence.
- In most cases circularity is not monitored. It would certainly be useful to measure the percentage of a specific waste stream that is brought into circularity, or additional financial gains if circularity is applied. It is still a challenge to develop ways of measuring circularity in relation to the broader societal objectives and in a way that satisfies the needs of the developers and target groups of circular initiatives. See for some ideas on monitoring and evaluation circularity Annex 1.

As to the private sector:

- Since entrepreneurship and the availability of capital seem to be key factors for economic success, the private sector would be a natural partner in developing circular initiatives.

How can a move towards circularity at larger scale take place?

- At case level, environmental concerns play a role as driving force as well as an entrepreneurial mentality, good contacts with a variety of stakeholders and access to funds for investment such as subsidies by governments, grants and crowd-funding.
- Scaling up in these cases happens through expansion of already existing activities ("horizontal scaling"). The cases demonstrate that innovation happens in different continents and by different actors. However, the transition of the whole agricultural and food sector in the direction of "circularity" is not (yet) taking place. At first sight the application of the concept of circular agriculture may seem to be more expensive than working in the common "linear" way. Most cases are rather young, so we do not know how sustainable they are. But some cases are older and remain economically feasible after several years. Thus we can conclude that at least part of circular initiatives do not depend on structural changes in the economy like "the polluter pays" principle and the introduction of subsidies for environmentally friendly products. As long as the economic feasibility of (processed) waste stream and resulting products is positive in today's economic system, the introduction of circular initiatives seems already feasible.

6.2 Risks

Risks at project level include registration time, cost of new product development and the difficulty and duration of registering a company. Also, rules and regulations should permit innovative ways of farming; European (food safety) standards may be an obstacle if an enterprise, situated in a LMIC, wants to enter the European market. Lack of product reputation or knowledge about a product can also be a risk (e.g. reusing waste or human excreta is culturally not accepted).

At system level a few other risks occur:

- There is the risk that a relatively unimportant cycle is closed, while other linear processes, including their waste streams, continue.
- Another risk, while using organic waste, is the introduction of toxic materials or pathogens in the food system.
- Transport in general, but international transport in particular has negative climate effects.
- If circularity is promoted taking into account only technical and economic aspects like recycling of nutrients, and building the business case, there may be negative social consequences, particularly for vulnerable groups.
- If not all environmental, social and economic impacts, including effects on climate, are monitored, unintended negative effects may still occur.

The cases we have described here all operate within the current international food system. As long as changes do not happen at this system level, the number, extent and impact of enterprises practicing circular agriculture will possibly remain limited. Such changes at the system level may be related to the food pricing system for example, which could (better) incorporate the cost of externalities of resource-intensive linear production models in the product price. A change at policy level to be considered is for example prioritizing investments in local agrifood systems development, while reducing those oriented towards exporting large quantities of produce. Finally, proposals for system level changes could be expected from the challenging discourse on the question to what extent animal production can be part of circular agriculture.

6.3 Recommendations

1. Governments in LMICs and their public and private partners could promote circular agriculture as a means to simultaneously reach a range of objectives, including better environmental conditions, climate mitigation, public health and income generation. However, careful design of circular initiatives and monitoring of effects are necessary to verify to what extent such objectives are reached.
2. From a transition point of view (transition from linear towards circular agriculture) we are still in the phase of generating experience through the introduction of a variety of circular initiatives. It is recommended to support and facilitate the development of a larger number of similar initiatives. It is suggested to focus on a differentiated package of products, good marketing, availability of starting capital and (development of) entrepreneurship. The private sector is strong in these aspects and should be involved in development of new cases as much as possible.
3. Develop ways of measuring the various aspects of circularity in a way that satisfies the needs of the developers and target groups of circular initiatives. There are interesting examples of monitoring systems but they do not seem to be applied at a larger scale. There is a need to develop monitoring systems for cases which deal with social, ecological economic and circularity aspects.
4. Combine waste management with agricultural production, as (especially in cities, but also in rural areas) a considerable stream of valuable organic waste and waste water is produced and currently discarded.
5. Realising circular agriculture in practice on small-scale farms in Low and Middle Income Countries still appears to be a challenge. SAs social aspects like inclusion, equity, youth and gender are generally not well integrated in the concepts of circularity, it is recommended to facilitate the development of circular cases in which deliberate attention is given to these aspects and monitor their implementation.
6. Document more cases as to their inclusiveness and sustainability in order to learn and in order to promote the promising concept of circularity in agriculture and food systems.

Image source: Ferm O Feed

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Annex 1 - Measuring circularity: some ideas from literature

Measuring the use of animals in food systems

De Boer & Van Ittersum (2018) state that in order to reduce the impact of food production on the environment, product footprints are increasingly used by industry and society. However, product footprints do not address interlinkages within the food system or the issue of feed-food-fuel competition. The concept of ecological footprint is often used either to explore options to produce more with less resources or on altering human consumption patterns to eating less and healthier foods, wasting less food or substituting high-impact foods with low-impact ones. The footprints of individual food products, however, fall short in addressing the complexity and circularity of food systems. For example, they do not acknowledge interlinkages in the food system (e.g. use of 'waste' like straw as feed for animals, which is an input for other food production). Likewise, dietary footprint studies advise that people should eat meat or eggs from grain-fed poultry rather than milk and meat from ruminants grazing on land unsuitable for crop production. This is contrary to what is intended in Circular Food Production. So there is a need to move away from the current product footprint approach and start using a food-system lens. The move towards using animals for the purpose which best suits them, namely converting biomass inedible for humans into valuable food, requires multiple metrics.

a) measure the efficiency with which biomass inedible for humans is converted into human food.
b) assess the resource-use efficiency of the entire food system, such as the land-use ratio which determines whether a net gain in protein output might accrue from the use of land by either animals or cropping.
c) Besides these product-based measures, however, we also need to look at the application of animal and human excreta per hectare of land (i.e. maximum nutrient fertilisation application rules) or emissions in a specific region (carbon dioxide emission ceilings).

A transition towards a circular food system, therefore, requires a smart combination of metrics at different scales (farm, product, region).

Means-end analysis

The means-end approach (Jones et al., 2011) is based on system analysis and emphasises that there are many 'means' to achieve each 'end'. Key aspects are:

- All options for meeting a specified human need are considered, including the alternatives to the predominant production, sourcing, distribution, marketing and waste management systems.
- The analysis is based on consumption and includes the impacts associated with the production and transportation of imports. In this approach the data collected are based on exact distances and reflect real life examples of current practice within production systems, the supply chain and consumer behavior.
- All stages involved when moving the product from source to the consumer (and subsequent waste management stages) are assessed.

The total embodied energy or greenhouse gas emissions of a product or service include all stages of the manufacturing process, from the mining of raw materials through to processing and packaging and the distribution process, to the final product provided to the consumer and then waste management.

Indicators of environmental and socio-economic performance that are used to assess initiatives include:

- greenhouse gas emissions;
- energy or fossil fuel use;
- solid waste;
- air pollution;
- water emissions;
- reduced household costs;
- reduced cost of inputs to farming systems and/or increased income;

Furthermore it is proposed to use a series of attributes and values to assess the socio-ecological resilience of different system. Resilience values include e.g. diversity, tight feedbacks, mutual aid and solidarity, innovation and openness. However no ways are suggested to actually measure these values.

Measuring circularity at national level in Colombia

Colombia recently produced a proposed national action plan for the transition to a circular economy (TECNALIA, 2018). In this publication a list of indicators is presented, but this list is about circular economy in general and not specific for agriculture. This list for the total circular economy for Colombia contains 10 indicators. For our study on circular agriculture we made the following list of 7 indicators linked to agricultural circularity.

Challenge	Indicator
Reduction of extraction/buying raw materials	1. Consumption of raw materials per inhabitant
Increase re-utilisation of products and recycle of materials	2. Products prepared for re-utilisation (%) 3. Percentage of use of generated (solid) residues
Reduction of climate change	4. Total emissions of greenhouse gases in the agricultural sector (CO2-equivalent)
Responsible consumption	5. Generation of rest streams after consumption at home, or more concretely: food wasted by the consumer(kg/inhabitant)
Socio-economy	6. Formal jobs related to circular agriculture (% of active population) 7. Investments related to circular agriculture (% of BNP)

Table1. Some indicators for measuring circular agriculture in Colombia. Source (TECNALIA 2018), adapted.

The list is partly based on experiences in the European Union and Spain but adapted to Colombian needs. We suppose that it would be easy to extent the list and add more indicators depending on the objectives of a national plan. But whether that is useful and feasible depends on the specific situation.

Such indicators at national level are also linked to the Sustainable Development Goals. For example by reducing indicator 1, consumption of raw materials per inhabitant, the impact on the environment because of extraction is reduced (SDG 15, Life on land) and later rest streams SDG12 (Responsible production and consumption), with a consequent reduction in greenhouse gase emissions (SDG13 Climate Action) and the Nationally Determined Contribution (NDC) within the framework of the Paris Agreement 2015.

Tiered monitoring structure for circular economy in Flevoland province

The proposed framework for measuring the circular economy in the Dutch province of Flevoland takes the form of a pyramid (Dekker et al., 2018). This pyramid consists of three different layers: the main indicator at the top, dashboard indicators in the middle and transition indicators at the basis. Each layer contains various indicators:

- The main indicator is at the top layer of the pyramid. It is an achievement indicator that gives a first impression of the degree of circularity of the economy and which is particularly suitable for communication purposes. This is similar to the role of GNP in communicating the state of a traditional economy.
- The dashboard indicator provides a broader context for the main indicator, and includes elements from different perspectives for the circular economy. These can be compared with existing indicators such as foreign debt, inflation, trade balance, etc. They give a more detailed image in order to get a comprehensive image of the circular economy.
- The transition indicator forms the bottom layer of the framework. This one indicators provide insight into systematic changes in the structure of the economy and can be used for applying accents in supporting the transition to one
- circular economy. Examples of circular transition indicators are: number of circular policy staff, number of circular initiatives, or the number of circular standards and rules.

This structure has been chosen because it is similar with existing macroeconomic indicators. The structure does not represent hierarchy, but holds balance between clear and simple communication on the one hand, and detail and completeness on the other. So how lower in the pyramid the more level of detail.

Annex 2 - Possible transition towards circular agriculture in The Netherlands

This annex is mostly based on (Termeer, 2019).

In order to develop current agricultural systems into circular agriculture fundamental changes are needed. A change towards Circular Food Production can be considered as a socio-technical transition (Jurgilevichw et al., 2016). This implies that that considerable and longstanding efforts are needed. This idea is further elaborated for the Dutch situation by Termeer (2019). We believe that these ideas could also have an application in LMICs and therefore we will elaborate them here further.
According to Grin, Rotmans and Schot in Termeer (2019) a transition[6] is a change in socio-technical regime. Regimes are composed of formal and informal structures that strongly determine practices of stakeholders in a certain sector. Regimes have a technological dimension (business systems, ICT systems, machines, knowledge, etc) and a social dimension (Norms and values, policy, rules, preferences of consumers, ways of collaboration, business models, networks etc).Technological and social dimensions are strongly interrelated. Technical and social innovation take place simultanuously.

Transitions are needed to deal with so called 'wicked problems': problems with many stakeholders at various levels dealing with many policy domains at the same time. The different stakeholders have often different views on the nature of the problem and possible solutions. Because of new events and because of autonomous developments (e.g. economic growth) the problems regularly change in their shape. Most of these problems (at least in the agricultural domain in The Netherlands) have a long history of policy interventions.
There are several barriers to overcome, which in the Dutch context are (a) material: investments in e.g. current business systems and technologies which have a long pay-back time, (b) knowledge: knowledge is focused on the current production systems, (c) finance: banks are hesitant to invest in new types of investment, (d) rules: it is easier to change current policies and regulations a little bit instead of starting something completely new.

The way that Termeer (2019) proposes to start this transition seems promising also outside the Dutch context, because the approach is proposed for transitions in general. Also in other countries a move towards circular agriculture will need to be profound and can be called a transition. She proposes a transition towards circular agriculture by 'accumulating small wins'. Properties of 'small wins' are:

- Tangible results for direct involved parties
- Meaningful steps on the way to system change
- Deep changes/rethinking
- Resistance encountered and barriers overcome
- Connection of technical and social changes
- A space with 'energy' (enthusiasm)

There are three transition pathways:

1. Dispersal of innovations, up-scaling, application elsewhere
2. Broadening: apply the innovation in other domains or for solving other issues
3. Deepening: make innovations more radical (e.g. maintain a list of problems encountered in order to redesign production processes).

Termeer (2019) mentions several catalyzing mechanisms for the next step to 'accumulate small wins':

- Energizing: a visible result of a small win gives people a direct incentive.
- The small win is an experiment which creates more insight in the wicked problem even if a specific 'small win' is not a success.
- Logic of attraction: winners are attractive.
- Oil stain: people follow what others do.
- Relate: a small change in one place in the system has consequences for other places often at other scales.

[6] Termeer (2019) observes that 'transition is often used in the Dutch context while internationally often 'transformation' is used, which is a fundamental change implying: change of paradigm, perceptions, underpinning norms and values, restructuring of social networks and interactions, change of power structures and introduction of new institutional arrangements and ruling systems. The term 'transformation' is used by IPCC to indicate the changes needed to deal with climate change. We conclude that transition and transformation are, if they are not the same, at least strongly related.

- Robustness: if in several places at the same time small steps are undertaken, then this could lead to a broader movement. Several small steps can provide a stronger fundament than one big solution.

Termeer (2019) stresses the importance of having a party/organisation that identifies existing 'small wins' and discusses with the owners of the 'small wins' the properties of small wins, e.g. its results, why this small win promotes circularity, which ways of thinking have been changed, etc. She also stresses the role of monitoring as a means to promote and sustain a transition. Process monitoring, reflective monitoring to learn, and impact monitoring all have their role in the transition process and are therefore important. Transition also needs a governance structure. Important aspects are: (visionary) leadership, (broad) ownership (several stakeholders), guarantee (that the transition process can continue at least for 10 years) and management (adaptive and prepared to learn and adjust).

Annex 3 - Cuba, a hard-way transition towards circular agriculture

In 1989 Soviet aid to Cuba was withdrawn. Jones et al., (2010) describe what happened. Up to this point, Cuban agriculture had been highly industrialised and was dependent on food and agricultural imports including farm machinery, fuel, fertilisers and pesticides. In 1988, for example, it imported 100% of its wheat, 90% of its beans, 94% of its fertiliser, 82% of its pesticides and 97% of its animal feed. The withdrawal of Soviet aid meant that 1.3 million tonnes of chemical fertilisers, 17,000 tonnes of herbicides and 10,000 tonnes of pesticides could no longer be imported; between 1989 and 1993, for example, there was a five-fold drop in synthetic fertiliser imports from 537,880 to 96,500 tonnes. Highly industrialised fuel- and capital-intensive farming came to an end. Cuba lost 85% of its foreign trade, including food, agricultural imports and petroleum. Already crippled by the US embargo, the country was financially devastated, with its food supply hit hardest.

Farming had also been highly specialised and based on monocultures—the country produced large amounts of sugar and tobacco for export, while importing many other food products. Since the beginning of the 1990s there has been a significant diversification of agricultural production. Between 1991 and 2006 there was a seven-fold decrease in sugar cane output and between 1989 and 2004 there were large increases in the production of fruit (114%), cereal (44%), vegetable oils (593%), pulses (842%), roots and tubers (182%) and vegetables (631%). Initially, food supplies decreased significantly and the crisis made the shift of food production to cities unavoidable, partly due to the cost and availability of transport fuel. In Havana, the largest city in the Caribbean with a population of over 2 million, land was distributed to individuals and co-operatives as 'parcelos' or plots and over 200 bio-pesticides production centres were set up. New co-operative farms—with or without a collectively cultivated, jointly held area—came into being and replaced some state farms. Raised beds units of between one-half and several hectares in size were established, together with intensive kitchen gardens on patios, rooftops and waste ground. Circularity became the key concept to maintain soil fertility. It is applied in urban agriculture in a variety of forms and also in rural agriculture.

The official website of the Ministry of Agriculture of Cuba describes what happens in the 'special period' and afterwards[7]:

> "From the beginning of the special period it was necessary to face the sharp decline in imports and work for solutions that would guarantee the people's food, implementing an austere program with a time-of-war economy style. In parallel, the country suffered from the increase in the limitations imposed by the US blockade.
>
> One of the difficulties was the large areas based on imported resources, so the Basic Units of Cooperative Production (UBPC) were created, which implied the de-nationalisation of a substantial part of the land and state capital in agriculture. The Urban Agriculture Movement was also created, and delivery of land plots in usufruct for self-supply began. At the same time, the collection of products and marketing management was perfected; the retail network for the sale of agricultural products was redesigned; and the Network of State Agricultural Markets was created, with direct attendance of the producers. Companies and State Farms that did not meet the conditions to be transformed into UBPC were organized as New Type State Farms (GENT), whose main feature is to have greater management autonomy compared to the old State Farms.
>
> As of 2008, the delivery of idle state lands was authorized, as usufruct, to natural or legal persons. These lands will be used rationally and sustainably in accordance with the suitability of land use for agricultural production. Suburban Agriculture is currently being promoted, which consists of the integral use of agricultural areas in an environment of up to 5 km on the periphery of urban centres, which also implies delivery of idle plots to producers. In the 1980-1985 period the emergence of the so-called Mercado Libre Campesino was authorized with supply and prices regulated only by demand, although the bulk of agricultural production continued to be commercialized by the State. With the creation in 1994 of the Agricultural Markets of Supply and Demand, an important step was taken in the improvement of the relations between the entities related to production and commercialization.
>
> Other important measures have been the programs to promote the use of animal traction, energy saving, irrigation electrification, use of renewable energy sources (biogas, windmills and others). The recent

[7] Source: https://www.minag.gob.cu/node/1 accessed 01-08-2019, translation by the authors.

program of delivery of idle land to farmers with possibilities of putting them to use, is playing an important role in the development of agricultural production."

The urgency of the agricultural transformation since 1989 is emphasised by the use of terms like 'time-of-war economy'. This description of the history focusses more on handing over (in usufruct) of state land to private persons or organisations and does not focus at all on circularity or agroecology. Still the result is an agriculture to a great extent based on circular principles. However, it should be noted that in the period 2005 -2016 the use of Nitrogen fertilizers has increased from 30700 tons to 78500 tons, Phosphate fertilizers from 13800 tons to 31100 tons and Potash fertilizer from 37700 to 38200 tons[8].

[8] FAO statistics http://faostat.fao.org/static/syb/syb_49.pdf accessed 30-7-2019.

Annex 4 - Opportunities for circular agriculture in Vietnam

CREM and Partners for Innovation (2018) prepared a scoping study on circular economy in Vietnam in which they identified several options for Dutch companies to become involved in activities to promote circularity. One of the sector they studied was the agricultural sector. The agricultural sector in Vietnam faces several challenges, like low productivity, excessive use of pesticides, herbicides and fertilizers, and unreliable food quality and food safety. The study identified several business opportunities for Dutch companies.

As to raw materials:

- Promotion of sustainable agriculture, resource mapping and circular strategies.
- Local production of organic fertilizers
- Use of stronger seed varieties to eliminate the excessive use of pesticides, herbicides and fertilizer.

As to production:

- Improving agricultural productivity (land-, labour- and water productivity) through closing yield gaps and the intensification of production processes. There is a need for technologies and farming techniques that put less strain on the environment and ensure sustainable agricultural practices.
- There is a need for smart technologies for small-scale agriculture to improve efficiency and sustainability (e.g. seeds and irrigation).
- There is a need to promote climate controlled agricultural production with greenhouse technologies for e.g. fruits and flowers.
- Introduction of new cattle breeding technologies and services.
- Cold chain: mobile cooling and transport facilities and cold storage facilities.

As to consumption:

- Further promotion of urban farming technology especially around big cities like Hanoi and Ho Chi Minh City.

As to waste:

- There is a vast potential for wastewater treatment technologies to be implemented in the agri- and aquaculture sectors.
- As an agricultural country, Vietnam has access to vast amounts of agricultural residues. Biomass waste streams can be used for several purposes such as biomass combustion or gasification. Examples include waste streams as feedstock for anaerobic digestion and ultimately for heat generation, or the use of a larger proportion of rice husk waste for domestic cooking, ceramic/brick kilns, electricity generation or as fertilizer.

It has to be observed that the opportunities mentioned under production focus on improved agricultural practices. Such practices do not automatically contribute to circularity.

Annex 5 - Three principles for Circular Food Production:

De Boer & van Ittersum (2018) define three principles for Circular Food production which is summarized as follows:

1. **Plant biomass is the basic building block of food and should be used by humans first**. Traditionally two ways of increasing productivity are used: improved genetics or improved crop management. However, circular plant production requires a broader lens: from the highest yield of a single cop towards the highest total quantity and quality of the entire cropping system including other vegetation (generating by-products like straw, leaves or stalks). So there is a need to focus more on the quality of by-products and the possibilities of mixed crops. It is not the efficiency of subsystems but the efficiency of the entire food system that matters. Some issues of circularity are :
    a. Important targets for plant breeding for the purpose of achieving circular food systems are improvement in the yield and quality of different plant components, suitability for downstream processing and functional use, and better resource-use efficiency in crops (low input and high output). It is not only about high productivity.
    b. In many agricultural systems there is a continuous removal of nutrients from natural vegetation towards agricultural fields, which is eventually depleting those soils. For example, dung from free gazing animals is deposited during night in a stable and used afterwards on the agricultural fields. This 'soil mining' still occurs today in low-input agriculture in many parts of the world?
    c. The use of cover and green manure crops in-between main crops is essential to keep nitrogen and other nutrients circulating within the system and avoid losses. But recycling of by-products is not enough as it is unavoidable that any system will lose some nitrogen. Adding biologically or chemically fixed atmospheric nitrogen is essential to avoid nitrogen limitation. Making use of leguminous species and mycorrhizas makes perfect sense in terms of nitrogen and phosphorous fertilisation and nutrition (grain legumes).The use of mineral nitrogen fertilisers remains necessary, however application of it should take place matching the need of the crops (moment, place, form) while not exceeding environmentally sustainable thresholds.
    d. A key principle in managing pests, weeds and diseases in crop production with low levels is advancing diversity in crop and variety mixes at different scales. Within circular food production intercropping (also use of different varieties of one species) and crop rotation are important. Also field crops, field margins and natural vegetation can create diversity at the landscape level.

2. **By-products from food production, processing and consumption should be recycled into the system.** Our food system leads to various by-products such as crop residues, co-products from food-processes, food waste and animals and ultimately also to human excreta. Our first priority should be to prevent human edible by-products and food waste. By-products that are not of immediate use for human consumption should be recycled back into the food system: beet pulp, slaughterhouse waste, animal and human excreta, unavoidable food waste. In order to enhance circular food production the following order of priority is proposed:
    i. Application in the field for the improvement or preservation of soil quality, ranging from soil fertility to soil cover and the avoidance of erosion;
    ii. Feeding to livestock or insects to produce food from animal sources;
    iii. Production of bioenergy, nutrient fertilizers or renewable biomaterials to mitigate greenhouse gas emissions;
    iv. Incorporation in the soil of more humus with the objective to sequester carbon and mitigate greenhouse gases.

3. **Use animals for what they are good at.** By recycling biomass unsuited for direct human consumption into the food system, animals can play a crucial role in feeding humanity. They convert biomass unsuitable for human consumption into high-quality, nutritious food, and recycle nutrients into the food system that would otherwise be lost to food production. Rather than consuming biomass edible by humans, such as grains, such animals convert so-called 'low-opportunity-cost feeds' (e.g. crop residues, co-products from the food industry, inevitable food losses & waste, and grass resources) into valuable food, manure and other products. Some observations made de Boer & van Ittersum (2018) are:
    a. In circular food production arable land should be used primarily for the production of food instead of feed crops and adopting this approach means that animals contribute to nutrition supply without using additional arable land. If this approach would be implemented, less arable land is needed for food production than in a scenario with no eating food from animal sources (vegan diet).
    b. Unavoidable human food waste can have value as animal feed, but is currently often restricted by law because of potential risks to human health. However there are promising processing methodologies available to avoid diseases like foot-and-mouth disease and classic swine fever.
    c. Which grasslands can be considered available for animals? While substantial areas of grassland could in principle be used for crop production, such land use change could also lead to a loss of soil carbon and biodiversity.

d. Which animals are best suited for which types of leftovers or grass resources? Often pigs are used to make the most of food waste but also other options should be investigated like insects or farmed fish. There are animals which are bred to be highly productive on high-quality feeds that may be less suited to utilise left-overs streams.
e. The quality of by-products for use as feed can sometimes be improved by making use of certain treatments, e.g. biological treatment of rice or wheat straw with fungi.
f. Cultural changes could influence the availability of waste and use of it by animals. If people avoid creating food waste altogether, less of it will be available as livestock feed.
g. Feeding primarily low-cost feeds to farm animals will also affect the availability of animal-source food for human consumption, because the amount of such food is limited by the availability and quality of low-cost feeds. This would lead to a reduction in consumption of animal-source food in rich parts of the world like Europe.

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