TOWARDS LOCAL BALANCE OF CROP AND ANIMAL FARMING FOR RECYCLING OF NUTRIENTS AND FOR LOCALIZING FOOD

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Abstract

Circular economy and nutrient recycling have become central aims of agricultural development domestically and internationally. In Finland the enhancement of nutrient recycling is hindered by the areal dividedness of agricultural production. The high animal densities in West-Finland produce more manure nutrients than the area can sustain whereas in the South-Finland the Uusimaa region is dependent on mineral phosphorus fertilizers as there isn't enough manures in the region. Also the unutilized grasslands have potential for increasing efficient silage and energy grass production, which enables nutrient recycling through biogas or livestock production.

In this thesis the agricultural production structure of Uusimaa is approached from the perspective of the regional feed production and the feed production potential as an enabler of more balanced regional crop-livestock production. Simultaneously the regional nutrient recycling and livestock product self-sufficiency enhances.

The method used is MFA (material flow analysis) which is applied to the case study area of the Mäntsälä municipality with results scaled up to the rural areas of Uusimaa County. The materials were based on annual statistics of Finland's production structure and agricultural production. The Mäntsälä municipality's nutrient balance of nitrogen and phosphorus, the average yields and self-sufficiency in livestock products were analyzed. Three alternative scenarios were introduced to analyze the possibilities of increasing livestock production, enhancing nutrient recycling and attaining livestock product self-sufficiency.

The case area has remarkable potential for livestock production increases. With these increases the cereal dominated region gains the possibility of replacing a majority of mineral fertilizers with the manures. Simultaneously, the municipal production can come close to meeting the municipal consumption. These additions of livestock can be carried out without changes in crop areas, but then the livestock production would depend on imported mineral and protein feeds. Also the increases in protein feed needs can be met by transforming the needed areas from cereal areas. In addition the unutilized grasses provide a potential for enhancing the areal silage production. The case study area can't meet the areal consumption of livestock produce without using the expanse of the present cereal cultivation areas.

The results suggest that Uusimaa and its surrounding rural regions have great potential for increasing livestock production and enhancing the nutrient recirculation, whereas the regional consumption cannot be met with the regional production. To enhance sustainable agroecosystem in Finland changes in production structure, way of production and the consumption patterns of citizens are needed.

Keywords
Food systems, production structure, nutrient balance, nutrient recycling, food self-sufficiency, agroecology, industrial ecology, symbiosis

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Tiivistelmä

Kiertotalous ja ravinteiden kierrätys on noussut keskeiseksi tavoitteeksi sekä kansallisesti että kansainvälisesti. Suomessa maatalouden ravinteiden kierrätyksen edistämistä hidastaa tuotantorakenteen alueellinen keskittyminen. Länsi-Suomessa suurien eläinyksikköjen lantojen ravinnemäärät ylittävät alueellisen kasvintuotannon tarpeen, kun taas Uudellamaalla Etelä-Suomessa maataloustuotanto on riippuvaista väkilannoite fosforista alueen vähäisen eläintuotannon vuoksi. Myöskään viljelmättömien nurmien potentiaalia rehun- tai energianurmen tuotantoon, joka mahdollistaisi ravinteiden kierrätyksen biokaasun- ja kotieläintuotannon kautta, on hyödyntämättä.

Tutkielmassa lähestytään Uudenmaan maatalouden tuotantorakennetta näkökulmasta, jossa alueen rehuntuotanto ja rehuntuotannon potentiaali nähdään mahdollisuutena tasapainottaa alueellista tuotantorakennetta lisäämällä alueen kotieläintuotantoa. Samalla alueen ravinnekierto ja eläintuote-omavaraisuus paranee.

Käytettynä menetelmänä oli MFA (material flow analysis) -tapaustutkimus rajautuen Mäntsälän kunnan alueelle, jonka tuloksia skaalataan Uudenmaan alueelle. Tutkielman aineisto perustui vuosittaisiin kansallisiin maataloustuotannon rakenne- ja tuotantotilastoihin. Niiden perusteella määritettiin Mäntsälän nykytilanteen typen ja fosforin ravinnetaseet, satokeskiarvot ja alueen omavaraisuus kotieläintuotteissa. Kolmen vaihtoehtoisen skenaarion avulla tarkasteltiin mahdollisuuksia lisätä alueen kotieläintuotantoa sekä parantaa alueen ravinteiden kierrätystä ja saavuttaa kotieläintuoteomavaraisuus.

Alueelta on huomattavaa potentiaalia kotieläintalouden lisäämiseksi. Lisäämällä alueellista kotieläintuotantoa viljanviljelyyn keskittyneellä alueella on mahdollista korvata valtaosa tuotantoon tarvittavista väkilannoitepanoksista eläinten lannoilla. Samanaikaisesti myös alueellinen tuotanto pystyy vastaamaan paremmin alueen kulutusta. Nämä kotieläintalouden lisäykset on mahdollista toteuttaa ilman pellonkäytön muutosta, mutta tällöin tuotanto tulisi nojautumaan tuontiin mineraali- ja valkuaisrehujen osalta. Myös valkuaisrehun kasvavaan tarpeeseen voidaan vastata alueella, muuntamalla osa vilja-alasta tarvittaville rehukasveille. Myös viljelemättömät nurmialat ovat potentiaalinen kohde alueellisen rehutuotannon parantamiseksi. Tapaustutkimuksen alueen kotieläintuotteiden kulutukseen ei kuitenkaan voida täysin vastata ilman alueellisen leipäviljan viljelyn heikentämistä.

Nämä tulokset viittaavat siihen että Uudenmaan alueella on paljon potentiaalia lisätä kotieläintuotantoa ja parantaa ravinteiden kierrätystä, vaikkakin asukkaiden kulutus on yli tuotantorakenteen mahdollistamien määrien. Jotta Suomen ruokajärjestelmä kestävyys vahvistuu, on tarpeen tehdä muutoksia sekä tuotantorakenteessa, tuotantotavoissa että kansalaisten kulutustottumuksissa.

Avainsanat
Ruokajärjestelmät, tuotantorakenne, ravinnetase, ravinteiden kierrätys, elintarvike omavaraisuus, agroekologia, teollinen ekologia, symbioosi

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Contents

1 INTRODUCTION

Modern agriculture has been stated to be failing in sustaining the people and resources on which it relies, and that it has come to represent an existential threat to itself (IPES-Food, 2016). Peaking fossil resources and accelerating climate change cause alarm about evident need for conversion towards more sustainable inputs to the food system. GHG emissions need to be reduced, as well as the consumption of primary resources, such as energy and water, reduced. Key to successful conversion is the adaption of the circular economy as the central function for the food system (Colonna et al. 2013).

Currently only 6% of all materials processed globally are recycled and contribute to the circular economy. Closing the circulations of biomass would raise this percentage to 37% and utilizing sustainably produced biomass can substitute a great amount of fossil energy sources (Haas et al. 2015). The change is not only needed in technical innovations and local actions but also in politics and economy (Colonna et al. 2013).

In Finland the two biomasses with greatest potential for nutrient recirculation are manure from agricultural animals and unutilized grasses (Marttinen et al. 2017). The issue hindering the utilization of these biomasses is the dividedness of the production structure. High animal densities have been concentrating to Western Finland (Tattari et al. 2012) whereas Southern Finland has diminishing livestock farming (Niemi and Väre, 2017). This dividedness leads to the disuse of grasses in crop cultivation dominated areas and piling up of manure nutrients in the high animal density areas (Ylivainio et al. 2015).

To pursue for sustainable food production this paper introduces industrial ecology and agroecology and their combined practical application **agroecological symbiosis (AES)** (Koppelmäki et al. 2016). Transition to AES is modeled in a case area of one municipality in a simplified model of balanced ratios of livestock and crop production. This modelling effects on local nutrient circulation and fulfillment of the local consumption are analyzed. These results mark the footmarks and frames of developing a regional sustainable agroecosystem.

2 BUILDING A SUSTAINABLE REGIONAL AGROECOSYSTEM WITH INDUSTRIAL ECOLOGY AND AGROECOLOGY

Regional specialization of agricultural production especially livestock production has increased the efficiency of the production while it has also increased the environmental burden of agriculture (Tilman et al. 2002). Methods of industrial ecology and agroecology can complement each other in reducing the negative environmental effects of agriculture (Dumont et al. 2012). This chapter considers the ecological issue of the Finnish agricultural production structure, introduces industrial ecology and agroecology from the literature and leads the reader over the concept of agroecological symbiosis.

2.1 Smoldering ecological issues of Finnish production structure

According to annual statistics (Luke, 2018), Finland had 48 562 agricultural and horticultural enterprises in year 2017. The medium farm area is 47 ha and 1/3 of farms have more than 50 ha of cultivated area. Ca. 29% of Finnish farms are livestock farms, 70% are crop farms and ca. 1% are other farm types including horse-, sheep- and goat-farms.

Finland’s nutrient balances have similar trends as other European countries. Nitrogen levels are close to the average of all EU-countries and the phosphorus levels are bit higher than EU-country average. In numbers these levels are 50 kg N /ha and 4 kg P/ ha (Hari and Riiko, 2017). When looking at regional nutrient balances in Finnish production structure the dividedness becomes visible. In nine out of fifteen administrative regions manure phosphorus is in excess to the needs of the cultivated crops (Niemi and Väre, 2017). Only half of Finland’s arable fields receive manures, so there is 1 mill. ha area left outside of the nutrient cycling in the form of manures (Seuri, 2018b). The area of high animal density in Ostrobothnia has high manure P surplus (even more than 10kg P /ha) and Southern Finland’s Uusimaa is a cereal dominated area, which doesn’t have enough manure phosphorus for to cover the plant need (3kg P/ha) (Ylivainio et al. 2015). The issue emphasizes geological location. For example, the eutrophication effect of nutrient leaching on the shore of south-west Finland is the highest in the country (Uusitalo et al. 2007). Granstedt (2000) underlines that the specialization of farms and regional production is the main reason for high surplus and losses of plant nutrients.

This imbalance of availability of recyclable nutrients has driven the conversation towards two alternative solutions. Processing the manure resources into a suitable form for long distance logistics or reversing the areal specialization of agricultural production.

2.1.1 Potential of uncultivated grass areas

In 2017 12% of Finland’s arable land (280 000 ha) was on unutilized grasses (Luke annual statistics, 2018). The majority of these are nature management fields 57%. Other unutilized fields are fallows (23%), green manure leys (11%) and old (>5years) grasses (9%). Theoretically these land areas provide the potential for increasing the cultivated grass areas with ca. 40% when fully utilized. In practice the majority of these fields are too small or too hard to reach for efficient production, but still the majority of the hectares (>60%) come from the biggest fields that have potential for efficient cultivation (Niemeläinen et al. 2014).

These land areas have potential for ether silage production or biomass production for bioenergy e.g. biogas production. For the biomass production of biogas the solubility of the grasses doesn’t play an important role, so the harvest can be postponed and optimized for biomass gain (Niemeläinen et al. 2014). Biogas production can improve the nutrient circulation and enhance the energy self-sufficiency in the region (Helenius et al. 2017). Converting unutilized grass fields to silage production especially on the areas that lack recycled nutrients offers a possibility to increase the livestock production in the area, improve the nutrient circulation and set in motion the reversion of the regional specialization of agriculture.

2.2 Industrial ecology

Industrial ecology (IE) is a theory by Frosch and Gallopolous (1989) that views industries´ relation to the natural ecosystem in the form of material and energy flows within and between these two independent systems (Jelinski et al. 1992; Korhonen 2002; Lifset 2002). Industrial ecology observes “industry” in its broadest sense, as a total sum of human activity (Graedel and Allenby, 2003)

2.2.1 The aim and operation of IE

The aim of industrial ecology is to minimize the need for imports and exports of resources between systems in order to decrease the environmental impacts at every stage of production and consumption (Despeisse et al. 2012).The material flows are redesigned from linear to cyclic, in such way that the use of new resources is replaced with recycling as much as possible (Lifset, 2002). IE has possibilities to reach a triple win situation on all three classical dimensions of sustainable development (environment, social and economic) as optimizing material and energy flows can also be economically beneficial and create employment (Niutanen and Korhonen, 2003).

IE operates on different levels (company, local, regional/global) and it reflects both theoretical aspect (systemic analysis) and application oriented activities (eco-design) (Lifset, 2002). The tools used are variable: recovery and recycling processes, products and process design, technology, organizational and management strategies and governmental operations (Niutanen and Korhonen, 2003). Gertler (1993) introduced two different practical approaches that have become general in IE.

The first approach of IE focuses on the product perspective. Life cycle assessment (LCA) has become a central tool for evaluating the environmental effects of a products full life span. The aim of this approach is to design a product that will generate minimum environmental impact or design the product component to be reusable (Korhonen 2002).

The second approach of industrial ecology is local-regional industrial ecosystems. Industrial ecosystems are closed loop systems, where the input reprocessing is optimized to a level that minimizes the emergence of waste. A local-regional industrial ecosystem is a collection of individual industrial actors in a geographically defined area, which form synergies to utilize each other’s by products and excessive energy. Usually these ecosystems are arranged with physical connection between production, consumption and recycling with short distances (Korhonen, 2002). This approach has developed into a concept of Industrial symbiosis (IS), which has taken shape in the form of eco-industrial parks (EIP) (Chertow, 2000).

2.2.2 Industrial symbiosis

Industrial symbiosis (IS) is described by Chertow (2000):"Industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity." Ten years later Lombardi et al. took up the task to redefine the concept of IS. Their view is that creating and sharing knowledge, cultural-exchange and eco-innovation of diverse organizations is more essential for Industrial symbiosis than geographical proximity and physical resource exchange (Lombardi and Laybourn, 2012).

The eco-industrial park is a community of companies integrating elements of sustainable design for greater collective environmental and economic benefit than possible in individual performance optimization. The EIP concept is based on the appliance of ecological principles to industrial activities and community design. EIP combines industrial ecology principles with principles of pollution prevention and sustainable design, architecture and construction. EIP demonstrates sustainable economic community by encouraging companies in cooperation toward mutual benefits, competitive advantage and to achieve these principles. EIP design includes the elements of integration into natural systems, energy systems, material flows, water flows, park management and support services and sustainable design and construction (Lowe 1996).

Chertow (1998) introduced the term anchor tenant as a more promising approach to modeling eco-industrial parks. An anchor tenant is the central private or government owned actor who is willing to “host” an eco-industrial park as a central function. The EIP would then be built as a network of businesses to supply and reuse residues from the anchor tenant. According to Chertow, since building an EIP from scratch will in many cases take tens of years of planning and forming linkages, approaching the issue from central anchor tenant perspective would be a useful starting point for greatly increasing the level of industrial symbiosis.

The first model of IS is Kalundborg eco-industrial park in Denmark (Chertow, 2000). It started as a synergy of coal-fired power station, an oil refinery, a biotech and pharmaceutical company, a producer of plasterboard and a soil remediation company. The material flows utilized were water, solid waste, steam and energy. Economic and environmental evaluation of Kalundborg IS shows significant benefits, but also potential for further optimization. Environmental benefits were seen in decreasing of groundwater use and pollution, which also brings direct economic benefit in savings of costly groundwater use. Also steam exchange is economically and environmentally feasible, as the GHG emissions are smaller and steam's market prices fluctuate. (Jacobsen, 2006)

2.3 Agroecology

Like industrial ecology, agroecology is based on integrating aspects of biological interaction and establishing cyclic rotations instead of the linear paradigm. Agroecology is a scientific discipline that views agriculture from an ecological and socio-economic perspective (Altieri, 1989). Francis et al. 2003 defined it as the ecology of food systems. It defines, classifies and studies agricultural systems for providing methodology to diagnose the current state of agriculture. Agroecology defines the necessary ecological requirements for sustainable food production (Altieri, 1989) whilst acknowledging the multidimensional aspects of socially equitable development (Altieri, 2004).

Agroecologists question the possibility of dealing with the complexity of resource use and design of future systems by only considering the production aspect, short-term economics and local environmental impacts. Agroecology embraces holistic systems thinking while underlining the uniqueness of each region to find innovative ways to increase productivity and sustainability of agriculture without unbalancing the ecological balance. The suitable solutions are always affected by the local resources and constraints (Francis et al. 2003). Agroecology works on every level from the concrete spatial scale of field and farm until the full extent of the global food system (Wezel et al. 2009). Agroecology can provide know-how to deal with challenges at the system level in development of sustainable societies (Francis et al. 2003). Agroecology uses two basic units: the agroecosystem and the food system.

2.3.1 Agroecosystem

The term agroecosystem originates from the ecological term ecosystem and is defined by Conway (1986): “ecological systems modified by human beings to produce food, fiber or other agricultural products. Like the ecological systems they replace, agroecosystems are often structurally and dynamically complex but their complexity arises primarily from the interaction between socio-economic and ecological processes.” The term agroecosystem can be used on every level of agroecological study from a single plant or animal environment to a global agroecosystem and consists not only of the bio-physical environment, but also of socio-economic and cultural environment (Conway, 1986). Instead of focusing on one particular component of agroecosystem, agroecology studies the relations of all agroecosystem components and the dynamics of ecological processes (Altieri, 1996). Natural ecosystems have evolved through centuries into a stable and resource efficient balance with the interaction of plants and animals species. These natural ecosystems can be used as examples when modeling agroecosystems. Many ecologically exemplary farming systems are found in traditional and indigenous agroecosystems, which have evolved in co-operation between nature and culture (Francis et al. 2003).

2.3.2 Food system

The term food system has been used to describe an agricultural or food chain which formally identifies all operations, flows and actions involved in the process from the farm to the consumer. This chain description has been criticized for not being broad enough. In a broader sense a food system reflects all the resources, institutions, practices and stakeholders through which societies organize their food. The food system is the global entirety of different types of food systems. It consist of domestic, local, regional, agri-industrial and differentiated quality food systems. Domestic, regional and local food systems as the traditional source of food are being replaced by agri-industrial food systems especially in the developed countries. Traditional food systems have been maintained and differentiated quality food systems, such as organic farming systems, developed as alternatives to agri-industrial food systems. To evaluate sustainability of these food systems every type must be evaluated individually (Colonna et al. 2013).

2.3.3 Applying agroecology

Concepts of agroecology can be applied to conventional farming systems. Altieri & Rosset (1995) described the conversion process to an agroecological farming system with four phases:

1) Progressive chemical withdrawal.

2) Rationalization and efficiency of agrochemical use through integrated pest management and integrated nutrient management.

3) Input substitution, using alternative, low-energy input technologies.

4) Redesign for diversified farming system.

The first three phases introduced by Altieri & Rosset (1996) focus on conversion from high-input conventional management into a sustainable low-input system by decreasing the use of agrochemicals and finding alternative inputs and management activities. The phases are to be managed to ensure processes of increasing biodiversity both in soil and above ground, increasing biomass production and soil organic matter content and decreasing levels of pesticide residues and losses of nutrients and water components. In the fourth phase the farming system should be rethought completely as a diversified system with an optimal crop or animal integration, which maintains soil fertility, natural pest regulation and crop productivity. Redesign should focus on establishment of functional relationships between the various plant and animal farm components and optimal planning of crop sequences and combinations and efficient use of locally available resources.

Dumont et al (2012) contributed the principles of applying an animal production to agroecology based on the previous principles of Altieri. The principles of adaptation of animal production are: 1) adopting management practices aiming to improve animal health, 2) decreasing the inputs needed for production, 3) decreasing pollution by optimizing the metabolic functioning of farming systems, 4) enhancing diversity within animal production systems to strengthen their resilience and 5) preserving biological diversity in agroecosystems by adapting management practices.

IPES-Food (2016) has approached transition to agroecological farming from the two different perspectives of subsistence agriculture and industrial agriculture. The steps for the transition are similar in their approach to diversifying and building agroecological knowledge but their approach to market and technology perspective they differ. For subsistence agriculture connecting to the markets and mechanizing has been seen as important steps of transition. For industrial agriculture the perspective is quite the opposite since relocalizing markets and reducing chemical inputs have been seen as important steps.

Applying only agroecological practices is not enough for the development of a sustainable society. For example the rising demand has moved the organic farming industry, which uses many agroecological practices, into the direction of industrial agriculture as the farm sizes have grown. As the farm sizes have grown the farming systems have specialized and developing countries have increased organic production. Organic farming is being abducted under the management of the industrialized conventional system. As organic certification doesn´t address social issues, Agroecology calls for more wholesome changes to resolve both the social (food security, small-farmer income, etc.) and environmental issues related to food production (Altieri, 2003).

2.4 Applications of Industrial ecology in food production

Agroecology and industrial ecology both are based on the ecosystem concept, which makes them applicable to agricultural systems as a combination. They offer contrasting alternatives: agroecology focuses on diversity of natural resources and preserving biodiversity and industrial ecology optimizes the material and energy flows while reducing pollution and resource use (Dumont, 2012). This combination generates possibilities of creating regional self-sustaining agricultural systems.

2.4.1 Agro-industrial symbiosis

At the regional level industrial ecology and industrial symbiosis can be adapted to geographically linked agricultural enterprise groups, e.g. agri-food clusters (Simboli et al. 2015). This kind of adaptation is defined as agro-industrial ecology by Fernandez-Mena (2016). The agricultural enterprise groups that are utilizing industrial symbiosis are called Agro-industrial Parks (AIP). AIPs are heterogeneous organizations of actors for example from horticulture, food, processing and logistic enterprises connected by symbiotic ties of waste, by-product, resources and information exchange (Nuhoff-Isaljanyan, 2016).

One example of agro-industrial symbiosis is Honkajoki Oy in Finland. Honkajoki Oy’s anchor tenant is a recycling facility for animal sourced waste and the other participants are a meat processing plant, a biogas plant and two nearby greenhouse producers. The waste (e.g. slaughter waste) is recycled in to animal protein, organic fertilizer or biomass for biodiesel. The waste heat from the recycling process is utilized in the nearby greenhouses. Waste gasses of the process are combined with biogas refined from the organic wastes and burned for heat in an energy plant. The energy plant produces steam and hot water, which are used to power the recycling facility and heat a nearby meat processing plant. For the wastewaters there is a sewage plant and the wastewater sludge is recirculated to the biogas plant. (Honkajoki Oy -webpage, visited 20.1.2017). The circulation of wastewaters and waste-biomass are especially efficiently utilized in this agro-industrial symbiosis.

Agro-industrial symbiosis has regional and even national potential to improve social, economic and environmental balance. Including small rural farmers into the agro-industrial symbiosis, creates possibility to distribute wealth and incorporate low income areas within the national economy (Ometto, 2006). It gains numerous benefits from sharing wastes, by-products, knowledge and innovations, such as reduction in use of non-renewable resources and decrease in emissions and wastes. It creates employment (Niutanen, 2009) and supports local and national economies (Ometto, 2006).

For achieving sustainable regional agroecosystem agro-industrial symbiosis stumbles on strong linkages to industrial agriculture and dependency on mineral fertilizers and fossil energy. The scale and the industrial character of agro-industrial symbiosis prefer the quantities and qualities of industrial agriculture (Ge et al. 2011). For example, as Honkajoki Oy utilizes the by-products large of scale meat industry, it can be seen as a part of the global food industry. From the agroecological view the agro-industrial symbioses don´t meet the needs for market restructuring and chemical withdrawal. Agro-industrial symbioses do address the environmental issues of conventional farming through waste utilization, but it lacks the ecological perspective of wildlife and nature conservation. Agro-industrial symbioses have a positive effect on employment, but it doesn’t address the social issues of modern agriculture. To fix these flaws in the food system a new idea of merging localism and agroecological practices within the model of agro-industrial symbiosis has risen.

2.5 Agroecological symbiosis

In this chapter a new model of industrial symbiosis is introduced. It combines agroecological knowledge and a perspective of environmental sociology on agro-industrial symbiosis. First the issues at hand must be addressed.

2.5.1. Social issues of food industry

The food industry’s prime objective has been historically to conserve and preserve essential nutrients to ensure their availability throughout the year. Especially the development of cold chains among other preservation techniques favored the development of abundant supplies. To ensure the quality of end products industry turned towards the assembly policy of breaking down the raw agricultural material and assembling it as products aimed at consumers. This process was made profitable through the standardization of agricultural raw materials, which meant the simplification of isolated agricultural producers. Industrial food stuffs started to change the markets from small specialized trades with smaller local product emphasized variety to non-specialized supermarkets with global emphasized vast variety of products (Soler, 2013). While gaining the economic and environmental benefits of outsourcing production of certain food commodities to the most favorable areas (Brodt, 2013) this development has created many long-term social and environmental issues. From the social perspective the issues that have arisen include displacement and dispossession, dietary changes and increasing distance between production and consumption. Environmental issues such as biodiversity loss, soil depletion, deforestation and greenhouse gas emissions are also drastic (IPES-food, 2016)

2.5.1.1 Metabolic Rift

The term metabolic rift is based on Carl Marx's theory of the separation between humans and nature as the cause of the shattering of the natural nutrient cycle. Metabolic rift describes the distance between the area where food is being produced and the place of the consumption (Robbins, 2015). As the production and consumption are distant, the nutrient cycle is broken by the piling waste in area of consumption and the excess environmental damage in the area of production. The gap in biophysical cycles causes nutrient loss, environmental loss and pollution (biophysical override) and the agro-industries cheap food regime has led to displacement of small producers, especially in developing countries, by land grabbing and market predation. This development has had major negative effects on food security (McMichael, 2014).

2.5.1.2 The disappearing middle

The power on the markets has shifted from farmers to industry. The major actors in food processing, marketing and retail have gained the ability to set the price of food and garner most of the profit (Sexton, 2000). The concentration of power has led to a continuous decrease in the share of income that the farmers get for the food produced. This has led to dividing the farm sector into small- and large-scale farms. Larger farms manage the situation by compensating the lower margins with higher volumes and smaller farms through lower volumes and shorter value chains or direct marketing. The middle sized farms have been disappearing as they are increasingly unable to fit in the two aforementioned market strategies. This has larger social effects as the mid-sized processors and retailers are publicly visible actors linking consumers with food production and processing activities. To defend the “disappearing middle” many agricultural scholars (e.g. agroecologists) have started to advocate alternative food networks. (Legun, 2016)

2.5.2 Localization

A counter movement against metabolic rift, localization stands for relocating food consumption and production in geographically fixed areas. It’s a direct critique of globalization and the physical distance between consumption and production. It also considers more complex notions of distance. Localization prioritizes local and national economies and empowers peasant and “family-scale” farms (Brown, 2008). The advantages of localization are especially based on the closeness of production and consumption, short processing chains, diverse local production and refinery co-operation and sharing of local resources. Localization means partial reorganization of food systems and that various affects, such as keeping the environmental impacts intact in the area of production. Local food generates willpower for enforcing sustainability in production (Kuhmonen, 2015)

2.5.2.1 Food sovereignty

The term food sovereignty also arises from localization, which is a political discourse, a proposition and a utopian concept of a desired system of agricultural production, distribution, consumption and social interaction (Robbins, 2015). Food sovereignty policy underlines the idea that food security's "right to food" isn't enough as there is a need for collective "right to produce food". At the core of food sovereignty is the desire to provide an alternative model of rural development as a landscape inhabited by farmers/pastoralists/fishers geared to sustainable ecological relations. By enhancing the rural livelihood and autonomy, food sovereignty acts as a vaccination against the rural exodus from countryside to urban areas, which has reached unsustainable levels (McMichael, 2014). Food sovereignty is a political and practical alternative which tries to challenge the capitalistic food regime and has become an important part of the discourse on restructuring the food system. (Robbins, 2015)

One example of food sovereignty's practical applications is farmer markets. Farmer markets are usually non-profitable market platforms for local food producers and consumers to build producer-consumer relationships. Ethics, politics and communalism meet in farmer markets in the form of alternative economic exchange as practical political activity. Some farmer markets also organize less lucrative markets for low-income citizen to have access to ethical food (Alkon, 2007). In wider terms these practical appliances are called Alternative food networks (AFN).

2.5.2.2 Alternative food networks

Alternative food network is an umbrella term for alternative forms of food production and distribution. AFNs, such as Community Supported Agriculture (CSA), farmers markets, farm shops and communal food hubs etc., including natural foods and organic farming, have been considered as a response to the current food systems environmental and social issues. AFNs have been claimed to be positive benefits environmentally, socially and economically. The environmental benefits are linked to reducing the distance of food transports and including of organic practices. Social benefits come from preserving food culture and enhancing access to food. Economic benefits are linked to adding value and income to rural livelihoods, creating employment, expanding markets, supporting local economy, and reducing the economic risk for producers. Because of the variability in organizing AFNs, all these linkages cannot be considered to always occur, but the most valuable aspect of AFNs is promoting and mainstreaming sustainable food through learning and participation (Forsell, 2014).

2.5.3 Agroecological symbiosis

Agroecological symbiosis is a totally new concept of agro-industrial ecology and agroecology. It combines industrial symbiosis, alternative food networks and agroecological farming methods. Agroecological symbiosis is a concept of food production where primary production (agriculture and horticulture), food processors, food retailers and consumers function as a symbiotic food system (Koppelmäki et al. 2016). The concept has started from the initiative of an organic enterprise network in Palopuro, Hyvinkää in Finland. The Palopuro Agroecological Symbiosis (AES) pilot is a co-operation of local primary producers, the regional energy company and an organic bakery (Fig 2).

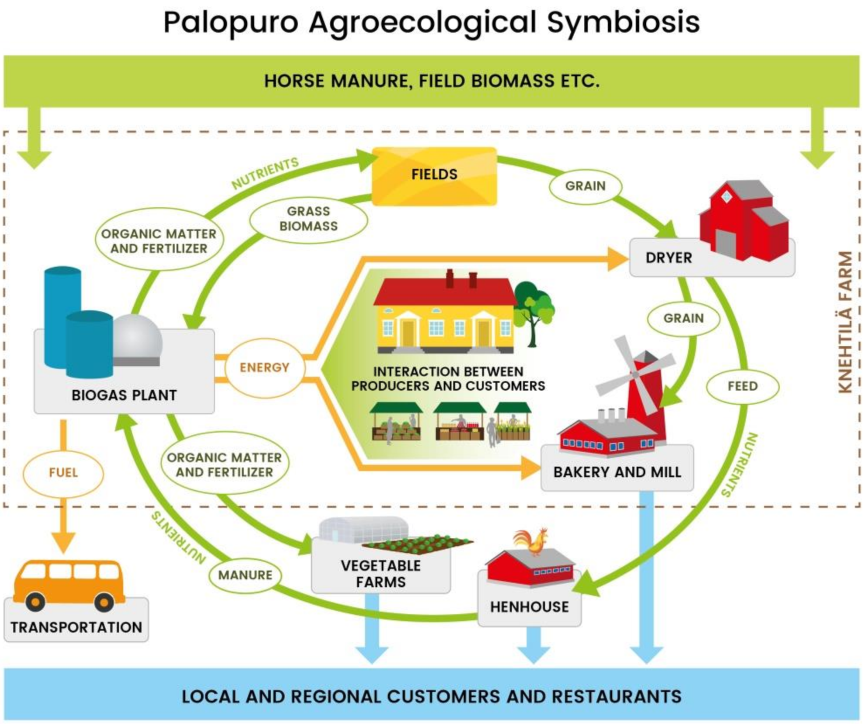

Figure 2: Palopuro agroecological symbiosis. Palopuro AES- webpage.

The anchor resident of Palopuro AES is Knehtilän tila, an organic cereal farm, which applies agroecological practices. In the center of this symbiosis is an on-farm biogas plant, which enables nutrient circulation from unutilized grasses and other organic waste streams. The symbiosis is planned to be accompanied by an organic bakery. The farm will produce cereals for the bakery and a local henhouse, which on the other hand will supply eggs for the bakery and manure for the biogas plant. The biogas plant will use also manure from local horse stables and the main source of biomass will be the grasses in the rotation of Knehtilä -farm.   The biogas will be used for providing energy to drying and milling of the grain and for the ovens of the bakery. The excess biogas will be refined as tractor and local car fuel. The biogas digester sludge will be used for organic fertilization on Knehtilä –farm and at a local organic vegetable and berry farms (Palopuro AES- webpage, visited 23.1.2017; Koppelmäki et al. 2016).

Palopuro AES aims at getting the majority of its products to be sold locally and regionally. Currently all the members of this network are selling products directly to local customers. There is a meeting/conference room and farm shop, which offers a vast variety of local products at the Knehtilä farm. The network also hosts numerous farmer markets annually. The pilot has shown that the entrepreneur driven cooperation is clearly feasible. The AES can increase productivity, sustain ecological balance, conserve local environment, form economic profits and increase the social support for sustainable food production (Helenius et al. 2017).

2.4.3.1 Network of agroecological symbioses as a model of sustainable regional agroecosystem

The vision of a network of Agroecological symbioses originates from the University of Helsinki’s AES-Networks project. This project aimed to multiply the AES-model on regional scale. The vision is that by implying the AES-model in the production structure it’s possible to gain crucial environmental benefits compared to conventional production structures. The vision is that the regional food production would be based on locally adapted agroecological symbioses, which would consist of the three actors, primary production, bioenergy and food processing (Fig 3). These symbioses would produce food, groceries and energy for transportation and heating. The symbiotic relations would enhance local nutrient recirculation, regional economy and food culture. (AES-Networks- project, 2018, Personal inquiry)

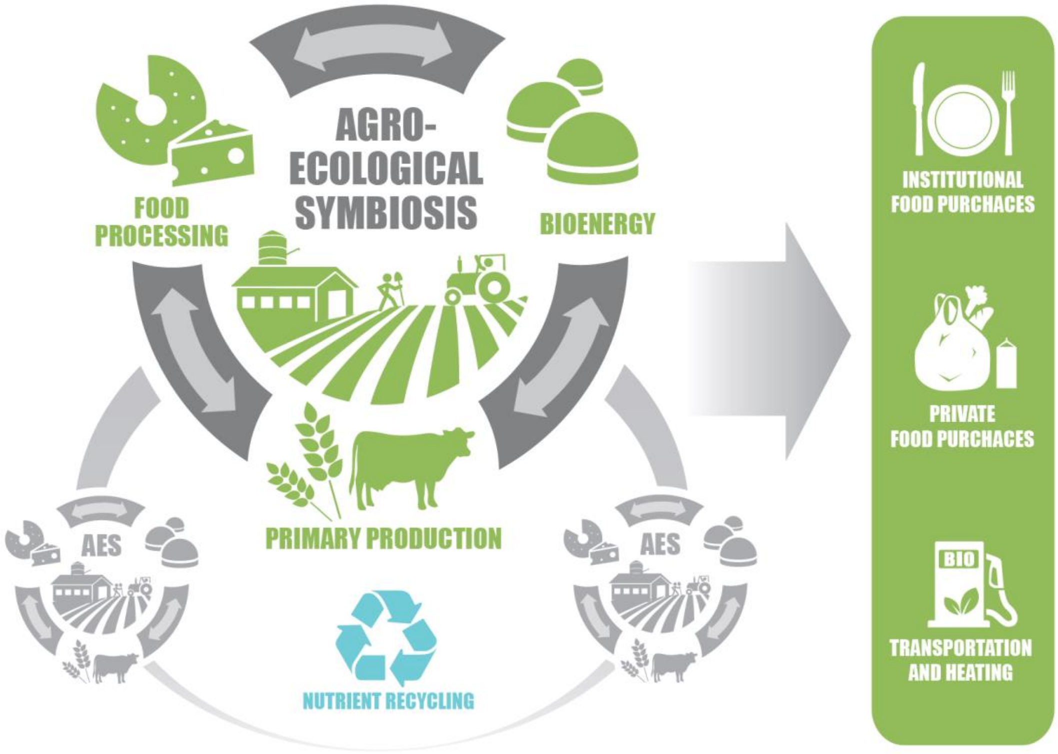

Figure 3. Network of agroecological symbioses, AES-Networks –project, 2018. Personal inquiry.

3. AIMS OF THE RESEARCH

This study tackles the issue of dividedness of Finnish agricultural production through reorganization of local production structure. It sees production structure as the key factor in change toward a sustainable local agroecosystem. The AES-network project strives for building a network of agroecological symbioses through optimizing the regional nutrient circulation through biogas production with the available agricultural side streams. This study takes an alternative approach to regional nutrient circulation by bringing animals, and therefore more manure into the case area. The focus of the study is to analyze the potential of case area production structure for livestock additions. The relation of areal production and consumption and the effects of that relation on the sustainability of the production are given focus. The research questions of the study are:

- What are the numbers of animals the current silage, cereal feed and protein feed areas could sustain?
- What additional potential to livestock production is available through use of unutilized grasslands as silage and complete local utilization of feed cereals?
- What kind of land-use changes are needed to maximize areal livestock production with local energy and protein feeds without compromising the food grain production proportions?
- How would converting a cereal dominated production structure toward more balanced, mixed livestock-crop production affect the nutrient circulation and fulfillment of consumption in the area?
- To what extent the current use of mineral fertilizers could be reduced by nutrient recycling from local feeds to the livestock and back to the fields in form of manure?
- Assuming current demand for primary production for food, to what extent food could be localized by the introduction of livestock? Is the current level of consumption even possible to be produced locally?

The study aims to find out how and to what extent the production structure in a cereal dominated area should be changed by replacing mineral fertilizers with recycled nutrients. At the same time local self-sufficiency and production potential for meat, eggs and dairy are analyzed.

4. MATERIAL AND METHODS

This research was linked to the AES Networks project, which has a Southern Finnish rural town Mäntsälä and its agricultural area as the case study area. In the region of Mäntsälä and its neighbors agriculture is dominated by specialized arable farming, with production of cereals dominating. The production is dependent on imported mineral fertilizers rather than on recycling plant nutrients within the region. Mäntsälä represents an average rural town in Uusimaa region and the results can be assumed to be scalable for the rural area of Uusimaa County (excluding the capital region of Helsinki, Espoo and Vantaa). One municipality isn’t a desirable unit for self-sufficiency, but through modelling one case it is possible to identify regional restrictions in transformation toward sustainable agroecosystem.

In this research, the challenge of transforming to sustainable agroecosystem is approached as a structural issue: A more balanced mixture of arable farming and dairy farming would allow for recycling plant nutrients through use of manure and slurry as organic fertilizers. Three scenarios are developed as redesigned structures of farming in Mäntsälä. The nutrient balances are analyzed from the perspective of substituting mineral nutrient inputs. Theoretically, the redesign to increased share of animal production with high local self-sufficiency in feeds would increase regional self-sufficiency in animal products, at cost of cereal exports. Hence, the changes in production in these scenarios are compared to consumption of dairy and meat products in Mäntsälä.

To assume complete feed self-sufficiency is not reasonable as the intensive animal production is based not just on grain and legumes but also on a range of minerals and additives. More relevant is to find out how would the local nutrient circulation be enhanced while the area also gains more diverse agriculture. Modeling of interlinkages between production structure, nutrient circulation and food consumption aims at revealing the potential to disassemble the regional specification of agriculture.

4.1 Data sources

The data sources are summarized in Table 1. The food production data are collected from Natural resource institute Finland’s statistics of agricultural production and food consumption (Luke, 2018). For animal manure statistics the data are collected from Finnish normative manure system -project manure statistics (Luostarinen et al. 2017) and the limitations of manure use are from the EU CAP regulations (Mavi, 2018). The region soil fertility data were inquired from Eurofins Scientific ltd.’s soil fertility database (Eurofins, 2018) and the regional levels of mineral fertilization were based on nutrient balance calculations of Turtola et al. (2017) and supplemented with personal inquiry from a soil scientist at (Tapio Salo, personal communication, June 2018) Natural resources institute Finland.

Table 1. Overview of the data sources.

Type of data	Data source
Production statistics	Luke annual statistics, http://stat.luke.fi/
Food consumption data	Luke annual statistics, http://stat.luke.fi/
Numbers of production animals	Luke annual statistics, http://stat.luke.fi/
Feeding requirements of production animals	MTT (2006); Luke (2015);Pulkkinen et al. (2019); Perttilä (2013); Siipikarjaliitto (2018).
Slaughter % and average carcass weight	Luke annual statistics, http://stat.luke.fi/
Nutrient balances	Ylivainio et al. (2015) ; Pulkkinen et al. (2019)
Nutrient content of crops	MTT (2006); Luke (2015)
Nutrient content of manures	Luostarinen et al. (2017)
N and P mineral fertilizer use	Turtola et al. (2017); Tapio Salo, personal communication, June 2018
N and P fertilization limits	EU CAP fertilization statistics (Mavi, 2018)
Municipal soil fertility statistics	Eurofins Scientific ltd (2017)

4.1.1 Scope of the study

The study focuses on the most central crops and production animals (Table 2.). Also some generalizations are made for simplifying the structure of the calculations.

Table 2. Scope of the study

Included	Excluded
Main crops:	
Focus on cereals, grasses and legumes and oilseeds. Turnip rape and rape are treated together as “rapeseed” Pea and broad bean area are as “ pea”	Vegetables and other marginal crops are framed out.
Production animals :	
Focus on cattle, pork, laying hens, chicks and broilers.	Turkeys, sheep and other marginal production animals are framed out of this study.
Feeds	
The main components of feed for:	Mineral feeds
Cattle Silage, cereal & rapeseed	Grazing on pastures
Pork Cereal & rapeseed	
Poultry Cereal & pea	
Nutrients	
Nitrogen Phosphorus	Leaching, evaporation and fallout of nutrients. Potassium and micronutrients

4.1.2 Case study area and its agriculture

The geographical area included in the study is the administrative area of Mäntsälä municipality. Mäntsälä is a rural town of ca. 21 000 inhabitants, located in Uusimaa county in Southern Finland ca. 50 km North to Helsinki. Of the municipality's land area (596 km^2) (Mäntsälä, 2017) 25.5 % is cultivated land (152 km^2). The typical soil type for the area is clay (ca. 73% of the field parcels) and the rest of the soils are ether organic soils (ca. 7%) or coarse mineral soils (ca. 20%) (Table 3). In comparison to soil types in the region Mäntsälä has ca. 2% more of organic soils, ca. 10% more of clay soils and ca. 10% less of course mineral soils. According to the Finnish soil quality classification (Eurofins, 2017) availability of phosphorus in the clay soils is typically in the category of acceptable, and tolerable in the coarse mineral soils and in the organic soils.

Table 3. Soil type distribution of arable field parcels in Mäntsälä, average pH values, and average phosphorus (mg l^{-1}) and potassium (mg l^{-1}) contents in the cultivation layers.

Soil type	Number of field parcels*	Soil fertility indicators*		
		pH	P	K
Coarse mineral soils	1097	6.0	10.3	172.0
Clay soils	3914	6.1	7.2	236.6
Organic soils	373	5.6	5.7	143.7

***Eurofins soil fertility statistics, 2018**

Cereals dominate in agricultural production in Mäntsälä (Table 4). The dominant cereal was spring barley, followed by spring wheat. When comparing the cultivated areas to the region of Uusimaa, Mäntsälä represents the region fairly well (Appendix 1,Table 1.). Cereals cover 60% of cultivated area in Mäntsälä and 56% in Uusimaa. The biggest difference in cereal cultivation areas is that Mäntsälä has a larger proportion of malt barley cultivation. Feed grasses use 14% in Mäntsälä and 16% in Uusimaa and the land proportions of pea and broad bean and rape and rapeseed are similar. Also the share of uncultivated grass areas in Mäntsälä corresponds to the regional average. For arable land per person Mäntsälä has greatly more (0.71 ha/person) than the region of Rural Uusimaa (0.36 ha/person) (Appendix 1, Table 2). In Finland the arable land per person was in 2015 0.41 ha/person and globally 0.19 ha/person (World Bank, 2017). For domestic animals per arable land Mäntsälä and Uusimaa have less than 0.25 animals/ha whereas high animal density area of Ostrobothnia has 0.8-1.5 (Ylivainio et al. 2015)

Table 4. The cultivation areas, crops, average yields, unutilized grass areas and their potential in Mäntsälä in 2016. Yield averages are the annual yield averages for the area harvested in Uusimaa.

Mäntsälä	Area ha*	Average yield kg*				Total yield mill. kg
Crop	**2016**	**2015**	**2016**	**2017**	**2015-2017 Average**	**2015-2017 Average**
Wheat	2995	3920	3410	3910	3747	11.2
Winter wheat	209	4 890	3 680	4 510	4360	0.9
Rye	440	3180	3810	3910	3633	1.6
Barley	3749	3670	3320	4270	3753	14.1
Oats	1828	3670	3330	3950	3650	6.7
Rapeseed	664	1640	1530	1710	1627	1.1
Pea	415	1965	2055	2105	2042	0.9
Silage	2163	16830	14180	10880	13963	30.2
Unutilized grasses	Area ha*	Potential area for efficient silage production ha**			**2015-2017 Average yield**	Yield potential mill. kg
Fallows	773			464	13963	6.5
Nature management fields	1054			632	13963	8.8
Green manure leys	95			57	13963	0.8
Old grasses >5years	85			51	13963	0.7

*** Luke annual statistics, 2018**
****Niemeläinen et al. 2009**

Unutilized grassland such as fallows, nature management fields and green manure lays stand for 15% of the arable land in Mäntsälä. The unutilized grasslands cover combined area of 2007 ha, of which 1204 ha can be assumed to be utilizable for efficient silage production (Niemeläinen et al. 2014). This area could increase the municipal silage yield by16.8 mill. kg. In 2017 Mäntsälä had 25 animal farms and the number of animal units in the municipality was 1939. All of these animals were cattle of which 43% were milking cows (Table 5). The animals in Mäntsälä already produce 23% more milk than is consumed in the area including all milk products. Also a third of the amount of beef consumption is already produced in the area (Table 6) For broiler, eggs and pork Mäntsälä is completely dependent of the production of other areas.

Table 5. Animals and manure nutrients in Mäntsälä in 2017

Mäntsälä 2017	Cattle combined	Milking cows	Calver	Heifers	Bulls	Suckler cows
Animals*	1 939	833	28	401	121	556
		43 %	1 %	21 %	6 %	29 %
Manure nutrients kg a^{-1}/animal-unit **						
N		135.54	78.95	57.40	78.23	40.16
P		23.87	7.90	8.24	11.73	5.66
Nutrients combined t a^{-1}						
N	170	112.9	2.2	23.0	9.5	22.3
P	28	19.9	0.2	3.3	1.4	3.1

*** Luke annual statistics, 2018**

**** Finnish normative manure system, Luostarinen et al. 2017**

Table 6. Relation of consumption and production in milk, beef, pork, broiler and eggs in Mäntsälä in 2017

2017 Mäntsälä	Milk	Beef	Pork	Broiler	Eggs
Production t*	7109	139	0	0	0
Consumption t**	5793	396	738	434	233
Balance	1316	-251	-738	-434	-233
Production / consumption %	123 %	37 %	0 %	0 %	0 %

***Luke annual statistics, 2018**

**** Appendix 2. Consumption averages**

4.2 Scenarios

As an addition to the current situation three scenarios were introduced in the study to compare how increasing dairy, pork or poultry production, or combination of these in the area would affect:

(1) Nitrogen and Phosphorus balance in Mäntsälä agricultural area.

(2) Need for mineral N & P fertilizers.

(3) Need for feed for energy and protein

(4) Self-sufficiency of Mäntsälä in dairy products, eggs and meat.

The scenarios were based on calculations of municipal nutrient inputs. The inputs were examined from the perspectives of nutrient recycling, substituting mineral fertilizers inputs, meeting crops nutrient need and meeting the demand of specific meat and dairy products in the area described. External fertilizer inputs were reduced by recycling side streams of the production and the many of the outputs returned to the municipal circulation.

As the scenarios model livestock additions to the case area the areal need for livestock feeds increases significantly. These scenarios are compared to the current state scenario Business as usual (BAU). The perspectives of land use and feed production in the scenarios are outlined in the table 7. First scenario (SUFC) doesn’t expect that protein feed would be produced in the area, it only concentrates the potential of utilization of local silage resources and cereal feed production. The second scenario (MAP) adjusts the available land for maximal animal production considering the need for increases in the protein feed production. Neither of these scenarios except total self-sufficiency in livestock feeds as localization of mineral feed production isn’t relevant objective for this study. Third scenario (MEC) concentrates on the relation of production and consumption. These scenarios outline the frames of enhancing the regional nutrient circulation while meeting the local demand of meat and dairy.

Table 7. Livestock addition scenarios (BAU, SUFC, MAP, MEC)

Scenarios	BAU	SUFC	MAP	MEC
Existing production areas	Constant	Constant	Adjusted for meeting the need for energy and protein feeds	Adjusted for meeting the need for energy and protein feeds
Unutilized grasslands	Non-productive	60% conversion to silage production	60% conversion to silage production	60% conversion to silage production
Cereal feeds	Oversupply exported from the area	Consumed within the area	Consumed within the area	Consumed within the area
Protein feeds	Produced in the area	Supplemented with imported feeds	Produced in the area	Produced in the area
Municipal consumption	Constant	Constant	Constant	Adjusted with the production

Scenario BAU: Business as usual

The BAU scenario in case area is analysed for the nutrient balances in nitrogen and phosphorus. That balance is then compared to the crops nutrient needs with the assumption that the efficiency of N fertilization is 70% (Salo et al. 2013) and P fertilization is 85% (Luostarinen et al. 2011). Also the current silage production is compared to the current number of cattle and the potential area for silage production from unutilized grasslands is calculated.

Scenario SUFC: Silage from unutilized grasslands and feed from local cereals.

In SUFC scenario the available unutilized grasslands and cereal feeds are analyzed individually as potential enablers of animal additions. In the SUFC scenario 60% of unutilized grasslands (fallows, nature management fields, green manure leys and old grasslands) are turned into silage production. The 60% is the minimum potential of unutilized grasslands for efficient production (Niemeläinen et al. 2014). This increase in total silage yield is then assumed to be consumed by adding the cattle number in the area. Needed increases to the area of rapeseed production were also calculated and how this can be met with existing production areas.

In SUFC the cereal feed produced in the area is modelled to be fully utilized with introducing pigs and poultry to the area according to the amount of feed cereals available. The proportions of feed in cereal production are calculated with the national feed percentage of cereal cultivation (Appendix 3. Table 2). The energy harvest of these feed cereals was then directly converted to pigs and poultry fed with the feeding recommendations (Luke, 2016; Appendix 5.). The pigs and poultry were added to the municipal production structure in ratio of 1/9, which is directly led from the relation of the number of animals in both animal groups in Finland (Luke, 2018). The needed amounts of pea and rape seed feeds and the area needed to produce that were calculated.

The abovementioned livestock additions also increase the amount of manures in the area. This additions effect on N & P nutrient balance was calculated and mineral fertilization substitution analyzed. The animal numbers were also compared to the consumption in the area with estimates of meat/milk/egg production per animal and the average consumption of municipality of 21 000 citizens (Luke, 2018; Appendix 3, Finnish production in numbers).

Scenario MAP: Maximal livestock production by local feeds

SUFC leaves the question of protein feed source unanswered. MAP takes the modelling further with finding out the highest potential of egg, pork and broiler production while introducing the cattle additions with the utilization of unutilized grasslands of SUFC scenario. As SUFC explains the energy feed potential in the area MAP focuses on how much also the protein feed areas would need to increase to satisfy the potential animal production and how those increases would affect the present cereal areas. The effects on municipal nutrient balance are calculated in this scenario without and with mineral fertilizers in different ratios to see how well different animal combinations respond to the municipal nutrient output.

Scenario MEC: Meeting the local consumption of food

As Mäntsälä can been seen as scalable for the whole rural Uusimaa region it is also relevant to consider the need of agricultural products for local food consumption. This scenario analyses the relation between consumption of different animal products and requirement for arable land to meet this consumption. As in MAP scenario the production is modelled to be self-sufficient in energy and protein feeds, MEC determines the consumption possible with the available land areas. This modelling introduces the cattle additions with utilization of unutilized grasslands as presented in SUFC. As the consumption of eggs is rather low compared to other animal products and meeting it needs just a fraction of the feed potential, egg production is decided not to be compromised over pork and broiler production in this scenario. MEC views also the present proportions of cereals going directly for human consumption (=food grains) as something not to be compromised as the trend of diverting cereals to animal feeds should be reversed to enhance global food security (Tscharntke et al. 2012). From this perspective the municipal livestock production can only utilize raw agricultural materials which aren't consumed directly by humans. This scenario answers to the question can the case area self-sustain its consumptions.

4.3 Material flow analysis

The method used was material flow analysis (MFA) to identify the nutrient inputs and outputs in current situation and in the three described scenarios and how this change affects the inputs as mineral fertilizers vs. manure. Sensitivity analysis was done to analyze the extent of mineral fertilizer substitution with manure. These results outlined the direction for environmentally sustainable production structure of incorporated livestock and crop production. All this data were compared to the municipal feed production and meat and dairy consumption.

Material flow analysis (MFA) is a tool for analyzing industrial or societal metabolism from a system perspective (Bringezu & Moriguchi, 2002; Bringezu, 1997). In this study it was used to analyze the interlinkages between feed cultivation, animal production and nutrient circulation and also the interlinkages between municipal production and municipal self-sufficiency.   Nutrient flows in the scenarios were compared to the BAU scenario to find out how well the scenarios succeed to meet the local consumption and enhance nutrient recycling.

4.3.1 Nutrient balance

Nutrient balance is a basic tool of analyzing the nutrient flows in agricultural ecosystems. It is commonly used as environmental indicator for agriculture (OECD, 2013). A positive balance displays nutrient surplus. This is to be avoided, as nutrients in excess create an environmental risk in form of potential losses to waterways and to air. A negative balance displays a risk of nutrient deficiency and loss of productivity of the soils.

$$N_{total} = N_{input} - N_{output}$$

N_{total} = Total nutrient balance of the specific system (kg)
N_{input} = Nutrient inputs to the system, e.g. fertilizer applications (kg)
N_{output} = Nutrients output from the system, e.g. nutrients in the yield (kg)

Nutrient balance analysis is a central method in this study. As this modelling is implemented at municipal scale also the nutrient balance calculations are done at this scale (Fig 1). The municipal nutrient balances are presented as gate balances for the municipality of Mäntsälä, and as per ha of agricultural land in Mäntsälä. The inputs considered in the study are imported mineral fertilizers and local manures. Also imported feeds are present in the nutrient amounts of local manures. The recycling of the waste flows of municipal consumption isn't involved in this study. The per ha balances are compared with crops nutrient needs with the assumption that the efficiency of N fertilization is 70% (Salo et al. 2013) and P fertilization is 85% (Luostarinen et al. 2011.

Biological nitrogen fixation is considered in case of leguminous plants (peas) with limiting the nutrient input per ha to 45 kg, which is in line with the European Union's Common agricultural policy (Mavi, 2018). Silages have been viewed as non-leguminous as the proportion of nitrogen fixation in Finnish nutrient balance is estimated to be less than 10% (Seuri, 2018a).

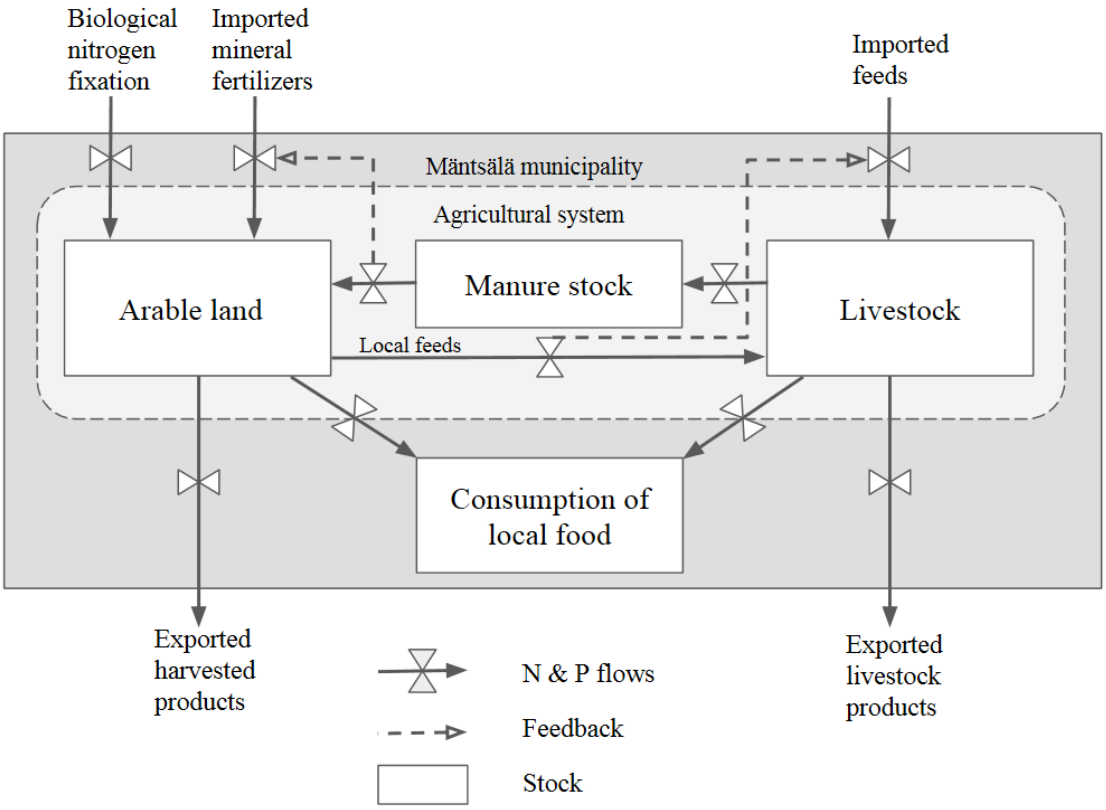

Figure 1: The nutrient inputs and outputs considered in the study. Feedback arrows indicate the relation of local feed production to imported fertilizer and feed substitution.

4.4 Sensitivity analysis

Sensitivity analysis studies the uncertainty of a model or a system from perspective of uncertainty of inputs. Hamby (1994) has described various methodologies of sensitivity analysis. The method chosen for this study is One-At-a-Time sensitivity analysis (OAT). It is a simplest method of sensitivity analysis. The basic idea of partial sensitivity analysis is to increase one parameter by a given percentage and leave the others constant. OAT was used in this study in scenario MAP for two purposes: for adjusting the level of mineral fertilization, for maximizing the different livestock production and for adjusting the available land areas for self-sufficient energy and protein feed production. For analyzing the needed level of mineral fertilization for meeting the crops nutrient needs the level of mineral N & P fertilization were adjusted separately with 20% steps. For maximizing the different livestock production selected animal group was maximized in expense of others. E.g. broiler production was maximized by replacing all of the laying hens with broilers in the poultry group.

4.5 Assumptions & limitations of the study

A number of assumptions were made (Table 8) and a number of limitations were accepted (Table 9).

Table 8. Assumptions overview

Mäntsälä	Assumption
Citizens as consumers of agricultural products	Average Finnish Consumers (5 year consumption average)
Ratio of different ages and gender in animal groups	National 5 years average of different ages and genders in species groups, used for grouping the animals in three groups: cattle, pigs & poultry.
Unutilized grass areas	60% are potential for efficient silage production. (Niemeläinen et al. 2014) productive as existing grass fields
Production of feed cereals	National 5 years average of the share of cereals for feed to total cereals
Yields	3 years average of yields in Uusimaa county
Straw yield	In units of weight, equal to the grain yield in the cereals (Lötjönen et al. 2011)
Straw harvest	Not harvested in current state. Fully harvested in the alternative scenarios.
Manure produced	Recycled locally
Mineral N & P fertilization	The Uusimaa region averages of years 2010-2015. (Salo, 2018)
N fertilization efficiency	Response rate 70% (Salo et al. 2013)
P fertilization efficiency	Response rate 85% (Luostarinen et al. 2011)
Area harvested	Area in cultivation

Table 9. Limitations of the study

Subject	Limitation
Mineral optimization in feeding	Was not optimized, as local supply of the whole range of minerals is not sufficient (due to complexity of required mineral feed compositions)
Micronutrients	Not included in the modelling of fertilization.
Farm labor, expertise & infrastructure	Not analyzed and not included in the modelling.
Biodiversity loss of turning uncultivated grasses for silage production	Not analyzed and not included in the modelling.
Scope of crops	Minor crops were not included in the study.
Other sources of recycled nutrients than manure	Not analyzed and not included in the modelling.
From of nutrients	Forms of N & P, which affect availability, solubility, etc., were not included in the modelling.
Nutrient losses	Evaporation, fallout, leaching were not included.
Unsuccessful field areas and areas that are left un-harvested	Only included indirectly through using three year averages of crop yields.

5 RESULTS

This chapter presents the results of different scenarios in comparison to the present state. Complementary charts of the scenarios are presented in the Appendix 4.

Scenario BAU: Business as usual

As there is animal production of ca. 2000 cattle in Mäntsälä, their manure can be counted as on source of manure inputs. The total nutrients in the manure are 170 t N and 28 t P and this combined with the mineral fertilization average (Salo, 2018 personal inquiry) combines to total nutrient inputs of 1213 t N and 110 t P. The total nutrient output in present state is 861 t N and 142 t P (Appendix 4. Table 1). These flows of nutrients leave the nutrient balance positive in Nitrogen and negative in Phosphorus (Table 10.).

For balancing inputs with outputs 32 t more P inputs would be needed. This amount of P if applied as manure corresponds to 2516 more animals when using the average of cattle manure including different ages and sexes (Appendix 3. Table 1). Comparing this information to the silage yields in the area there is enough silage to feed 3647 heads of cattle (milking cows, sucker cows, heifers, bulls and calves included) so there is not enough silage for fulfillment of the phosphorus balance even without replacing mineral fertilization with manure use.

Table 10. Nutrient balance in Mäntsälä in present situation and in utilization of full silage potential with increasing the amount of cattle in the area.

	BAU		**Silage potential**	
Nutrient	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Inputs				
Manure t	170	28	306	50
Mineral fertilization t	1043	82	1043	82
Output t	861	142	861	142
Balance t	351	-32	488	-10
Kg /ha	28.2	-2.5	35.7	-0.7

As there are 1939 animals in the cattle group in area the silage production has an oversupply of ca. 88%. If this oversupply would be directly consumed by increasing the number of cattle, that would mean an addition of 1 708 animals. This addition would increase the manure nutrients in the area to 136 t N and 22 t P. This addition stands for 7.5 kg N/ha and 1.8 kg P/ha, which has potential to replace a minor part of mineral N but still leaves the P levels deficient.

Scenario SUFC: Silage from unutilized grasslands and feed from local cereals.

60% of the 2007 ha of unutilized grasses allows for a potential to double the number of cattle in the area by 2031 animals. Combining this with the potential of the oversupply of silage this number grows to 3739. With the average distribution of cattle in Finland this group would consist of 1161 milking cows, 241 suckler cows, 638 heifers, 451 bulls and 1249 calves (Table 11). Such an increase in animal numbers would increase the need of rapeseed and cereal feed need. The need for rapeseed increases to ca. 878 t/year, which is equivalent to 540ha with the current 3 year yield averages. For feed cereals the need increases to ca. 5.2 mill. kg /year, which is equivalent to 1398 ha. Both of these needs are satisfied with the present production structure and amounts of feed production.

The total cereal feed production in Mäntsälä is ca. 14.1 mil. kg, which consists of barley (ca. 47%), oats (ca. 30%) and wheat (ca. 23%) (Appendix 3. Table 2). This amount has the potential to feed ca. 40 000 animals in pig group or ca. 800 000 animals in the poultry group. When adjusting these numbers to ratio 1:9 the outcome is 27 999 animals in pig group and 251 994 animals in poultry group (Table 12). These groups were spread to different ages, sexes and functions according to the ratios of animals within these groups in Finland in the averages of 2013-2017 (Appendix 3. Table 3). The additions would also affect the municipal need for rapeseed and pea. The pig group would require a rapeseed harvest of ca. 0.7 mill. kg which is equivalent to ca. 475ha. The poultry group would require a pea harvest of ca. 1.4 mill. kg which would require an area of ca. 700ha.

Table 11. Potential of meeting silage need with unutilized grass areas in Mäntsälä (numbers of animal sustained).

	Cattle combined	Milking cows	Suckler cows	Heifers	Bulls	Calves
Potential to increase	3739	1161	241	638	451	1249
Present number	1939	833	28	401	121	556
Total	5678	1994	269	1039	572	1805
Manure N t *	468	270.3	21.2	59.6	44.7	72.5
Manure P t *	75	47.6	2.1	8.6	6.7	10.2
Meat t **	416	108	13	178	113	
Milk t **	17017	17017				

*** Finnish normative manure system, Luostarinen et al. 2017**

**** Meat, milk and egg production averages, Appendix 3.Table 4.**

Table 12. Pigs and poultry fed with the feed cereal production of Mäntsälä in the ratio (1:9) of national monogastrics production

	Pigs combined	Boars 50 kg and over	Sows 50 kg and over	Heavy pigs 50 kg and over	Pigs 20-50 kg	Piglet under 20 kg	Poultry combined	Laying hens	Chicks	Broilers
Potential to increase	27999	47	2706	10466	6809	7972	251994	75852	14695	161447
Manure N t *	312	1.0	81.0	176.6	53.7	***	151	57.6	11.2	82.3
Manure P t *	58	0.2	17.7	30.2	9.7	***	89	56.9	2.8	29.1
Meat t **	1086	4	152	930			272			272
Eggs t **							1489	1489		

*** Finnish normative manure system, Luostarinen et al. 2017**

**** Meat/milk/egg production averages, Appendix 3.Table 4.**

*****Piglet manure included in the amounts of sows**

The available nutrients in form of cattle manure increase to 468 t N and 75 t P with the utilization of silage oversupply and 60% unutilized grasses. As the area of silage cultivation increases the cultivation area this increase in manure nutrients could substitute mineral fertilization by 34.3 kg N/ha and 5.5 kg P /ha. Mäntsälä's P-balance would become less negative with the increase of manure P and no increases of mineral fertilization are needed for the increased area of silage cultivation. The present amounts of mineral fertilization would still be needed to cover the need for phosphorus and meet crops requirement for N-fertilization (Table 13.).

Consuming Mäntsälä's cereal feeds produced locally would circulate 463 t N and 147 t P in manure. These are equivalent of 28.1 kg N/ha and 10.4 kg P /ha to the current cultivation areas. This would mean that regional need for P would be sustained with the P in manures, but the need for N would still require ca. 60% of mineral N of the present scenario to meet the crops needs. One-at-time analysis of the mineral fertilizations shows that neither the present level nor completely giving up of mineral fertilization would result in balanced N & P levels (Table 13)

Table 13. Nutrient balances in Mäntsälä with utilization of 60% unutilized grasses and silage oversupply and local consumption of the cereal feed production

Utilization of silage oversupply and 60% of unutilized grasses			Utilization of the municipal feed cereal production					
	N	P	N	P	N	P	N	P
Mineral fertilization rate (% of BAU)	100%	100%	100%	100%	0%	0%	60%	0%
Nutrients input								
Manure t	468.3	75.2	633.4	174.6	633.4	174.6	633.4	174.6
Mineral fertilization average t*	1043.8	82.4	1043.8	82.4			626.3	
Nutrients output t	1078.2	177.8	861.1	142.2	861.1	142.2	861.1	142.2
Nutrient balance	443.9	-20.2	816.1	114.8	-227.8	324.0	397.9	324.0
kg/ha	31.7	-1.5	65.5	7.9	-15.7	2.2	27.5	2.2

***Salo, 2018, personal inquiry)**

Utilization of silage oversupply and 60% of the unutilized grasses enables satisfying the municipal consumption in beef (Fig 3). For milk the possibility is to produce ca. 3 times the amount consumed in the area.

Consumption of all the feed cereals produced within the area has great effects on meeting the local demand of animal products. When the pigs and poultry are added to the area production of pork exceeds the local consumption with 47% and eggs with 539% (Fig. 4). Production of broiler stays under the consumption.

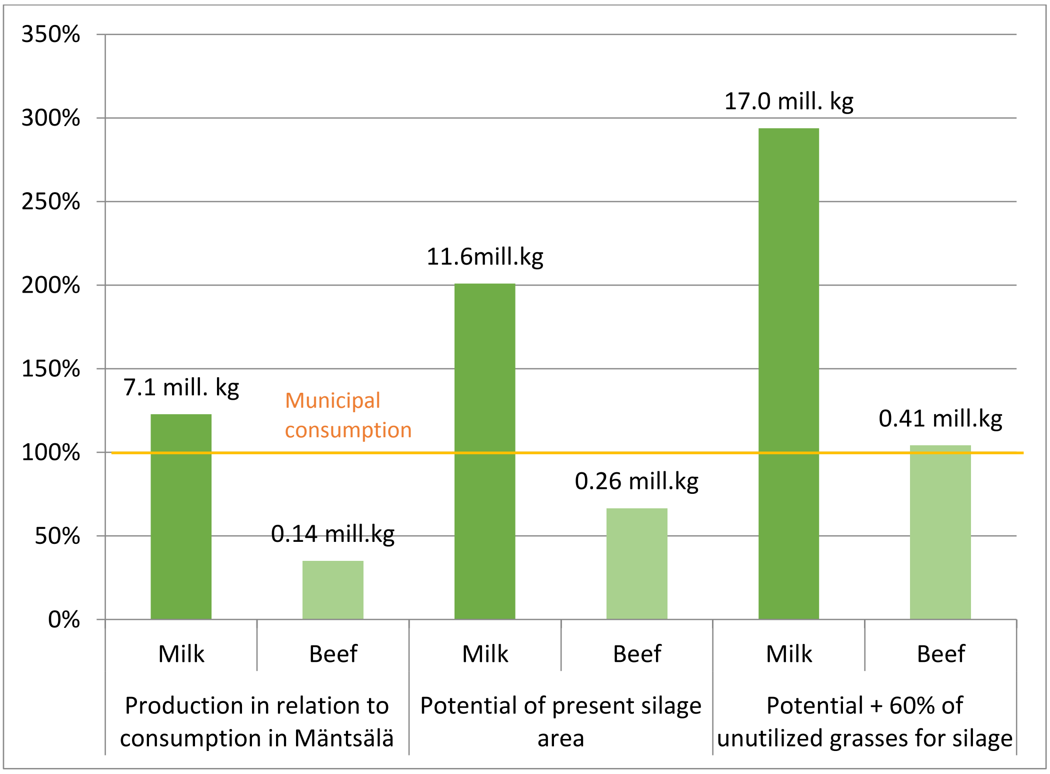

Figure 3. Production of milk and beef in Mäntsälä relative to consumption in the SUFC scenario.

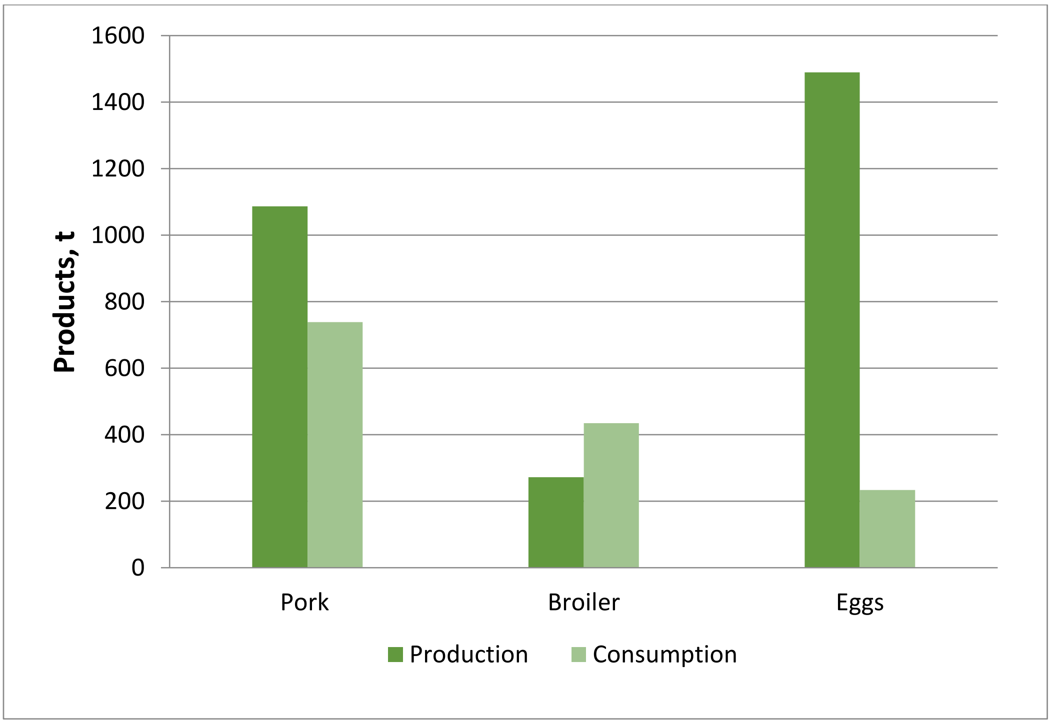

Figure 4. Production potential with utilization of municipal cereal feeds in Mäntsälä in the SUFC scenario.

Scenario MAP: Maximal animal production by local feeds

When extending the local feed production not only to energy feeds but also to protein feeds the potential animal numbers drops considerably. The expansion of silage production to unutilized grasses and growing the number of cattle multiplies the need of rapeseed and cereal feeds. This reduces the feeds available, which also affects the number of possible additions of pork and poultry.

After fulfilling the needs of the 5677 heads of cattle demonstrated in the SUFC scenario, the required changes in land-use are 401 ha increase to rapeseed areas of which 394 ha would be converted from the cereal area and 7 ha from pea area. These changes would enable additions of 16 337 animals in the pigs groups and 147 037 in the poultry group when using the national ratio of pigs and poultry (1:9). For optimizing either the pork-, broiler- or egg production more adjustments in land-use are need (Table 14). For maximized pork numbers, expanding rapeseed areas is essential as for optimized poultry production pea areas rise as the limiting factor.

Table 14. Land use changes for maximized pork, poultry and egg production in the scenario MAP: Maximal animal production by local feeds

Land use change +/- ha	1:9 ratio of pork / poultry	Maximized pork production	Maximized broiler production	Maximized egg production
Cereals area	-394	-246	-890	-422
Rapeseed area	401	661	-82	-82
Pea area	-7	-415	972	504
Potential increases in livestock				
Pigs	16 337	24 414		
Poultry	147 037		441 939	384 899

The land use changes also affect the inputs needed for the production. The biggest inputs are needed in the optimized pork production, whereas optimized broiler production needs the least nutrients (Table 15). The need for nutrient cannot be satisfied with the animal additions introduced and neither does the need for phosphorus in cases including pork production. Optimized egg production adds up more manure phosphorus than is needed or even contained in the local energy and protein feeds. This is caused by high phosphorus content in mineral chicken feeds (Evira, 2014). When the numbers are optimized to meet the consumption of eggs the phosphorus need exceeded greatly, which is mainly caused by the high consumption of broiler.

Table 15. Nutrient balances with the production structure changes for maximized pork and poultry production in in the scenario MAP: Maximal animal production by local feeds

	1:9 ratio of pork / poultry	Maximized pork production	Maximized broiler production	Maximized egg production
Input				
Manure				
N t	738.7	740.6	699.8	760.3
P t	160.7	125.7	154.9	350.8
Output				
N t	1067	1076	1040	1059
P t	178	181	171	174
Balance without mineral fertilization				
N t	-328	-336	-340	-30
N kg/ha	-24.0	-24.6	-24.9	-21.9
P t	-17	-55	-16	177
P kg/ha	-1.3	-4.1	-1.2	12.9

The highest export potential in volumes is in egg products (Table 16.). For pork and broiler production satisfying municipal consumption takes a large portion of the areal potential. All of the optimized products have the potential to satisfy the local demand and produce for export at the cost of other animal production.

Table 16. Production potentials of pork, broiler and eggs in Mäntsälä in the scenario MAP: Maximized livestock production with local feeds

Focus	1:9 ratio of pork / poultry			Maximized production potential		
Product	Pork	Broiler	Eggs	Pork	Broiler	Eggs
Production t	633.8	159.0	869.0	947.0	701.0	7103.7
Consumption t*	738.4	434.3	233.1	738.4	434.3	233.1
Balance	-104.6	-275.3	635.9	208.7	266.7	687.1
Production/ consumption-%	86 %	37 %	373 %	128 %	161 %	3047 %

***Appendix 2. Consumption averages**

Scenario MEC: Meeting the local consumption of food

Previous scenarios have shown that the consumption of meat and dairy cannot be completely satisfied without changing the proportions of feed use of cereals. As Mäntsälä's milk and beef production has been shown to reach the local consumption with extending the silage areas to unutilized grasses, the consumption of these products in the case area can be viewed to be on a sustainable level. Same results could be achieved by increasing silage cultivation in the cereal crop rotations. Consumption of eggs is comparably low compared to the production volumes of egg production. More problematic is to meet the consumption of pork and broiler.

Through the perspective of keeping the egg consumption satisfied and the proportions of feed cereal production at current levels the level of self-sufficiency possible in pork and broiler sets to ca. 70% in Mäntsälä (Fig. 5). In other words the diet consists of 30% of pork and broiler consumption over the amount that the area can sustain without compromising the present production of cereals for human consumption. If the compromise is done it would mean a conversion of 1055 ha of food grain to feed production which would mean a 28% decrease in the food grain yields.

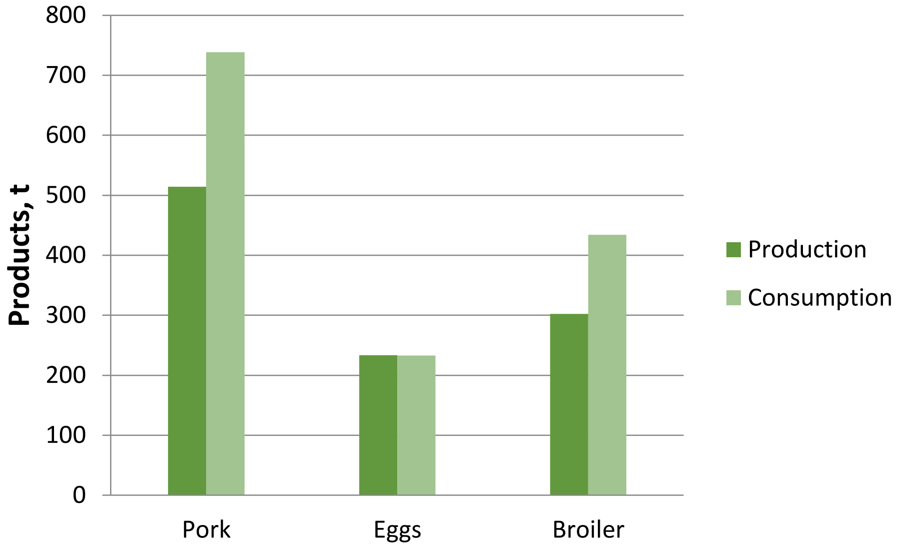

Figure 5. Maximized pork and broiler production with local feeds when meeting the consumption of eggs and keeping the feed cereal proportions at present levels in the scenario MEC: Meeting the local consumption of food.

6 DISCUSSION

In establishing regional sustainable agroecosystem through adopting localized circular economy the possibilities are numerous. In this study these possibilities were modelled in cereal cultivation dominated area of Mäntsälä through production structure changes. The unutilized grasslands offer a hidden potential for ruminant production and the feeds exported from the area could feed numerous ruminants and monogastrics within the area.

Bringing animals to an agricultural region which has depended on mineral fertilizers increases the potential for nutrient recycling in manures. Even in an extreme case of using all the farmland for producing local feeds to a stock of farm animals maximized to depend fully on these, the system would not be nutrient self-sufficient. This is because of exports of nutrients in losses and through exported animal products. In the Mäntsälä case, the animal/manure additions can replace ca. 50% of mineral N fertilization and can replace P fertilization completely, when losses are not considered.

Assuming that all the manure nutrients can be used for efficient organic fertilization losses of nutrients are significantly lower and nutrients surpluses smaller than in situation of when the volumes of manure exceed the possibility of using it as fertilizer. If the animal production addition in cereal dominated areas are taken off from the areas of high animal concentrations it’s possible to unburden the environmental effects of areal specialization demonstrated by Ylivainio et al. (2015). If the areal silage production is converted toward nitrogen fixation utilization with e.g. clover grasses the results for local nutrient balance would be even greater. Granstedt (2000) had even more optimistic results with integrating livestock and nitrogen fixation plants to crop production, as his results suggest that for Baltic Sea region this integration could halve the nitrogen losses and minimize the phosphorus losses. Larsson & Granstedt (2010) had similar results with modeling mineral fertilizer free, nitrogen fixing and livestock-crop integrating production to future scenarios of Baltic regions agriculture.

In farming the optimal conditions are rarely present. Nutrient leaching and evaporation both in animal housing, in storage and on field decrease the availability of manure nutrients for plan production. Through these insecurities the fertilization need is higher than crop uptakes. Also as long as the nutrients in animal products consumed are not returned to the circulation agriculture will be consuming the soil phosphorus or the global phosphate resources with use mineral fertilization.

What comes to reliability of this study, it can be assumed to be scalable for the region of rural Uusimaa and similar regions in Finland, through the similarity of production structures. As it uses data and model parameters from Finland it cannot be assumed to be repeated in for example the cereal regions of central Europe where the circumstances are relatively different. The scenarios did not include any assumptions on political feasibility, concerning increasing of livestock production or redistributing it at national scale.

In case of Mäntsälä there is potential to produce meat and dairy products more than the consumption is in the area. Most production potential is in eggs, broiler and milk. Fulfilling the local consumption of milk, beef, pork, broiler and eggs simultaneously without importing more feeds isn’t possible with the current land areas, yields and size of the population. While milk and beef consumption are relatively simple to be met with remodeling cattle into the production structure, the feed areas left aren’t enough to feed the needed numbers of pork and poultry without compromising the proportions of cereals produced for national human consumption. Risku-Norja et al. (2008) study shows on the other hand that predominantly rural regions in Finland can be easily localized and become food exporters even with converting to organic agriculture if the diets are more plant based.

Abovementioned brings up the question of sustainable level of consumption. When the area of Mäntsälä is observed it comes obvious that the consumption and diets rely on production that is based on imported feeds and nutrients. The level of pork and broiler consumption cannot be sustained by livestock production based only on side-streams of food grain production. A proportion of human edible grains would need to be used for animal feeding, which is not sustainable from global food security perspective. For rural

Uusimaa MEC scenario gives clear signs of unsustainable levels of livestock product consumption as Mäntsälä has double the arable land for per citizen. As in Mäntsälä the consumption of pork and broiler is 30% higher than it’s possible to produce locally without compromising food grain production proportions, the consumption of pork and broiler in rural Uusimaa can be assumed to be 65 % over the level that could be produced in the area. Similarly the lower arable land per citizen raises the consumption of beef 50% over the local production potential. Globally similar results have been found by Pradhan et al. 2014. Their study presents that meeting regional consumption is possible with focusing agricultural practices to meet regional demands. They also found that in some regions excess consumption of calories and animal products hinders the possibility of meeting the regional consumption. They underline the importance of dietary pattern change and lowering food wastage for future sustainable food production.

For building a sustainable agroecosystem, discussing only nutrient circulations and meeting the consumption isn’t enough. Another great input in agriculture is energy as it is used to run the tractors, process the harvest, warm the buildings and etc. There is no simple answer to how that should be organized in the scenario presented. It can be biogas production from the manures and other side streams of agriculture, bioethanol produced from side streams of forestry or electricity based solutions of solar, wind and geothermal energy. The vision of a network of agroecological symbioses approaches this topic through optimized biogas solutions which are founded on the special need and available biomasses of every symbiotic farm community (Helenius et al. 2017, Koppelmäki et al. 2018).

7 CONCLUSIONS

For change of the local food system toward regionally sustainable agroecosystem the production structure needs enabling of nutrient circulation. The enabling factor can be biogas processing or animal production. This study demonstrates how introducing animals to cereal cultivation dominated region can enhance the local nutrient circulation and mineral fertilizer substitution. Majority of mineral Nitrogen fertilizers and all of mineral Phosphorus fertilizers can be replaced with manure nutrients in an balance crop- and livestock production.

Recycling nutrients helps only until certain point. This study presents also the relatedness of land use to consumption. The diets determine what should be produced and with what intensity. With existing land resources, yield levels and consumption it can be assumed that for rural Uusimaa the arable land isn’t vast enough to meet the consumption neither to meet the consumption of whole Uusimaa including the capital region. For achieving of regional sustainable agroecosystem the consumption should be adjusted toward the limitations set by the regional circumstances. Following the balancing of consumption and nutrient circulation to local restrictions, the next steps for achieving the vision of network of agroecological symbioses are bridging the primary production with food processing, building alternative food networks and finding solutions of decentralized energy production.

Essential follow-up study would be to model the opposite changes in an animal production dominated area to find out the frames of sustainable regional animal production. Other interesting follow up study topics would be the logistics of network of agroecological symbioses, energy input/output balance in sustainable agriculture, involving ecological aspects to production structure remodeling and analyzing the consumer behavioral obstacles of localization of food systems. Also forestry’s and aquacultures suitability to agroecological symbioses should be studied.

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APPENDIX 1. MÄNTSÄLÄ IN NUMBERS

Table1. Comparison of the crop areas of Mäntsälä and Uusimaa in 2017

	Total cultivated area	Winter wheat	Wheat	Rye	Feed barley	Malt barley	Oats	Mixed cereal	Other cereals	Feed grasses	Pastures	Seed hey	Potato	Pea	Broad bean	Turnip rape	Rape	Flax	Cumin	Horticultural plants	Other crops	Fallows	Nature management fields	Green manure lays	Grasses >5years	Perennial horticultural plants	Greenhouse production
Mäntsälä ha *	15157	209	2 995	231	1 497	2 252	1 828	91	29	2 163	231	72	2	110	305	373	291	24	235	76	128	773	1054	95	85	6	2
Percentage		1 %	20 %	2 %	10 %	15 %	12 %	1 %	0 %	14 %	2 %	0 %	0 %	1 %	2 %	2 %	2 %	0 %	2 %	1 %	1 %	5 %	7 %	1 %	1 %	0 %	0 %
Uusimaa 1000 ha *	185.3	4	38.7	4.5	16.3	14.8	23.4	0.9	0.7	30.1	3.0	0.9	0.3	1.8	3.2	2.3	6.2	0.2	3.2	1.4	0.7	9.1	16.2	1.5	1.7	0.2	0
Percentage		2 %	21 %	2 %	9 %	8 %	13 %	0 %	0 %	16 %	2 %	0 %	0 %	1 %	1 %	2 %	1 %	3 %	2 %	1 %	0 %	5 %	9 %	1 %	1 %	0 %	0 %

***Luke annual statistics**

Table 2. Arable land per person in Mäntsälä and Uusimaa in 2016

	Mäntsälä	Rural Uusimaa (Exluding Helsinki, Vantaa and Espoo)
Residents*	20803	508 732
Arable land **	15157	185300
Arable land / person	0.73	0.36

*** Helsinki-Uusimaa regional council, 2018**
**** Luke annual statistics, 2018**

APPENDIX 2. CONSUMPTION AVERAGES

Table 1. Consumption of meat and eggs in 2012-2016 Finland

Consumption / citizen*	Beef pork, poultry and eggs combined	Beef	Pork	Broiler	Eggs
2012	84,2	18.9	36	18,7	10,6
2013	84,2	18.4	35,6	19,5	10,7
2014	84,2	18.7	34,6	20,1	10,8
2015	87,2	19.2	34,9	21,6	11,5
2016	89,3	19.2	34,7	23,5	11,9
Average	85,82	18.9	35,16	20,68	11,1
		22,0 %	41,0 %	24,1 %	12,9 %

***Luke annual statistics, 2018**

Table 2. Consumption of milk products in 2012-2016 Finland

Consumption / citizen*	Combined	Full milk	1-2% milk	Far-free milk	Sour milk	Yoghurt	Cream	Cheese
2012	195.9	12.5	68.9	50.8	11.8	23.3	6.7	21.9
2013	194.4	12.8	66.6	51.2	11.3	22.6	6.7	23.2
2014	193.2	12.5	66.4	50.7	10.9	21.2	6.5	25.0
2015	190.4	11.7	66.0	48.0	10.1	21.3	6.7	26.6
2016	183.3	11.5	65.4	43.4	9.6	20.1	7.0	26.3
Average	198.62	12.5	68.9	50.8	11.8	23.3	6.7	24.6
Total milk l**	275.9							

***Luke annual statistics, 2018**
**** Multiplier led from Eurostat, 2017.**

APPENDIX 3. FINNISH PRODUCTION AVERAGES

Table 1. The proportions of animals in cattle group and their average manure N & P content in Finland 2013-2017.

1000 animals	**Cattle combined**	**Milking cows**	**Calver**	**Heifers**	**Bulls**	**Suckler cows**
2013*	911.8	283.1	57.3	161.8	109.6	300
2014*	914.4	285.2	57.8	158.1	109.9	303.4
2015*	914.8	285.1	58.7	154.6	109.4	307
2016*	909	282.4	59	150.2	107.8	309.7
2017*	893.2	275	59.9	150.3	110.8	297.3
Average	908.6	282.2	58.5	155	109.5	303.5
Precentage		31,1 %	6,4 %	17,1 %	12,1 %	33,4 %
Manure kg/animal/y**						
N	351.4	96.7	79.0	57.4	78.2	40.2
P	48.4	14.9	7.9	8.2	11.7	5.7
Precentual N	67.7	30.0	5.1	9.8	9.4	13.4
Precentual P	9.8	4.6	0.5	1.4	1.4	1.9

*** Luke annual statistics, 2018**

**** Finnish normative manure system**

Table 2. 2014-2016 averages of cereal feed production in Finland.

Finland	**Wheat**			**Rye**			**Barley**			**Oats**		
Year	**2014/15**	**2015/16**	**2016/17**	**2014/15**	**2015/16**	**2016/17**	**2014/15**	**2015/16**	**2016/17**	**2014/15**	**2015/16**	**2016/17**
Usable t *	1 347.4	1 289.5	1 148.6	235	257.5	255.9	2 049.0	2 015.2	1 972.3	1 106.2	1 093.5	1 120.4
Feed use t *	460.7	493.7	455.1	1	2	2	1 031.40	882.1	916	593.6	546.8	530.4
3 year average												
Usable t	1261.8			249.5			2012.2			1106.7		
Feed use t	469.8			1.7			943.2			556.9		
Feed %	37.2 %			0.7 %			46.9 %			50.3 %		

*** Luke annual statistics, 2018**

Table 3. Proportions of animals in pigs and poultry groups in Finland 2013-2017

1000 animals	Pigs combined	Boars 50 kg and over	Sows 50 kg and over	Heavy pigs 50 kg and over	Pigs 20-50 kg	Swine under 20 kg	Poultry combined	Laying hens	Chicks	Broilers	Turkeys	Other poultry
2013*	1 307.9	2.3	125.9	490	325.3	364.5	11 980.6	3 432.2	857.6	6 861.1	274.3	555.3
2014*	1 244.8	2	120.8	464.2	295.5	362.3	12 576.9	3 645.3	714.1	7 341.2	292	584.3
2015*	1 242.6	N/A	N/A	N/A	N/A	N/A	12 926.9	3 594.5	662.2	7 827.3	245.9	596.9
2016*	1 234.9	N/A	N/A	N/A	N/A	N/A	13 444.9	3 598.9	747.6	8 271.6	260.3	566.4
2017*	1 135.6	N/A	N/A	N/A	N/A	N/A	13 135.6	3 745.9	508.9	8 046.7	291.6	542.5
Average	1233.1	2.1	123.4	477.1	310.4	363.4	12813.0	3603.4	698.1	7669.6	272.8	569.1
Percentage		0.2 %	10.0 %	38.7 %	25.2 %	29.5 %		2.1 %	5.4 %	59.9 %	2.1 %	4.4 %

***Luke annual statistics, 2018**

Table 4. Average production of animal products in different animal groups in Finland

Meat/milk/egg production	Milking cows	Sucler cow	Heifers	Bulls	Sows	Boars	Heavy pigs	Laying hens	Broilers
Slaughter %	20 %	15 %	75 %	60 %	31 %	100%	100%		100%
Meat per slaughter kg * & **	271	332	228	331	184	95	89		1.7
Average milk kg /cow	8534								
Average egg kg / hen								19.6	

***Beef data, Pulkkinen et al. 2019, unreleased**

****Pigs and poultry lead from the annual slaughter amounts and average carcass weights, Luke annual statistics, 2018.**

APPENDIX 4. SCENARIOS

Table 1. Present state of N & P outputs in Mäntsälä with 3 year yield averages in 2016

Crop	Wheat	Winter wheat	Rye	Barley	Oats	Rape seed	Pea	Silage	Combined
Area 2016 ha *	2995	209	440	3749	1828	664	415	2 163	**12463**
Area % ha	24 %	2 %	4 %	30 %	15 %	5 %	3 %	17 %	
2015-2017 Average kg/ha	3747	4360	3633	3753	3650	1627	2042	13963	
TS kg/ha**	3222	3745	3125	3228	3139	1562	1756	3491	
N kg/ha**	69.0	75.0	55.0	65.2	65.3	58.7	45.0	89.4	
P kg/ha**	11.9	13.9	12.2	11.6	11.0	14.7	7.0	10.1	
N Output total t	206.5	15.7	24.2	244.4	119.4	39.0	18.7	193.3	**861**
P Output total t	35.7	2.9	5.4	43.6	20.1	9.7	2.9	21.9	**142**

*__Luke annual statistics, 2018__

**** Feeding recommendations, Luke, 2015**

Table 2. Animal additions of silage oversupply and utilization of 60% of unutilized grasses

	Present Silage potential	**Present potential + 60 % Unutilized grasses for silage**
Area 2016 (ha)*	2 163	3 367
2015-2017 yield *average (kg)	13963,3	13963,3
Total yield (mill. kg)*	30,20	47,02
Feed %*	100 %	100 %
Total feed yield (mill.* Kg)	30,20	47,02
ME MJ/kg DM**	10.9	10.9
Dry Matter %**	25 %	25 %
Total mobilizable energy MJ	82302330	1,28E+08
Cattle energy requirements**	22565.4	22565.4
Animals fed	3647,3	5677,8

***Luke annual statistics, 2018**

****Appendix 5. Feeding averages**

Table 3. Pork and poultry additions with municipal consumption of feed cereals.

	Wheat	Barley	Oats	Cereals combined
Area 2016 (ha)*	2995	3749	1828	8572
2015-2017 yield average (kg)*	3746,7	3753,3	3650	
Total yield (mill. kg)	11,2	14,1	6,6722	
Feed %*	37,2 %	46,9 %	50,3 %	
Total feed yield (mill. Kg)	4,18	6,60	3,36	14,1
ME MJ/kg DM	13,6	13,2	12,4	
Dry Matter %	86 %	86 %	86 %	
Total mobilizable energy MJ	48867607	74873727	35806551	1,6E+08
Animals E				15361,83
Pigs and poultry 9/91 ratio				
Pigs feed requirements**			3931,9	
Animals fed			40577	
Poultry feed requirements**			196,2587	
Animals fed			812947	
Ratio			1:9	
Poultry fed			251994	
Pigs fed			27999	

***Luke annual statistics, 2018**

****Appendix 5. Feeding averages**

Table 4. Scenario APP. Animal additions with municipal cereal feed consumption and protein feed production after the cattle additions of scenario SUFC.

	Wheat	Barley	Oats	Cereals combined	Rapeseed	Pea
Area 2016 (ha)*	2858	3577	1744	8 179	1082	390
%	35 %	44 %	21 %			
2015-2017 yield average (kg)*	3747	3753	3650		1626	2042
Total yield (mill. kg)*	10.7	13.4	6.4		1.8	0.8
Feed %**	37.2 %	46.9 %	50.3 %		100 %	100 %
Total feed yield (mill. Kg)	4.0	6.3	3.20	13.5	1.8	0.8
ME MJ/kg DM***	13.6	13.2	12.4			
Protein g/kg DM***					124	230
Dry Matter %***	86 %	86 %	86 %		92 %	86 %
Total protein kg					2007867	157498
Total Mobilizable energy MJ	46627177	71440996	34164930	1,52E+08		
Cattle energy requirements total****				63538014		
Cattle protein requirements total****					107912	
Determing factor			Energy			Protein
Pigs feed requirements****			3931,9			5,96125
Animals fed			38717			15580
Poultry feed requirements****			196,2587			1,1
Animals fed			775676			140429
Ratio			1:9			
Poultry fed			140087			140429
Pigs fed			15565			15580
Ratio			1:0			
Pigs fed			23367			22397
Ratio (only broilers and chicks)			0:1			
Poultry fed			423508			423829
Ratio (only laying hens and chicks)			0:1			
Poultry fed			368878			369224

*Luke annual statistics, 2018**

****Appendix 2. Table2.**

***** Feeding recommendations, Luke, 2015**

******Appendix 5. Feeding averages**

Table 5. Animal numbers in the scenario of balanced consumption in relation to production, Scenario MCC

	Boars 50 kg and over	**Sows 50 kg and over**	**Heavy pigs 50 kg and over**	**Pigs 20-50 kg**	**Piglets under 20 kg**	**Laying hens**	**Chicks**	**Broilers**
Percentage*	0.2 %	10 %	37 %	24 %	28 %	6 %	6 %	88 %
New animals	22	1280	4952	3222	3772	11878	11840	179136
Manure N**	20.4	30.0	16.9	7.9		0.8	0.8	0.5
Manure P**	4.4	6.5	2.9	1.4		0.8	0.2	0.2
Total N	454.3	38343.2	83536.7	25418.6		9027.3	8998.6	91359.4
Total P	98.0	8360.0	14310.7	4606.9		8908.5	2249.7	32244.5
Slaughter -%	100 %	31 %	100 %	0 %	0 %			100 %
Meat/eggs per animal kg***	94.7	183.5	88.8			19.6		1.7
Total meat/eggs kg ***	2114	71998	439794			233220		302262,9
Total meat/eggs kg	513905					233220		302262,9
Consumption	738360					233100		434280
Balance	-224455					120		-132017
Self sufficiency	70 %					100 %		70 %

***Appendix 2. Table 3.**
**** Finnish normative manure system**
***** Feeding recommendations, Luke, 2015**

APPENDIX 5.FEEDING AVERAGES

	Milking cows*	Suckler cows*	Heifers (growth= 1000g/d)*	Bulls (growth= 1400g/d)*	Calves*	Boars 50 kg and over (~76kg)**	Sows 50 kg and over (~77,5kg)**	Heavy pigs 50 kg and over (~76kg)**	Pigs 20-50 kg**	Swine under 20 kg**	Laying hens ***	Chicks ***	Broilers ***
Weight	640,0	681,0	350,0	341,0		76	77,5	76,0	30,0	15			
Average milk production / day	23,2	4,4											
Energy Need MJ/d****	184,9	91,2	85,0	96,0	25,0	27,2	28,6	27,2	11	11,5	1,32	0,46	1,736
Energy need MJ/y	67503,0	33298,8	31025,0	35040,0	9125,0	9928,0	10439,0	9928,0	4015,0	4197,5	481,8	167,9	633,6
DM kg/d****	16,1	7,9	7,4	8,3	2,2	2,4	2,5	2,4	1,0	1,0	0,1	0,04	0,2
Protein need g/d****	2228,1	2164,6	366,0	467,0	260,0	334,56	371,8	334,56	158,4	178,25	175	75	200
Protein need kg/year	813,3	790,1	133,6	170,5	94,9	122,1	135,7	122,1	57,8	65,1	63,9	27,4	73,0
Silage DM kg/y	3639,3	2055,8	1834,5	1950,1	777,6								
Energy from silage	39668,3	22408,7	19996,3	21255,6	8475,9								
Protein from silage	305,7	172,7	154,1	163,8	65,3								
Oats DM kg/y*****	821,8	0,0	107,9	0,0	0,0								
Barley DM kg/y*****	821,8	868,7	620,5	914,1	7,9						20,9	2,9	16,5
Energy from cereals	21037,5	11466,4	9528,7	12065,9	104,7	6833,1	7184,8	6833,1	2763,4		240,9	33,6	190,1
Protein from cereal	155,3	83,4	69,6	87,8	0,8	93,4	104,5	93,4	45,0		2,0	0,3	1,6
Rapeseed DM kg/y	410,9	86,9	80,9	0,0	0,0	86,3	90,8	86,3	34,9				
Energy from rapeseed	7642,5	1615,7	1505,4	0,0	0,0	1605,7	1688,4	1605,7	649,4	0,0			

Protein from rapeseed	49,3	10,4	9,7	0	0	10,4	10,9	10,4	4,2	0,0			
Pea DM kg/y											4,189565	1,46	5,509913
Energy from pea											54,04539	18,834	71,07788
Protein from pea											0,9636	0,3358	1,26728
Animal group percentage******	31,1 %	6,4 %	17,1 %	12,1 %	33,4 %	0,2 %	9,7 %	37,4 %	24,3 %	28,5 %	30,1 %	5,8 %	64,1 %
Energy	20961,7	2145,3	5292,4	4222,7	3047,7	16,72297	1008,814	3710,944	976,3836	1195,058	145,0251	9,790948	405,9598
Protein	252,5	50,9	22,8	20,5	31,7	0,205693	13,11459	45,64461	14,05992	18,52339	19,22682	1,59635	46,76956
Silage energy	12318,2	1443,7	3411,1	2561,5	2830,9								
Silage protein	94,9	11,1	26,3	19,7	21,8								
Cereal Energy	6532,8	738,7	1625,5	1454,1	35,0	11,50977	694,3274	2554,097	672,0066		72,51257	1,95819	121,7879
Cereal protein	48,2	5,4	11,9	10,6	0,3	0,157389	10,09472	34,92563	10,9321		0,605322	0,016347	1,016664
Rapeseed Energy	2373,2	104,1	256,8	0,0	0,0	2,704759	163,1648	600,2048	157,9194				
Rapeseed Protein	15,3	0,7	1,7	0,0	0,0	0,01745	1,052676	3,872289	1,018835				
Pea Energy											16,26804	1,098289	45,5381
Pea Protein											0,29005	0,019582	0,81192
Cattle Combined	Silage	Cereals	Rapeseed			Pigs combined	Cereal	Rapeseed			Poultry combined	Cereal	Pea
Energy	22565,4	10386,0	2734,1			Energy	3931,941	923,9938			Energy	196,2587	62,90442
Protein	173,9	76,3	17,6			Protein	56,10984	5,96125			Protein	1,638333	1,121552

*Pulkkinen et al. 2018, unreleased
**Perttilä, 2013
***Suomen siipikarjaliitto, 2018
**** Feeding recommendations, Luke 2015
***** Pulkkinen et al. 2019, unreleased
******Appendix 3, Finnish production averages