

Optimization of arable land use to guarantee food security in Estonia

R. Põldaru*, A.-H. Viira and J. Roots

Estonian University of Life Sciences, Institute of Economics and Social Sciences, Department of Business Informatics and Econometrics, Fr. R. Kreutzwaldi 1, EE51006 Tartu, Estonia

*Correspondence: Reet.Poldaru@emu.ee

Abstract. Agricultural and food sector has an important role to play in ensuring food security. A competitive agricultural sector warrants food security through increasing level of self-sufficiency in food, and export of surplus production in the sub-branches where it has a comparative advantage. One of the strategic tasks of the state is to secure food supply for the population. To perform this task, the state should estimate if the agricultural producers have the necessary capacity and resources to produce food to meet the needs of population. Mathematical modelling can be used as a tool in solving this analytical problem. The paper demonstrates possibilities of implementing linear programming model in optimizing the use of arable land for ensuring the food demand of Estonian population. The Estonian arable land use optimization model is essentially a static balancing model that simulates the demand and supply of basic food products (meat, dairy products, cereal products and potatoes). The basis for the demand side in the model is Estonian population, divided into 10 groups according to gender and age. The energy and protein needs of the respective population groups are taken into account. The supply side of the model is a typical agricultural production model that guarantees the consistency of crop and livestock farming. The model consists of 163 variables and 178 constraints (equations). The objective of the model is to minimize the use of arable land for field crops to ensure fodder for animal feed, and food for human food consumption. The model is used to analyse various land use strategies. According to the modelling results for ensuring food security of Estonia and to maintain export of dairy products, for which Estonia has a comparative advantage, in the 2016 volume, the total optimal arable land equals to 490,688 ha. There should be 83,600 dairy cows (with average milk yield 9,000 kg cow⁻¹). It is necessary to grow 755,700 piglets per year in order to secure 40 kg of pork per inhabitant. Land use optimization results indicate that Estonian agriculture is able to supply Estonian people with the minimum necessary main food products to guarantee food security, and allows to export essential products (cheese, butter, skimmed milk powder, whole milk powder).

Key words: food security, linear programming model, Estonian agriculture, land use optimization.

INTRODUCTION

Global food security

Food security has been an age-old issue in the human society since people have always worried about the availability and supply of food. Throughout history, agriculture

and food production have been among the most important sectors, ensuring food supply for the population. How to guarantee supply of sufficient, safe and nutritious food for everyone? In 2016, there were over 815 million undernourished people around the world (Roser & Ritchie, 2018), indicating that more than 10% of the world's population does not access enough food due to scarce supply, poor infrastructure or low purchasing power. This problem has been intensified by factors such as urbanisation (Miccoli et al., 2016); ageing (Kudo et al., 2015); climate change (Lal, 2013; Misra, 2014), limited resources (both fossil fuels (Naylor & Higgins, 2018) and biological resources such as fertile soil, water (Davis et al., 2016); changes in people's consumption patterns (Kastner et al., 2012; Alexander et al., 2016). These together with increasing global population have created the need to use resources more efficiently, reduce food waste (Koester, 2014), and develop sustainable waste management (Tielens & Candel, 2014; Govindan, 2018).

Food security problems have caused concern around the world. The United Nations (UN) agenda 'Transforming our World: the 2030 Agenda for Sustainable Development' provides guidelines for protecting the people and the planet, and for achieving welfare. Its aim is to integrate the three dimensions of sustainable development – economic, social and environmental – in a balanced and unified manner. Sustainable development goals are interlinked and inseparable, global, and obligatory for all developed countries (UN, 2015; Martin, 2017). Each country must contribute to reaching UN's 17 Sustainable Development Goals through setting their own targets, goals, and priority areas of activity, taking into account the local situation and capacity (Review..., 2016). One of the goals of the sustainable development agenda (Goal 2) is to achieve food security and improved nutrition for everyone, end hunger, and promote sustainable agriculture (UN, 2015). Considering that the EU's Common Agricultural Policy (CAP) aims to create the conditions that enable farmers to fulfil their numerous functions in society, the first of which is provide affordable food for citizens (Agriculture..., 2017) and taking into account the trends of the agricultural policy of the Estonian government (Development..., 2017). Estonia cannot remain a mere spectator of these developments both from national and global viewpoints.

Evolvement of the concept of food security

Food security as a term was first used in the global context during World War II when 44 Heads of State met in the US to discuss the freedom from want in the context of food and agriculture (FAO, 2012a; Hamblin, 2012). Over time, the term food security has meant different things. It has undergone significant development and is understood in various ways. The term food security has evolved from its narrow focus on national and global food availability, now covering several dimensions (Coates, 2013). This is partly due to its multidimensional and multi-sectoral nature (Fairbairn, 2012; Jones et al., 2013; Cafiero et al., 2014; Briones Alonso et al., 2018). As Pinstrup-Andersen (2009) said, 'in its narrowest definition, food security means that enough food is available, whether at the global, national, community, or household level'. Initially, the concept of food security was used to clarify whether a country has access to enough food to meet dietary energy needs (Pinstrup-Andersen, 2009). Food security is generally understood as food availability and access to food in a sufficient quantity and quality required for a healthy life (Aborisade & Bach, 2014).

The widespread definition of food security dates back to the 1996 World Food Summit: 'Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life' (FAO, 2009). This definition consists of four key dimensions. The first dimension is physical availability of food which means there are sufficient quantities of food in different forms. Food availability relates to the supply of food through production, distribution, and trade. The second dimension is access, which is related with the affordability of food within households. Utilization is the third dimension of the food security concept and is related to meeting the nutritional needs of people. The fourth dimension is stability, which means that access to food is guaranteed over time (Jones et al., 2013; van Dijk & Meijerink, 2014; Stringer, 2016; Briones Alonso et al., 2018). Adequate availability is necessary, but does not ensure universal access to sufficient, safe and nutritious food (Barrett, 2010).

Several researchers have further developed the 4-dimensional definition of food security adopted by FAO (2009). Coates (2013) offers five different dimensions to better assess the various aspects of the concept of food security. These alternative dimensions are a) the sufficiency; b) nutritional adequacy; c) cultural acceptability; d) safety; e) certainty and stability of food. These dimensions can be considered at the global/national level, at the household level, as well as at the individual level (Coates, 2013). Burchi and De Muro (2016) proposed five different approaches: a) food availability, b) income-based, c) basic needs, d) entitlement, and e) sustainable livelihood. The food availability approach can be used at country or world level and in the agricultural sector, focusing on its production and productivity (Burchi & De Muro, 2016).

Food security is closely linked to food self-sufficiency. National food security was conceived as food self-sufficiency, which means that the country produces food as much as the population demands (Pinstrup-Andersen, 2009; Coates, 2013). Clapp (2017) defines food self-sufficiency as domestic food production that equals or exceeds 100% of the country's food consumption. For assessing a country's self-sufficiency, the ratio (SSR) may be used, which is defined as the percentage of food consumed that is produced domestically. Production, export-import and stocks data are used for calculating the amount of consumed food (Puma et al., 2015). The self-sufficiency ratio is typically calculated for a specific commodity or a class of commodities. FAO recommends that caution be taken when using this ratio for the assessment of food self-sufficiency throughout the country, as it may conceal the situation where the country produces some food abundantly and hopes for imports in order to meet the needs of some other foodstuff (FAO, 2012b).

Food self-sufficiency is primarily related to the availability pillar of food security, focusing on the origin of food or the capacity to produce it domestically and in a sufficient amount (Clapp, 2015).

According to forecasts, the need for a physical availability of food will increase around the world in the coming decades, whereas land resources for food production are limited. In some parts of the world, this presses for a more intensive use of agricultural land, whilst it is important to secure sustainability of agriculture. Verburg et al. (2013) have said that land-based production gives the main biophysical basis for food security and it is therefore an important component in ensuring food security. Hence, land use issues must be taken very seriously also in Estonia, primarily because Estonia's population may be decreasing, but the world's population is still growing rapidly, and is

estimated to reach 9.6 billion by 2050 (FAO, 2017). This means that more resources will be needed to satisfy people’s primary needs (food, water), and therefore, efficient land use is increasingly important.

Food security in the Estonian context

During past centuries, the volume of agricultural produce in Estonia has been sufficient to provide food for its population and export the surplus production. After Estonia regained its independence in 1991, the country’s agricultural land use and production started to decrease, as illustrated by the decrease in the area of agricultural land (Fig. 1). While there was 1,374,000 ha of agricultural land in Estonia in 1992, the area had decreased to 698,200 ha by 2002. In 2016, 1,003,505 ha of agricultural land was in use, i.e. 27% less than in 1992. This means that the use of agricultural land is over ¼ lower than in the first years of independence, but different support measures of the EU’s CAP have stimulated the growth of the use of agricultural land by more than 40% by 2016, compared to the lowest point in 2002.

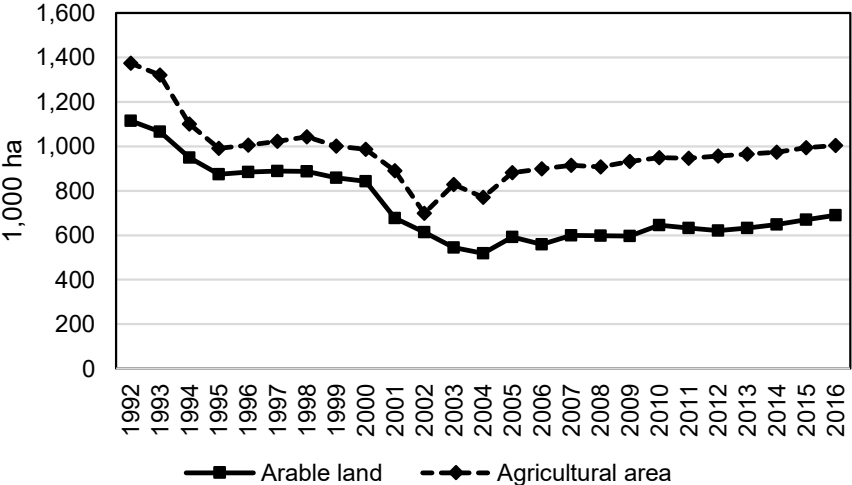


Figure 1. Agricultural land and arable land dynamics in 1992–2016 (SE, 2017; FAOSTAT, 2018).

The area of arable land was in decrease until 2004 (Fig. 1). From 2005, the area of arable land started to increase again and amounted to 690,208 ha in 2016. By 2016, there was 36,918 ha of agricultural land (permanent grassland) not used in agricultural production but maintained in good agricultural and environmental conditions, i.e. land that does not produce agricultural products, thus not producing direct economic added value but provides public goods. As these 36,918 ha of permanent grassland has to be maintained as permanent grassland, added value could be produced via increasing the stock of grazing livestock.

How to make a rational use of existing resources, primarily arable land? Dairy sector is the cornerstone of Estonian agriculture as Estonia is and has been net exporter of milk and dairy products. Hence this study is looking to:

1) define the rational structure of land use in order to ensure food security of the population in terms of the main foodstuffs and the existing production and export volume for milk products (Scenario 1);

2) define the rational structure of land use assuming a significant increase of dairy production and export in the future (Scenario 2).

Expectation for a considerable expansion of the dairy sector is supported by the historical experience. After all, the years 1986–1989 saw nearly 1.3 million tonnes of milk being produced. Around 300 thousand dairy cows were required for this, with average annual milk production per cow slightly above 4,000 kg (SE, 2017). Resources required for such production volumes were already present, i.e. land for producing feed, barns for the cattle and the calves, as well as people and their skills (experience). Although some feed cereals and concentrates were imported from neighbouring Soviet republics, fodder was produced locally, and that arable land is still present and usable in the future.

Various studies have targeted food security issues both at the world scale and at different national levels (Coles et al., 2016; Halldorsdottir & Nicholas, 2016; Peters, et al., 2016; Shepon et al., 2016; Bureau & Swinnen, 2017; Flachowsky et al., 2017; Martin, 2017; Meyfroidt, 2017; Stephens et al., 2017; Sadowski & Baer-Nawrocka, 2018). Different mathematical models have been used in food security modelling (Koh et al., 2013; Davis & D'Odorico, 2015; Chavas, 2017; Qi et al., 2018), including linear programming models (Ward, 2014; Monaco et al., 2016; Sali et al., 2016; Van Kernebeek et al., 2016).

The current study focuses on the physical availability dimension of food security. The use of arable land is optimised in order to define the production capacity of the main foodstuffs and export capacity of dairy products of the Estonian agricultural and food sector. This in turn allows to adjust crop and livestock production in order to ensure the population's food security in terms of the main foodstuffs.

MATERIALS AND METHODS

Estonia's food security and agricultural production capacity were assessed using a linear programming model (Põldaru & Roots, 2012) which has been updated according to changes in the population's structure, consumption habits, and nutritional recommendations for minimal food basket suggested by Estonian nutritional scientists, as well as developments in agriculture (Table ..., 2004; Calculations ..., 2016; Estonian ..., 2017; SE, 2017).

Linear programming models are used for solving problems which requirements are represented by linear equations or inequalities, and the purpose of which is clearly expressed and mathematically formulated (Taha, 2003).

The following presents an overview of the linear programming land use optimization model used in the study. The optimization model includes 163 variables that are divided into 7 groups and 178 constraints that are divided into 6 groups (Table 1).

Table 1. Groups of variables and constraints in the optimization model

Groups of variables	Groups of constraints
1. Number of population by gender and age groups (thousands) – 11 variables	1. Population's food demand – 11 constraints
2. Total consumption and production of foodstuffs (tonnes) – 23 variables	2. Food production and consumption – 17 constraints
3. Number of animals (head) – 11 variables	3. The number of animals and structure of livestock farming – 13 constraints
4. Crop sown areas (ha) – 15 variables	4. Feed production – 107 constraints
5. Feed sown areas by animal species (ha) – 67 variables	5. Export product – 8 constraints
6. Cost variables (thousands of euros) – 33 variables	6. Cost – 22 constraints
7. Auxiliary – 3 variables	

In case of the given model, the optimization criterion is the minimum sown area of all crops required for the production of foodstuffs – cereal products and food potatoes, and self-produced feed.

Baseline data for the optimisation model is the following:

1. The number of inhabitants in Estonia by sex and age groups (1,315.8 thousand inhabitants), and the calorie and protein requirements of each group. Weighted average demand over all groups is 2,160 kcal of energy and 58 g of protein per capita per day (Estonian ..., 2017; SE 2017).

2. Characteristics of eating habits (minimum quantities of meat products, dairy products, cereals, and potatoes consumed per year – a total of 9 different foodstuffs). The minimum consumption amount of these foodstuffs per person are presented in Table 2.

3. Energy content (kcal) and protein content (grams) of primary foodstuffs (9 different foodstuffs).

4. Crop yields (kg ha⁻¹) of 12 different crops, the amount of energy (MJ) and protein (kg) obtained from each hectare.

5. Characteristics of livestock productivity (milk production per cow, slaughter weight of fattening cattle and pigs, meat production from broilers, and egg production per hen per year).

6. Characteristics of the reproduction of animals (the proportion of culled cows per year, the number of calves per one cow, the number of piglets per one sow per year).

7. Yearly energy requirement (MJ) and protein requirement (kg) per year for different species of animals (cattle, pigs, poultry – total of 10 species).

8. The energy content (MJ) and the protein content (kg) of the yield (feed) proposed for feeding different species (10 animal species) obtained from one hectare of feed growing area.

The optimization model uses three equilibrium conditions that ensure balance between production and consumption of agricultural production. Fig. 2, where dashed line ovals visualize the equilibrium conditions depict the main groups of variables and their interaction in order to satisfy the equilibrium conditions and produce results on optimal land use (sown area).

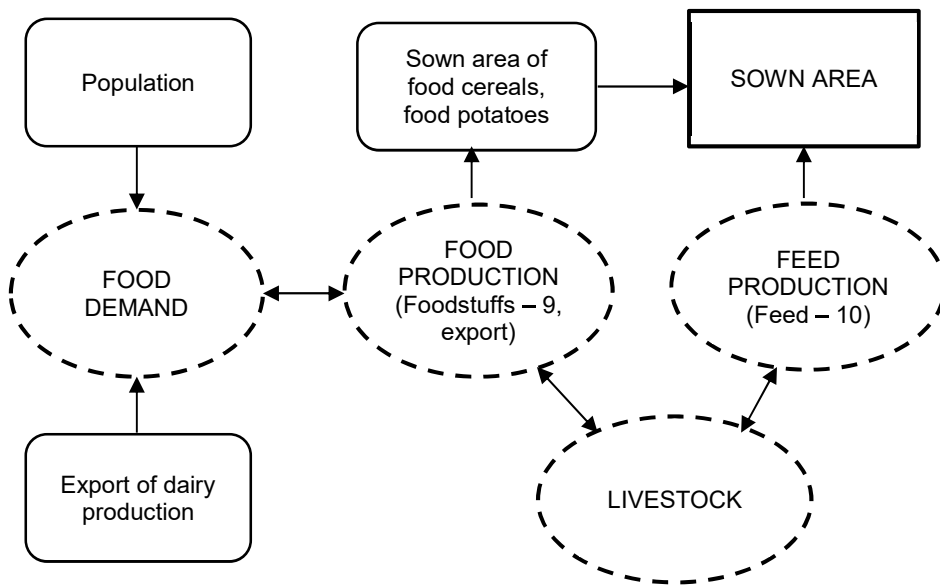


Figure 2. Flow diagram of equilibrium conditions of model.

1. The 1st equilibrium condition (food demand) is based on the population of Estonia and export volumes of dairy products. The supply side consists of estimated amounts of produced foodstuffs. To ensure a balance between consumption and production, the model defines numbers of animals and sown areas (food cereals and food potatoes) required for producing each of the main foodstuffs (Fig. 2). Consumption volumes also determine the numbers of slaughter animals (beef heifers, fattening pigs, and broilers), dairy cattle, and laying hens, which ensure a balance between demand and production (supply).

In modelling dairy production milk is divided in three main components: raw milk, milk protein and milk fat. Produced raw milk (total milk production) is divided into drinking milk, processed milk, and feed for calves and piglets. Milk protein and milk fat obtained from processed milk are the modelling basis (production, consumption and export) of the main products: cheese, butter, whole milk powder (WMP) and skim milk powder (SMP).

2. The 2nd equilibrium condition describes the relation between slaughter animals and slaughter animals (cows, pigs, hens) which satisfies the demand side, i.e. the consumption side, and is in balance with the number of animals produced by the reproductive chain of the respective animal species (supply).

3. The 3rd equilibrium condition describes a balance between feed consumption and production in all animal species. The feeds of all animal species are balanced in terms of the main feed parameters (energy and protein), and are produced in Estonia. There is a different selection of feeds designed for feeding each animal species.

The model has the following limitations:

1. The model is not used for modelling non-agricultural products (aquaculture products), non-local products (coffee, sugar, tea, etc), non-land based foods (honey), fruits, or vegetables.

2. Cereal export and import are not modelled.
3. Only self-produced feeds are used for feeding animals.
4. This study addresses one dimension of food security – food availability and does not take into account the effect of food prices and the purchasing power of various social groups.

This paper provides an analysis of two scenarios:

Scenario 1 defines a rational land use structure in the context of 2017 production conditions with some exceptions:

- a) average productivity is 9,000 kg milk per cow,
- b) export of dairy products is modelled. Contrary to the actual situation, raw milk export to Latvia and Lithuania is not modelled, but the respective quantity of milk is used for processing to make cheese, butter, WMP, and SMP. Therefore, the results of this scenario do not fully match the current situation in Estonia.

Scenario 2 is used to assess how land use would change if the dairy sector was to increase the production volume considerably:

- a) model stipulates a total annual milk production per cow – 10,000 kg,
- b) estimated export volumes are chosen so that the estimated total milk production is approximately equal to the total milk production of 1986–1989 (ca 1.3 million tonnes).

The linear programming model is used to identify different land use scenarios which allow to assess how much food the agricultural and food sector are able to produce and export. MS Excel's Premium Solver Pro was used to solve the model.

RESULTS AND DISCUSSION

Consumption of foodstuffs and land use for the food production

Food security and prospective rational land use in Estonia has been analysed using two different scenarios. The modelling results indicate that Estonia's agriculture and food production sector is able to provide the Estonian population with the main foodstuffs (Table 2).

In order to ensure food security, minimum daily energy consumption per person must be 1,700–1,900 kcal (FAO, 2008). The model estimates a daily energy consumption of 2,207 kcal per person, which exceeds the minimum level of food energy and is in line with food consumption recommendations. The consumption of sugar, fish products, cooking oils, fruits and vegetables is added to this amount of energy.

The planned consumption level of protein according to the optimum plan is 97 grams per day. An analysis of the main foodstuffs consumption shows that people tend to exceed the minimum daily requirements of the main foodstuffs in terms of energy and protein.

The analysis of the structure of consumption by consumed calories shows that 1.06×10^{12} kilocalories of energy must be produced to ensure sufficient food for the entire population. Most of the energy (48.6%) is obtained from cereal products, pork (12.9%) is on the second position, leaving drinking milk and drinkable dairy products (10.3%) on the third position.

Cereals are also the largest source of protein (33.8%), pork (19.2%) the second, and drinking milk along with drinkable dairy products (12.1%) the third.

Table 2. Estimated consumption of foodstuffs per year, and agricultural land needed for producing them

Foodstuff	Specified minimum kg per capita	Total t	Calories 10 ⁶ kcal	Percentage of calories %	Protein t	Percentage of protein %	Area ha
Beef	9.0	11,777	21,788	2.1	2,355	5.1	14,
Pork	40.0	52,343	136,616	12.9	8,898	19.2	18,
Poultry meat	25.0	32,714	45,800	4.3	4,024	8.7	23,
Eggs (1,000 pcs)	245.0	320,602	39,113	3.7	3,591	7.7	23,
Milk (products)	130.0	170,115	108,874	10.3	5,614	12.1	41,
Cheese	10.0	12,432	41,273	3.9	3,481	7.5	22,
Butter	6.0	7,197	52,611	5.0	216	0.5	19,
Cereal products	120.0	157,029	515,057	48.6	15,703	33.8	53,
Potatoes	130.0	170,115	98,667	9.3	2,552	5.5	8.5,
Total	X	x	1,059,799	100	46,434	100	392,
Per capita (1,000 kcal, kg)			805		35		

An analysis of the sown areas required for producing the planned foodstuffs demonstrates that 392,105 ha of land must be cultivated in order to feed Estonia's population, i.e. approximately 0.3 ha of land is needed to supply one person with the main foodstuffs (Table 2). The majority of land would be taken up for producing pork, i.e. 185,332 ha, making up 47.5% of the sown area of crop. 13.7% of the sown area of crop would be used for producing food cereals, and 10.5% of the sown area of crop required for feeding the population would be used for producing drinking milk and dairy products made from the latter.

Analysing the amount of energy (the number of calories) produced from one hectare, it appears that the highest amount of energy – 1,160 kcal – is produced from 1 m² of potato field, and the lowest amount from 1 m² of sown area used for producing pork, i.e. only 74 kcal. 15.7 times less energy is obtained from 1 ha in case of pork production than in case of potato production. Cereals are in the second position when it comes to energy production – 960 kcal m⁻².

A similar analysis focusing on protein production shows that the highest amount of protein – 300.0 kg is also produced from one ha of potato field. One ha of sown area used for producing cereal products is on the second position, providing 291.9 kg of protein, and one ha of sown area used for producing poultry is on the third position, providing 168.8 kg of protein.

Sown area of field crops and their structure

Table 3 gives an overview of planned sown areas of field crops and their structure in different scenarios. In the first scenario, the entire planned sown area is 490,689 ha, 61.2% of which is sown area of cereals. In addition to providing a necessary area to guarantee food security to the population (Table 2), such sown area of field crops also guarantees the amount of raw milk production required for producing export dairy products.

The actual sown area of field crops in Estonia was 672,905 ha in 2016 (SE, 2017). Cereals were sown on 351,353 ha which made up 52.2% of the total sown area. Thus, the planned and the real sown areas of crops and their shares differ remarkably. Such big difference of sown areas of field crops is caused by the fact that the sown area of export cereals makes up an important part of the real structure of sown areas of crops. Therefore, the structural indicators presented in Table 3 are not comparable to the indicators of national statistics. 1 million tonnes of cereals were exported in 2015/2016 (SE, 2017). As a result of modelling, 53,821 ha of land is planned as sown area of food cereal, making up 11.0% of the entire sown area of crops, and 21.7% of sown area of the cereal crops.

The estimated sown area of crop in Scenario 2 is 619,928 ha which exceeds the sown area of crop in Scenario 1 by 129,239 ha. Such a large sown area ensures that the production of the dairy sector can be increased to the expected level. Compared to Scenario 1, sown areas of cereal and feed crops are larger. Sown area of cereal crops increased by 38,602 ha, whereas the sown area of all feed cultures increased by 90,638 ha. There were also some changes in the structure of sown areas. The share of feed crops grew from 33.4% to 41.1%.

However, even in the Scenario 2, the sown area of cereals is 18.6% below the actual sown area in 2016. At the same time, in 2016, the self-sufficiency of pork and poultry were 73.5% and 57.4% respectively (SE, 2018). This suggests that if Estonia wants to

reduce export of cereals, it should improve its self-sufficiency of pork and poultry and increase pork and poultry production.

Table 3. Planned areas and structure of field crops

Field crop	Scenario 1		Scenario 2		
	Area, ha	Share, %	Area, ha	Share, %	Change, ha
Cereals	248,114	50.6	286,716	46.2	38,602
inc. food cereals	53,821	11.0	53,821	8.7	0
Forage crops	164,069	33.4	254,707	41.1	90,638
multiannual forage crops	24,836	5.1	57,548	9.3	32,712
green fodder	74,709	15.2	113,093	18.2	38,384
inc. mixed hay	17,734	3.6	20,062	3.2	2,327
pasture	54,190	11.0	90,247	14.6	36,057
annual forage crops	2,784	0.6	2,784	0.4	0
succulent feed	64,523	13.1	84,066	13.6	19,543
inc. silage crops	37,553	7.7	57,095	9.2	19,543
potatoes, beets	26,970	5.5	26,970	4.4	0
Food potatoes	8,506	1.7	8,506	1.4	0
Rape	70,000	14.3	70,000	11.3	0
Total	490,689	100.0	619,928	100.0	129,239

In 2016, permanent grassland and fodder crops comprise 48.3% (485,019 ha) of utilised agricultural land. The results of Scenario 1 indicate that 164,069 ha of forage crops are required to ensure self-sufficiency with beef and dairy products, and allow for export of dairy products in 2016 volumes. Increase in milk production in Scenario 2 increase the forage area to 254,707 ha. This suggests that in Scenario 2 approximately 230,000 ha of permanent grassland and/or area of fodder crops could be used to produce beef or even more dairy products for export. Therefore, beef and dairy farming should be developed if Estonia aims to maintain the area of permanent grasslands and keep them in good agricultural and environmental conditions via agricultural production.

Livestock and feed production

Table 4 provides an overview of the estimated number of livestock, sown areas of crops required for producing feeds, as well as energy and protein amounts. The indicators characterising cattle farming are defined on the basis of total milk production. The amount of total milk production is defined on the one hand by the amount of raw milk required for producing dairy products, and on the other hand, the amount of milk that goes for the internal use of agriculture. Total milk production is in balance in terms of demand (consumption) and supply (production). The number of cattle and other indicators characterising the reproduction of cattle are derived from the specified productivity and the required total milk production. In Scenario 1, milk production per cow is 9,000 kg, and in Scenario 2, it is 10,000 kg. The other indicators characterising cattle farming depend directly on the number of cows, and act as a reproductive chain (balancing out the number of cows).

Table 4. Planned number of animals, and feed consumption

Animal species	Scenario 1				Scenario 2						
	No. 1,000	Area 1,000 ha	Share %	Energy 10 ⁶ MJ	Share %	Protein t	Share %	No. 1,000	Area 1,000 ha	Share %	En 10 ⁶ MJ
Dairy cows	83.6	152.3	35.6	7,178	44.4	52.7	38.6	130.7	268.9	48.2	12,178
In-calf heifers	26.8	24.5	5.7	1,030	6.4	10.3	7.5	41.8	38.3	6.9	1,030
Fattening bulls	12.7	9.6	2.2	427	2.6	3.5	2.6	3.3	2.5	0.4	11,427
Calves	82.0	9.2	2.2	246	1.5	2.8	2.0	128.1	16.6	3.0	64,246
Fattening pigs	755.7	129.6	30.3	4,715	29.2	35.5	26.1	755.7	123.5	22.2	3,915
Sows	42.8	48.6	11.4	1,261	7.8	14.5	10.7	42.8	48.6	8.7	1,261
Piglets	771.1	7.1	1.7	246	1.5	2.0	1.5	771.1	7.6	1.4	30,246
Broilers	27.3	20.5	4.8	436	2.7	6.5	4.8	27.3	24.6	4.4	93,436
Laying hens	1.3	20.2	4.7	456	2.8	6.4	4.7	1.3	20.2	3.6	45,456
Breeding hens	0.4	6.7	1.6	156	1.0	2.1	1.5	0.4	6.7	1.2	15,156
Total	X	428.4	100	16,152	100	136.3	100	x	557.6	100	21,152

An analysis of indicators related to dairy cattle shows that 83,600 cows (Scenario 1) are enough for producing the necessary quantity of milk. Planned total milk production is 752,465 tonnes. The analysis shows that 730,000 tonnes of milk goes for human consumption (for preparing milk and processed dairy products), with the rest is given to calves and piglets as feed. National statistics show that in 2016, there were 86,100 cows in Estonia, and 783,200 tonnes of milk was produced, meaning that average milk production per cow was 8,878 kg (SE, 2018).

152,300 ha of land must be cultivated to feed the planned 83,600 cows – this is 35.6% of the total sown area of crops required for feed production (428,400 ha). The total amount of energy of feed produced from this sown area is 7,178 million MJ, meaning that 85,900 MJ of energy is produced per one cow per year. The planned amount of energy is in line with normative energy needs, and using the existing feeds fulfils energy and protein needs.

In Scenario 2, the total planned milk production is 1,306,886 tonnes. The number of cows needs to be increased to 130,689 heads to achieve this. 286,900 ha of land must be cultivated to feed the cows. This is 48.6% of the total sown area of crops required for feed production. The total amount of energy of feed produced from this sown area is 12,451 million MJ, meaning that 95,900 MJ of energy is produced per one cow per year. The energy spent on feeding cows makes up 56.8% of the energy used for feeding all animals.

Total pork production is the primary indicator characterising pig farming. Total pork production consists of two parts: the quantity of meat from fattening pigs, and the quantity of meat from slaughtered sows. 755,700 fattening pigs must be reared to produce the quantity of meat required for the population. This exceeds the number of fattening pigs currently being reared in Estonia. According to national statistics, 464,900 fattening pigs were slaughtered in Estonia in 2015 (SE, 2017). Thus, the planned number of fattening pigs exceeds the 2015 level by 1.66 times. The planned sown area of feed crops for feeding fattening pigs is 129,600 ha, which makes up 30.3% of the total sown area of feed crops.

Summary of the main results

Table 5 shows a comparison of the main results of different scenarios, showing that most of the production volume indicators in Scenario 2 exceed the Scenario 1 indicators by 1.16–2.39 times. Such difference is related to the fact that Scenario 2 aimed to model a situation which would describe milk production levels in the years 1986–1989. In Scenario 2, the estimated total milk production is 1,306,886 tonnes, which surpasses the total milk production in Scenario 1 by 1.74 times. To reach this amount, the number of cows must be increased to 130,689, with a milk production of 10,000 kg per cow, which is 1.56 times more cows than in Scenario 1. With an increased number of animals, the total sown area must increase by 1.26 times, the sown area of cereals should increase by 1.16 times, and the sown area of feed crops by 1.55 times. The biggest change in Scenario 2 is the increase of the amount of raw milk required for export dairy products by 2.39 times.

Table 5. Brief comparison of the main results of Scenarios 1 and 2

Indicator	Unit	Scenario 1	Scenario 2	Change
Total sown area	ha	490,688	619,928	1.26
Cereal sown area	ha	248,114	286,716	1.16
Feed crops' sown area	ha	164,069	254,707	1.55
Number of cows	head	83,607	130,689	1.56
Total milk production	t	752,465	1,306,886	1.74
... milk for animal feed	t	22,465	39,018	1.74
... milk for export dairy products	t	386,407	924,275	2.39
... export of cheese	t	15,000	50,000	3.33
... export of butter	t	10,429	25,000	2.40
... export of SMP	t	49,317	87,279	1.77
... export of WMP	t	1,000	2,000	2.00

The optimisation helped to estimate Estonia's agricultural and food sector's capability to produce the main foodstuffs, i.e. it found the optimal crop and livestock structure that ensures availability of domestically produced main foodstuffs for the Estonian population, and the export of dairy products.

CONCLUSIONS

A linear programming model was used for optimisation, with the criterion of optimality being the minimisation of arable land required for producing foodstuffs.

The analysis of the solution results shows that 392,105 ha of arable land is required to supply the Estonian population with the main foodstuffs. This implies an energy use of 2,207 kcal, i.e. approximately 0.3 ha of land is needed to supply one person with the main foodstuffs. In order to supply Estonian residents with sufficient main foodstuffs and to maintain the export of dairy products in 2017 volume, 490,689 ha of land are needed. Increasing dairy production to 1.3 million tonnes per year implies increasing the number of cows up to 130,700 heads and increasing arable land use to 619,928 ha.

Further studies could aim to reduce limitations of this study, analyse the sensitivity of the results with regards to different crop yield levels, consider the export-import of cereals, and assess the impact of changing diets on the agricultural and food production and agricultural land use.

If Estonia aims to maintain its almost 500,000 ha of permanent grasslands and annual and multi-annual forage crops area and keep these areas in good agricultural and environmental conditions via agricultural production activities, beef and dairy farming and exports should be further developed.

The results of the analysis show that improvements in the self-sufficiency of pork and poultry are needed if Estonia aims to reduce its exports of cereals.

This analysis demonstrated that Estonia's agricultural and food sector has necessary land resources to contribute towards the goal of ensuring food security for the world's population.

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