Moving towards biotechonomy: an applied case in agriculture sector

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Abstract

A System Dynamics model has been built for biotechonomy analysis at sectoral, federal or national level. Allocation of land for production of bioresources and further production of high added value products is based on the highest added value of product chain produced from the bioresources in a sustainable way. Ten submodels are interlinked within the model: acquisition of raw material; production of products from raw material; infrastructure and technologies; research, development and education; investments and financing; demand, supply and prices; revenues, costs and profit, and sustainability index. The model is applied to one agriculture sector in Bauska county in Latvia. Results show the dynamics of agriculture land allocation for different products based on the highest added value of product chain operating on market conditions only, i.e., without policy interventions. Policy tools are discussed.

1. Introduction

Biotechonomy is a science-based efficient use of local resources by creating new, marketable, competitive products that are manufactured with innovative and up-to-date biotechnologies. It combines both cultivation and harvesting of biological resources, and the use of biotechnologies for the processing and transformation of raw materials by means of innovative and advanced technologies in order to obtain new products with added value (see Fig. 1). The overlap between three pillars determines the efficiency of usage of biological resources and its impact on the national economy. The higher the total contact area, the greater the national macro-economic benefits, lower the impact on climate change, greater the environmental, economic and socioeconomic benefits.

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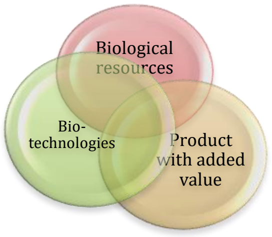


Fig. 1 Three main pillars of biotechonomy concept

Biotechonomy idea is well described by the pyramid ilustrated in Fig. 2. The base of the pyramid is the simplest use of biological resources, i.e. waste that goes into the waste disposal. This is the simplest, least environmentally friendly and least profitable alternative. The second alternative is to use biological resources to produce heat in combustion processes, which is then used in heat supply for industries, agriculture and the service sector. It will always remain an open question: whether these biological resources can be used more efficient. Biological resources fired in furnaces can be used for other purposes, such as to produce a gaseous or liquid biofuels. These products have a higher added value. The bioenergy production increases the employment rate, replaces imported fossil fuels, and reduces the climate change impact, which sums up in a positive impact on the national macroeconomics. It is possible to produce new product from any biological resource. It is important to assess what will be the use of this new product, what will be the demand in the market and costs of production, what will be the impact on the environment and climate change, and what will be the socio-economic indicators. At the top of the pyramid lies new, innovative, environmentally sound and climate-friendly and economically and socio-economic based products that can gve the highest benefits for national economy and society.

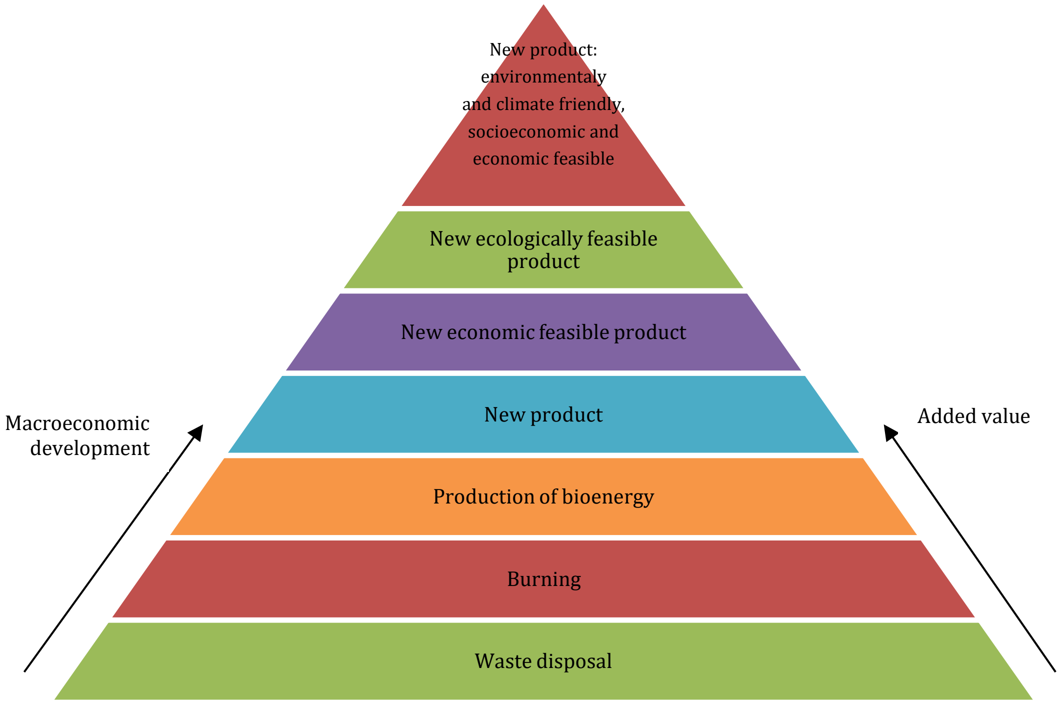


Fig. 2 Biotechonomy pyramid for use of biological resources

Different system dynamics models have been built to simulate development both national economy and its' impact on environment. The most well known are the national model developed by Forrester (1980), the world development models by Forrester (1971) and Meadows et al. (1972). A number of system dynamics models have been built to study complex systems in agriculture sector. Li et al.(2012) have focused their attention to eco-agriculture based on the interaction between short and long term economic and ecologic aspects. Wang et al. (2012) have studied relationship between human activities, land systems, and natural environmental change. Policies on water distribution, land use, pollution and agricultural production, all in the context of changing population dynamics have been the main research focus for Saysel et al.(2002). Boumans et al. (2015) have modelled ecosystem services and human well being which are affected by the relationship between socioeconomic and environmental factors. System Dynamics model created by Ferreira et al. (2016) includes structure that allows assessing the potential gains from an integrated planning of agricultural and industrial production in a citrus agrichain. Dace et al.(2015) have used system dynamics model to find out policy tools for the national greenhouse gas emission reduction action plan. Kenny (2017) has carried out detailed review on different modelling tools used for farming, including system dynamics models. All above mentioned models have been built with the purpose to study different aspects of agriculture but they are either to narrow or to wide in their application for biotechonomy study.

The main goal of this research is to apply System Dynamics modelling for evaluation of biotechonomy potential (the highest added value for bioresource with the lowest impact on environment) in agriculture sector. The first chapter of this paper is devoted to the structure of the System Dynamics model. It is followed by application of the model structure to biotechonomy in agriculture sector. Chapter 3 presents the main results generated by model. The paper is finalised with conclusions and discussions.

2. System Dynamics model

The model contains 10 sub-models representing different sub-sectors within biotechonomy sector including:

- Land use
- Acquisition of raw material
- Production of products from raw material
- Infrastructure and technologies
- Research, development and education
- Investments and financing
- Demand, supply and prices
- Revenues, costs and profit
- Sustainability index.

Land and inland water bodies are the most important resources for the biotechonomy. Material and information flows between different sub-models link them together. Raw materials are grown on the land by means of nutrients. The allocation of land for different products depends on several factors. Typically, land use is determined by a yield. Yield can be expressed as the amount of the raw material obtained from one hectare. However, whether the land will be used for cultivation of certain raw material determines profit which is compared with other land-use alternatives. The profit is dependent on the other factors of production (including technology and labor) costs, and the final product market prices. Productivity of the land, as a production factor is influenced by its characteristics and location, i.e. soil composition, nutrients available, the climatic conditions (temperature, rainfall, etc.). These factors may be subject to high uncertainty - particularly with regard to the weather. Productivity is also affected by the availability of technology and human capital, i.e. knowledge about the cultivation. By increasing raw material added value it is possible to increase the value chain profits of specific resource, which in turn gives a feedback that affects the decision as to which product to produce and which resources to grow. The higher profits can be derived from the added value chain, the higher the investment is likely to be attracted to technology and more money diverted to research, development and education, which in turn allows to increase the value chain profit. The calculation takes into account sustainability and environmental factors, so the costs include emergy tax. Sustainability index is determined taking into account the production chain invested in materials and energy resources, as well as the proportion of non-renewable resources. Thus, we can say that between the product value chains competing for resources (land, financial and human) the value added and environmental considerations determine the redistribution of resources amoung value chains. Different policy instruments (taxes, subsidies, public investment, legislation, etc.) can be used to influence the redistribution of wealth.

2.1. Land use

The land use sub-model is a key element of the model. The output of a particular product is determined by how large land area is allocated for its production. The main stock of the land use sub-model is the total area (see Fig. 3) allocated to a certain product and is regulated by flows of increasing and decreasing land area.

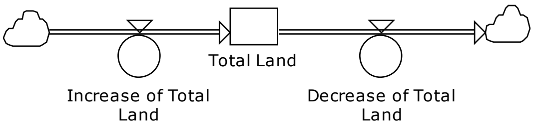


Fig. 3 Land use submodel

2.2. Acquisition of raw material

Annual production of particular raw material is determined by allocated land and current yield (see Fig. 4).

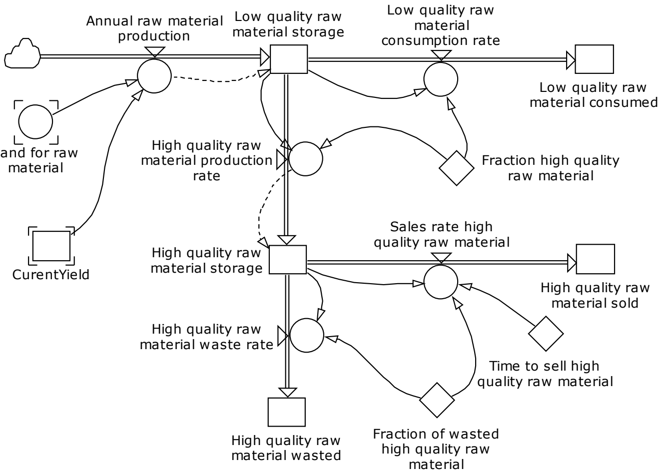


Fig. 4 Sub-model of aquision of raw materials

Bio-resources can be used in many different ways - they can be sold for direct consumption, e.g. apples for eating. They can also be used as raw material for other products, thus increasing its value, e.g. apples used for production of cider and juice. Many bio-resources are not fully used and they are wasted thus not being profitable, e.g. apple peels, seeds and cores. This model is designed to reduce the wasted part and find economically feasible solutions and additional value-added creation.

If needed the annual production can be divided into two parts – low quality raw material stock and high quality raw material stock (see Fig. 4). High quality raw material can be sold for direct consumption while the low quality raw material can be used to produce higher added value products. The sales rates, production rates and waste rates are determined by fractions. Sales rate of high quality raw material depends on time to sell raw material and amount of high quality raw material available in the stock.

2.3. Production of products from raw material

Products, which are expected to be produced from the low quality raw material determine how much and what additional components should be added during production process, as well as what will be the cost of the product, e.g. for production of apple sider sugar, water and yeast is added. Production sub-model contains number of stocks, including product in the production, stored product and sold product (see Fig. 5). The production of the product is governed by a number of inflows depending on the production processes and one outflow. The main inflow is equal to the outflow from the low quality raw material stock. The number of inflows depends on the number of components needed to produce the product.

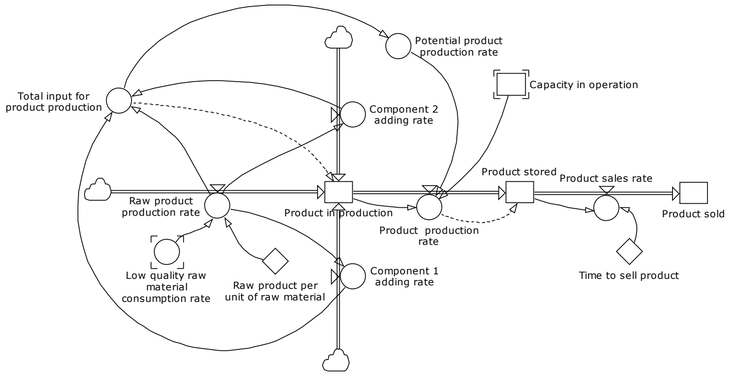


Fig. 5 Sub-model of production of products from raw material

Sub-model presented in Fig. 5 can be built for different products and combined with other products produced from the same raw material. Profit from all products produced from the same raw material determines land area allocated for this raw material production, e.g. profit from apple sales, apple cider, energy bars from apple cores and tocoferrol from apple seeds determines the land allocated for apple orchards.

2.4. Infrastructure and technologies

Capacity in operation is stock where existing production capacity is accumulated and it is adding up through commissioning rate and drained with decommissioning rate. Commissioning rate is calculated as division of stock of capacity under construction and average construction time. Decommisioning rate depends on stock of capacity in operation and average lifetime of technology (Fig. 6).

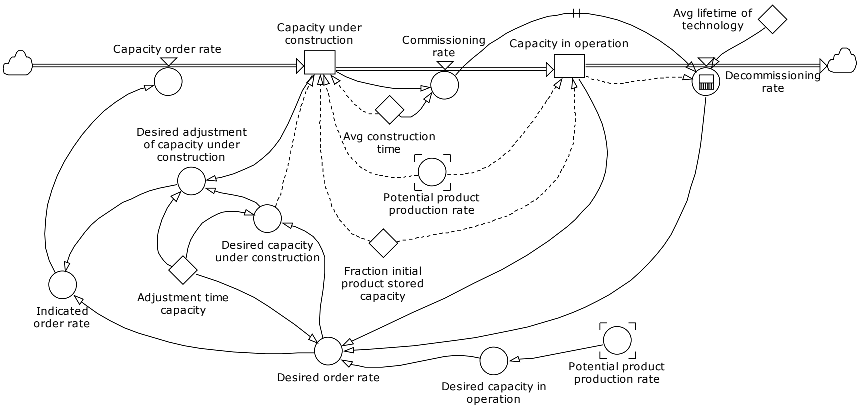


Fig. 6 Sub-model of infrastructure and technologies

In the sub-model of infrastructure and technologies, consumption of energy resources used for production needs is modelled. Each energy source (fuel, electricity, heat, water) is modelled separately and includes technology development represented as energy efficiency. Changes in energy efficiency due to technology development are calculated in sub-model of research, development and education. Fig. 7 illustrates example of model structure of electricity consumption for production needs.

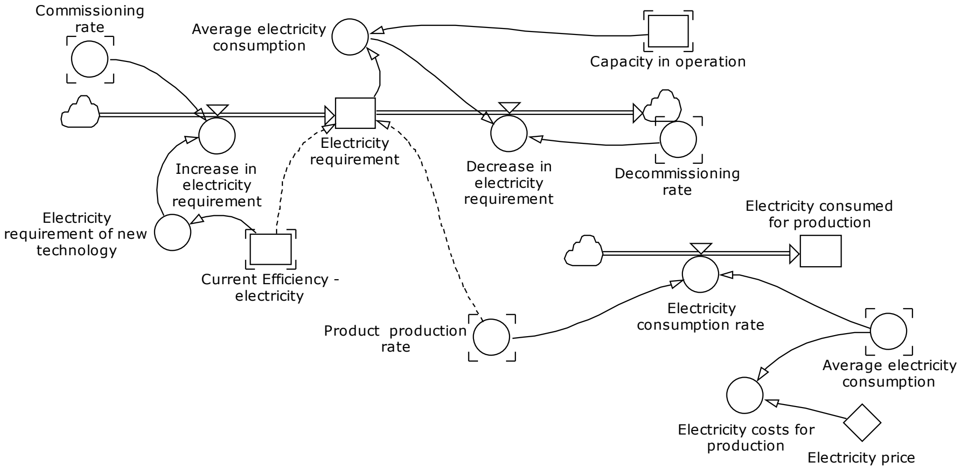


Fig. 7 Sub-model of infrastructure and technologies: structure for electricity consumption

Stock of current efficiency of electricity (Fig. 7) shows electricity consumption (kWh) for production of 1 t of product with new production technologies, e.g. value reflects the current technological state of the art with the best available technology. However, the calculation should take into account that this is the energy efficiency of equipment being installed at this moment, while for existing technologies it is lower. Therefore, the stock of electricity requirement is used to define the "average specific energy consumption", taking into account production capacities with a different energy efficiency levels.

2.5. Research, development and education

Sub-model of research and development, and education gives insights into the structure that illustrates impact of knowledge on productivity of bio-resources. This sub-model consists of four stocks and three flows (Fig. 8). Stocks characterize research and development progress, showing a variety of land productivity potentials. Stock of research potential yield shows the potential increase of land productivity (t/ha/year) by performing additional research activities. The initial value of this stock is determined by perceived maximum yield minus initial values of other three stocks.

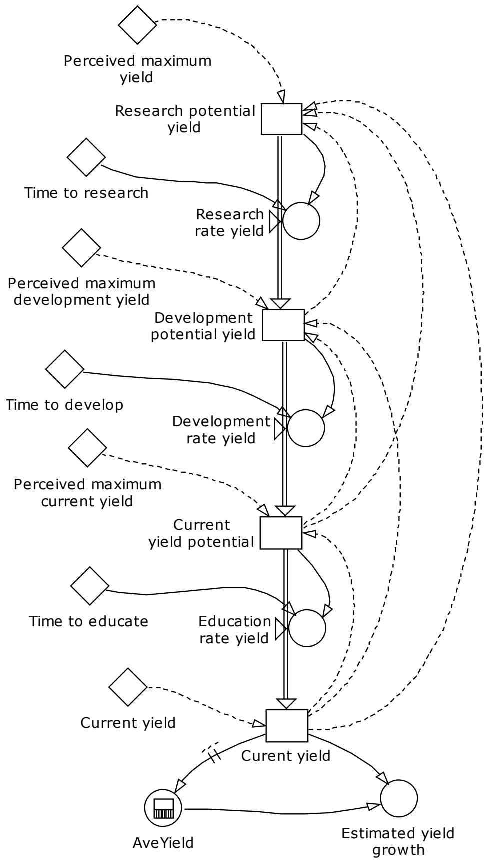


Fig. 8 Sub-model of research, development and education for productivity of land use

The knowledge gained during research activities the can be used (rate research rate yield) to increase land use productivity. At the same time the stock of research potential yield is reduced, assuming that there is a maximum perceived value for yield. Time to research determines the research rate yield and by decreasing research potential yield, the rate is also decreasing.

Stock of development potential yield shows the value of yield if already developed yield productivity increase methods are used. Development rate yield illustrates the process of technology transfer when the research results are implemented in real life conditions. This process requires time to develop technologies and apply them. Both the time to research and time to develop can be decreased or research potential yield increased if more financing is allocated for research and development, which in turn can be increased by increasing the added value of products produced. The stock current yield potential shows yield values if developed productivity increase methods are used. The stock current yield gives initial value of yield. To move from the current yield to current yield potential the education of personell about well known methods is needed (education rate yield). Current yield value is used as input for land use sub-model.

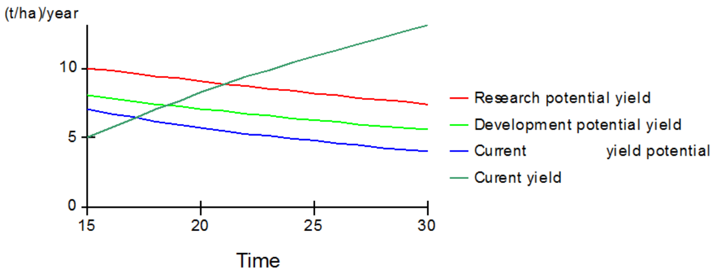


Fig. 9 Example of behaviour of four yield stocks of the sub-model of reaserch, development and education

The same structure is used to describe how reaserch, development and education is improving energy efficiency of equipment used to produce products (Fig. 10). This structure can be used for any energy source used for production purposes.

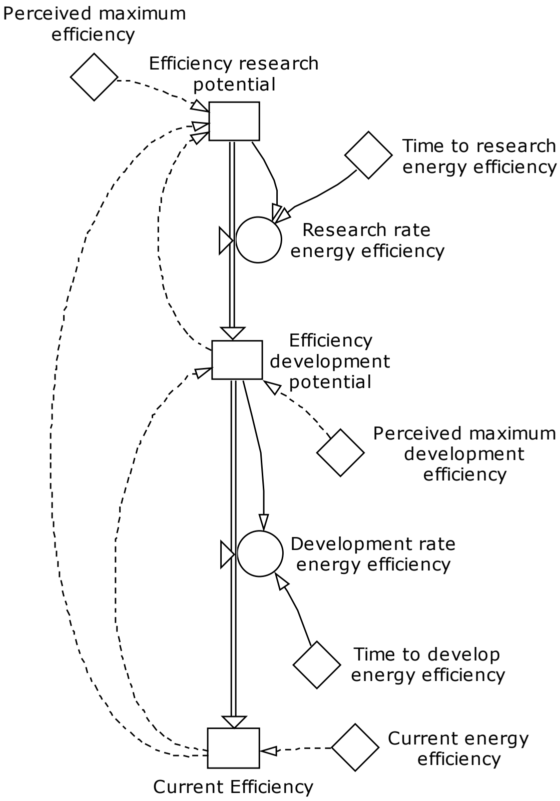


Fig. 10 Sub-model of research, development and education for energy efficiency

2.6. Investments and financing

Capacity order rate is used to calculate investments needed and capital costs of production technologies (see Fig. 11).

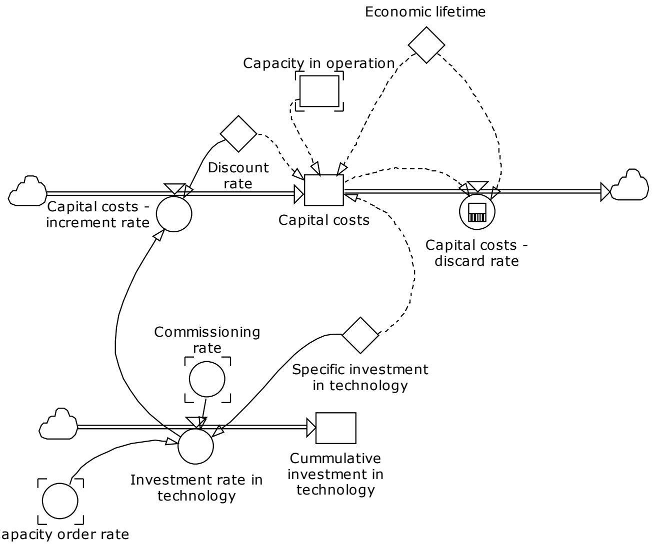


Fig. 11 Sub-model of investments and capital costs

2.7. Supply, demand and prices

The production volumes in Latvia are not sufficient to affect the supply and demand on international markets and, consequently, the price. Thus, it is assumed that the price of products is an exogenous parameter. Prices may either be constant, or may variate if the forecasts are available.

2.8. Labour and labour costs

Labour needed for production processes depends on production capacity under commissioning and decommissioning. The main stock in this sub-model is labour for production (see Fig. 12).

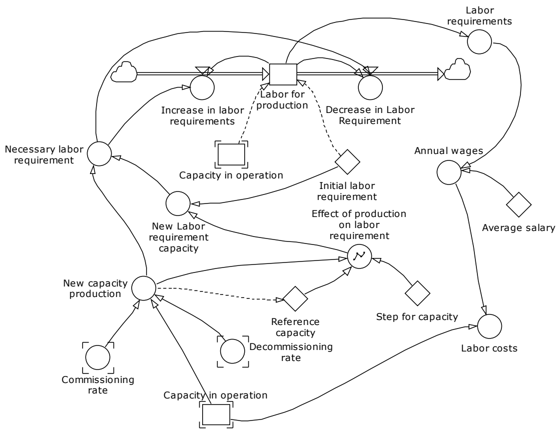


Fig. 12 Sub-model of labour and labour costs

Increase Revenues, costs and profit

The main goal of this sub-model is to estimate profit that will further be used in sub-model of land use to determine allocated land to particular raw material. The total annual profit is calculated as total annual costs substracted from total annual revenues. Total annual revenues is the sum of income from all products produced from the raw material while total annual costs is the sum of all production costs generated during particular year to produce these products (Fig. 13).

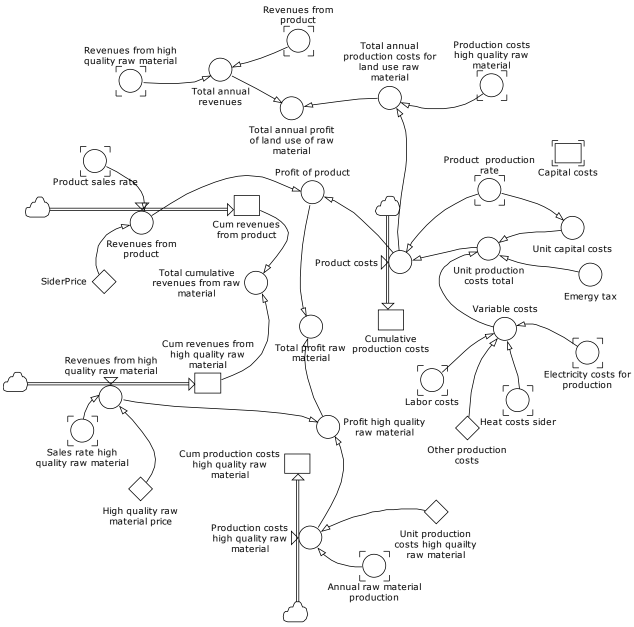


Fig. 13 Sub-model of revenues, costs and profit

Total economic annual profit per land unit is shown in Fig. 14.

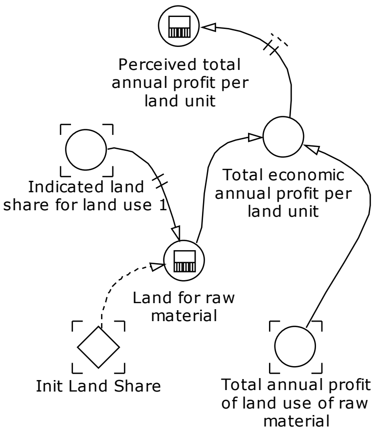


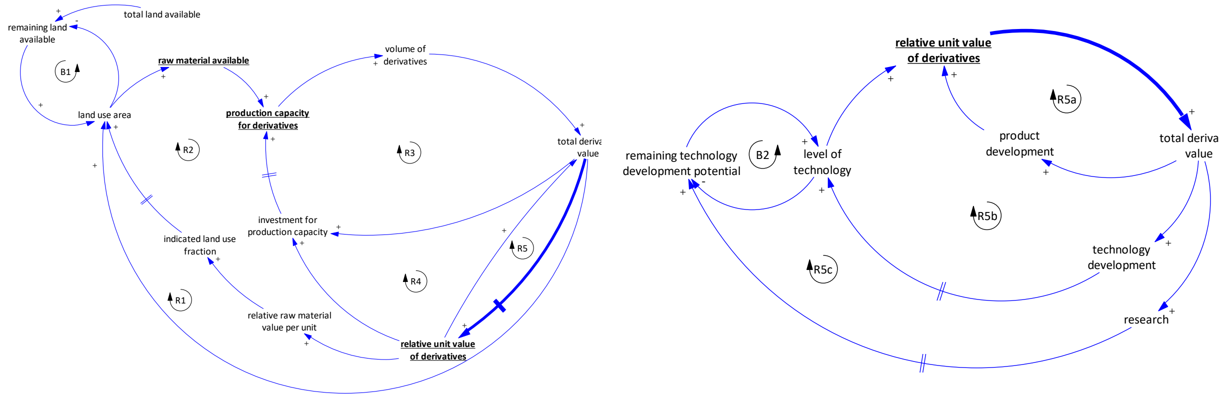
Fig. 14 Sub-model of land use

2.9. Sustainability index and emergy tax

Sustainability index illustrates the impact of raw material production and products chain on environment and is calculated based on emergy. If the sustainability index is less than 1, the product chain is unsustainable. If the value is more than 1, it is considered to be sustainable. Unsustainable production is punished with emergy tax.

2.10. Causal loop diagrams

The main causal loop diagrams are illustrated in Fig. 15. They are described in more details in Blumberga et al.(2017).



a)

b)

Fig. 15 Causal loop diagrams: a) the main feedback structure of the model; b) the three processes that may modify the relative unit value of derivatives (adopted from Blumberga et al.(2017))

3. Case study

3.1. Bauska county

For this research, the model was applied to the Bauska county in Latvia, and initial data about current situation – agricultural land area and crop diversity- was taken from Bauska county. Bauska county was chosen as it is one of the most agriculture intensive region in Latvia. More than 80% of the territory is used for agriculture. Bauska county consists of 8 parishes and one city, but in our research, we didn't separate them, but looked at it altogether.

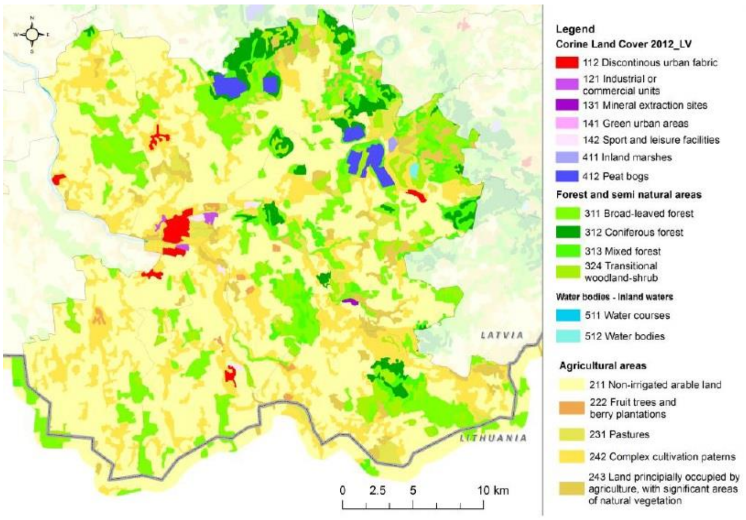


Fig. 16 Land cover in Bauska county (Zvaigzne, 2016)

As can be seen from Fig. 16, More than 80% of the territory is used for the agriculture. The rest is the forest land and an urban land. Most of the territory is used for cereal crops, followed by grassland, rapeseed, corn, legumes, and also fruit (Table 1).

Table 1. Crop categories and their share

	Cereals	Grass	Rapeseed	Permanent grassland	Corn	Fallow	Fruits	Legumes
Share	72%	10%	8%	3%	2%	2%	2%	1%

There is no detailed and accurate information about share of different type of cereals and fruits in Bauska county, therefore an average distribution from annual report of Latvia was taken.

For this research, initial data of the current situation in Bauska county was taken, but to study the effect of bioeconomy development on agriculture, model was supplemented with potential high added value product chains for four different agricultural types – cereal crops, vegetables, fruits and animal farming. There was one example from each of the types selected: wheat from cereal crops, potatoes from vegetables, apples from fruits and pigs from animal farming. For each of them there were different kind of product chains selected, trying to cover all of the resource, so that there would be no waste from the raw resource and it would be used almost completely. Products used in this research are used only as an example, to demonstrate how the bioeconomy can develop the agriculture sector.

3.2. Wheat added value chain

Wheat is the most widely cultivated crop in the Latvia and it occupies highest percentage of the agricultural land. More than 90% of the wheat is exported, and only small amount of the wheat grown in Latvia is used for internal consumption. Even more – 70% of the wheat used for internal consumption is imported (CSP, 2015). It creates an absurd situation when it is more profitable for local farmers to export the wheat, but for local manufacturers of food products to import wheat. Currently the only products with added value manufactured in Latvia is flour, bread and pastry. However, less than 50% of the wheat from internal consumption is used to manufacture the products with added value – the rest is used as a seed or an animal feed [CSP, 2015]. It reveals that there is still a lot of resource wasted or used inefficiently, and from the bio-economy perspective, there is still huge potential for a wheat based product development.

In this research, we present one example of how the added value chain for wheat can be developed, but it only serves as an example, and there are many more products and possibilities of how to add higher value for a wheat and develop wheat based bio-economy.

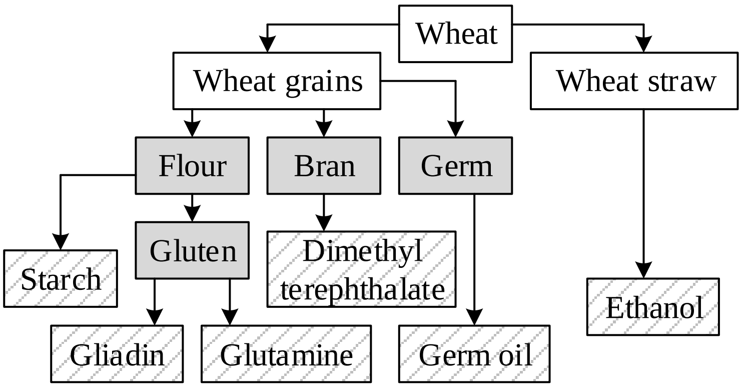


Fig. 17 Added value chain for wheat

There are a lot of valuable products obtainable from the wheat. A lot of the technologies and processes are already very well known, while others are novel and still developing. By supplementing and optimizing wheat milling process, which is very well known, it is possible to separate the endosperm, i.e. the white flour from the grain, as well as the bran and the germ. Currently in Latvia only products manufactured from the grain is white flour, while the bran and the germ is not used separately – only as much as the supplement for whole-grain flour production. Value to the wheat cultivation can be added by manufacturing starch and gluten from the flour, while the value to the gluten can be added even more by extracting and manufacturing the main components of the gluten – gliadin and glutamine (Fig. 17).

The most chemical diversity and highest percentage of the vitamins is concentrated in the wheat bran, which makes it a good source for high added value products. Bran can be used as a supplement to the flour, therefore making whole-grain flour, however there is low added value for such a product, which makes the alternatives more appealing. One of the elements with highest percentage in the bran is the dimethyl terephthalate which can be extracted from the bran and have very high added value. It can later be used as a food supplement, in the medicine or even in the cosmetics.

Wheat germ value can also be increased, and one of the products with high market value is wheat germ oil.

It should be taken into account that not only grains, but also straw is obtained from the cultivation of the wheat, and although most of the straw is used as an animal feed or a litter, which is not very profitable, there is a part of the straw that can be used for adding value. One of the possibilities of how to add value for a straw is ethanol production.

An important aspect for manufacturing the products with high added value is rentability, or in other words, ability to function in efficient manner and to gain profit. High added value products for this research were selected based on these criteria.

3.3. Potato added value chain

Potatoes are widely cultivated vegetables not only in the Latvia, but also in the world, and the area occupied by potatoes are many times higher than area for other vegetables counted together. Unlike wheat, which are mostly exported, potatoes are mainly used for internal consumption, and only 5% of the total amount is exported. Export rate is practically the same as the import rate. Half of the potato stock is used as a seed material and for an animal feed, while the other half for the human consumption. At the current moment value to the potatoes is added only by the food industry, mainly by manufacturing chips and potato starch. Value to the potatoes can be added by not only using potatoes themselves, but also by using potato stems and leaves.

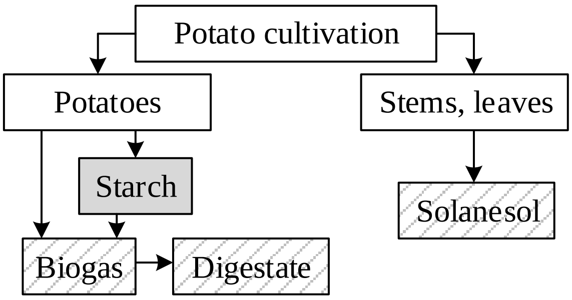


Fig. 18 Added value chain for potatoes

There already is starch manufacturing in Aloja, Latvia, where starch from potato tubers are produced. "Aloja Starkelsen" is the biggest potato starch producer in Baltic states, and one of the biggest biologic starch producers in the world. After starch manufacturing process, there is a waste in a form of potato juice and potato pulp, which is currently embedded back into the soil, but value for this waste can be added even more, by using it for biogas production. In this case, there is biogas produced, which can later be used in energy sector, however there is also a byproduct, called digestate, which can be later embedded into the soil. Unprocessed potatoes also can be used for a biogas production, but there is a question whether it is economically justified.

As a result of potato cultivation, there is also a surface part with stems and leaves, which is often forgotten and undervalued, but it also can be used to manufacture the products with high added value. Stems and leaves contain high level of solanesol, which can be extracted (Fig. 18). Although this substance is highly toxic to human health, it is used for medicine purposes and have high added value.

3.4. Swine added value chain

Animal farming can also be allocated under the agriculture sector, because there is a huge area necessary for growing the feed for the animals. Pig farming is the second biggest animal farming practice in Latvia, only behind cattle farming. Pigs are mainly bred for the pork, and half of the annual internal pork consumption is provided by the local farmers, but another half is imported. The small export rate indicates that pigs are bred mainly for local consumption. Based on the import rate, there is still development potential for pig farming, but the main obstacle is the land availability for the cultivation of an animal feed. Most of the pig farmers are growing the feed (mostly wheat and potatoes) themselves, and to increase intensity of the pig farming, also cultivation of the feed needs to increase.

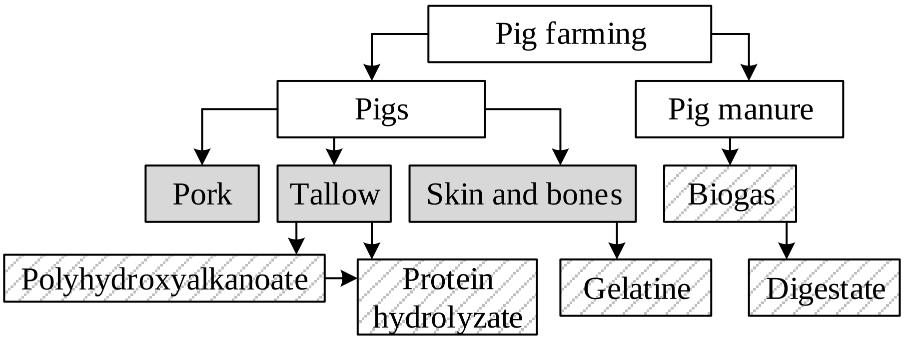


Fig. 19 Added value chain for swine

Slaughter weight of the pig is only 60% from the total weight, but the rest is considered waste. In Latvia, the use of livestock waste products for manufacturing of high added value products is not well developed. They are mostly incinerated, therefore adding insignificant value to the total value of pig farming, however there are different alternatives for livestock waste.

Main product from pig slaughter is the pork, but in the slaughterhouse tallow, bones, skin, blood and internal organs are separated from the pork, and they can also be used as a raw material for further manufacturing of the products with high added value. In this research, polyhydroxyalkanoate and protein hydrolysate from tallow as well as gelatin from the skin and bones are considered (see Fig. 19). Polyhydroxyalkanoate can later be used in manufacturing process of bioplastic. It is important to mention that polyhydroxyalkanoate and protein hydrolysate can both be produced from the tallow, and manufacturing of one doesn't exclude the manufacturing of the other. Protein hydrolysate can later be used in sport medicine and as a dietary supplement.

One of the possibilities from skin and bones is the gelatin manufacturing. It is already very well-known process.

Pig farming have another waste product, which is generated throughout entire life of the pigs: it is the manure slurry. It can be used as a raw material for biogas production. This option is already being adapted in Latvia.

Similar to previous raw materials, these are only few of the possible products which can be manufactured from pigs.

3.5. Apple added value chain

As there is already one example from cereal crops, one example from vegetables and one example from animal farming, it is necessary to also include one example from fruits and berries for all the large agricultural groups to be represented. Apples are selected based on a fact that they are occupying the vast majority of the land used for fruits and berries, compared to other sorts.

Latvian market is dominated by imported apples. That is due to the lower price, because in Poland and in other countries, from where the apples are imported, yield from one hectare is up to 10 times higher than in Latvia. Nonetheless, despite the yield and the price, local apples can also be used for added value products.

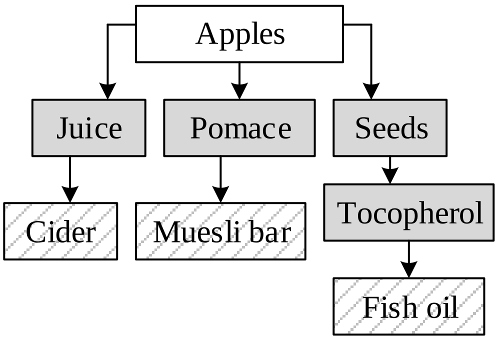


Fig. 20 Added value chain for apples

At the moment, there is no high added value products being manufactured in Latvia, however harvest yield is sufficient to do so. Apple can be divided in three parts. First of all, there can be juice extracted, which is 2nd most popular use of apples in Latvia. Juice can later be used to manufacture the cider, which have higher added value.

After juice is extracted, there is still pomace left with low moisture content, but high dietary fiber content, which can be combined with pomaces from other fruit or berries and used to produce the muesli bars.

There is still another part of apple which can be separated – apple seeds. They can be used together with pomace to produce the muesli bars, but they can also be separated before juice extraction, and used for manufacturing of higher added value products. Apple seeds have high tocopherol content in them, which makes it feasible to extract it. It can be used as a vitamin in the diet, but value can be added even more by using it in the fish oil production process.

4. Input data

To successfully use model for system analysis, it is necessary to acquire the credible input data. Data is acquired for every single crop and for every manufacturing process.

Table 2. Input data

Potato		**Wheat**	
Data	**Reference**	**Data**	**Reference**
Potato yield	(CSB, 2015)	Wheat yield	(CSB, 2015)
Potato stem and leave yield	(Wang, 2014)	Grain/straw ratio	(VSIA, 2009)
Potato price	(CSB, 2015)	Industrially available straw amount	(VSIA, 2009)
Potato production costs	(LLKC, 2012)	Wheat price	(CSB, 2015)
Raw material for potato starch production	(B category permit, 2013)	Wheat production costs	(USDA, 2013)
Obtainable potato starch amount	(Potato starch, 2016)	Necessary water for starch and gluten production	(GEA, 2013)
Potato starch price	(Potato starch price, 2016)	Obtainable gluten and starch amount	(GEA, 2013)
Electricity consumption for potato starch production	(B category permit, 2013)	Gluten price	(Gluten price, 2016)
Necessary labor for potato starch production	(B category permit, 2013)	Starch price	(Starch price, 2016)
Biogas amount obtainable from potato waste	(Kalniņš, 2009)	Raw materials for glutamine and gliadine production	(US 5610277 A, 1997)
Biogas price	(Gebrezgabher, 2010)	Obtainable glutamine and gliadin amount	(Žilić, 2013)
Digestate price	(Pelše, 2012)	Gliadin price	(Gliadin price, 2016)
Biogas plant capital costs	(Kalniņš, 2009)	Glutamine price	(Glutamine price, 2016)
Raw material for solanesol production	(US 7649120 B2, 2010)	Raw materials for dimethyl terephthalate production	(Buranov, 2009)
Obtainable solanesol amount	(Chen, 2010)	Obtainable dimethyl terephthalate amount	(Buranov, 2009)
Solanesol price	(Solanesol price, 2016)	Dimethyl terephthalate price	(Dimethyl terephthalate, 2016)
Pig farming		Supercritical CO_2 amount for wheat germ oil production	(Shao, 2008)
Data	**Reference**	Obtainable wheat germ oil amount	(Shao, 2008)
Average weight of fattened pig	(Pig weight, 2016)	Wheat germ oil price	(Germ oil price, 2016)
Pig manure amount	(Pig manure, 2016)	Raw material for bioethanol production	(Leistritz, 2006)
Water necessity for pig breeding	(Pig water, 2016)	Obtainable bioethanol amount	(Leistritz, 2006)
Feed necessity for pig breeding	(Pig feed, 2016)	Bioethanol price	(Leistritz, 2006)
Pig slaughter weight	(Slaughter weight, 2016)	Bioethanol capital costs	(Leistritz, 2006)

Tallow amount in pig live weight	(Tallow, 2016)	**Apples**	
Pork price	(CSB, 2015)	**Data**	**Reference**
Pig breeding and farming costs	(Schaffer, 2008)	Apple yield	(CSB, 2015)
Raw material for polyhydroxyalkanoate production	(Riedel, 2015)	Juice content in apple	(Krasnova, 2013)
Obtainable polyhydroxyalkanoate amount	(Riedel, 2015)	Seed amount in apple	(Gornas, 2014)
Polyhydroxyalkanoate price	(PHA price, 2016)	Apple price	(CSB, 2015)
Raw material for protein hydrolysate production	(Riedel, 2015)	Apple production costs	(LLKC, 2012)
Obtainable protein hydrolysate amount	(Pasupuleti, 2010)	Raw material for cider production	(Krasnova, 2013)
Protein hydrolysate price	(PHL price, 2016)	Cider price	(Cider, 2016)
Raw material gelatine production	(Sebastian, 2014)	Raw material for muesli bar production	(Kaufmane, 2014)
Obtainable gelatine amount	(Sebastian, 2014)	Muesli bar price	(Muesli, 2016)
Gelatine price	(Gelatine, 2016)	Raw material for fish oil production	(OMEGA-3, 2016)
Biogas amount obtainable from pig manure	(Kalniņš, 2009)	Tocopherol amount from seeds	(Gornas, 2014)
Biogas price	(Gebrezgabher, 2010)	Fish oil price	(Fish oil, 2016)
Digestate price	(Pelše, 2012)		
Biogas plant capital costs	(Kalniņš, 2009)		

5. Results

Each of the products from added value chains, adds more value to the total value of crop cultivation. If there is no manufacturing process for the crop, and it is only sold or exported, only added value comes from crop cultivation, but if the crop is used as a raw material for other products, these products and their added value also comes into total added value from crop cultivation.

In Fig. 22 it is shown how much each of the products, chosen in this research, adds value to the raw material. It can be seen that the highest profit comes from the apple products, while the second highest profit is for wheat. It should be noted that the profit values from Fig. 22 are taken at the end of the simulation. Profit is calculated per 1 metric tonne of raw material.

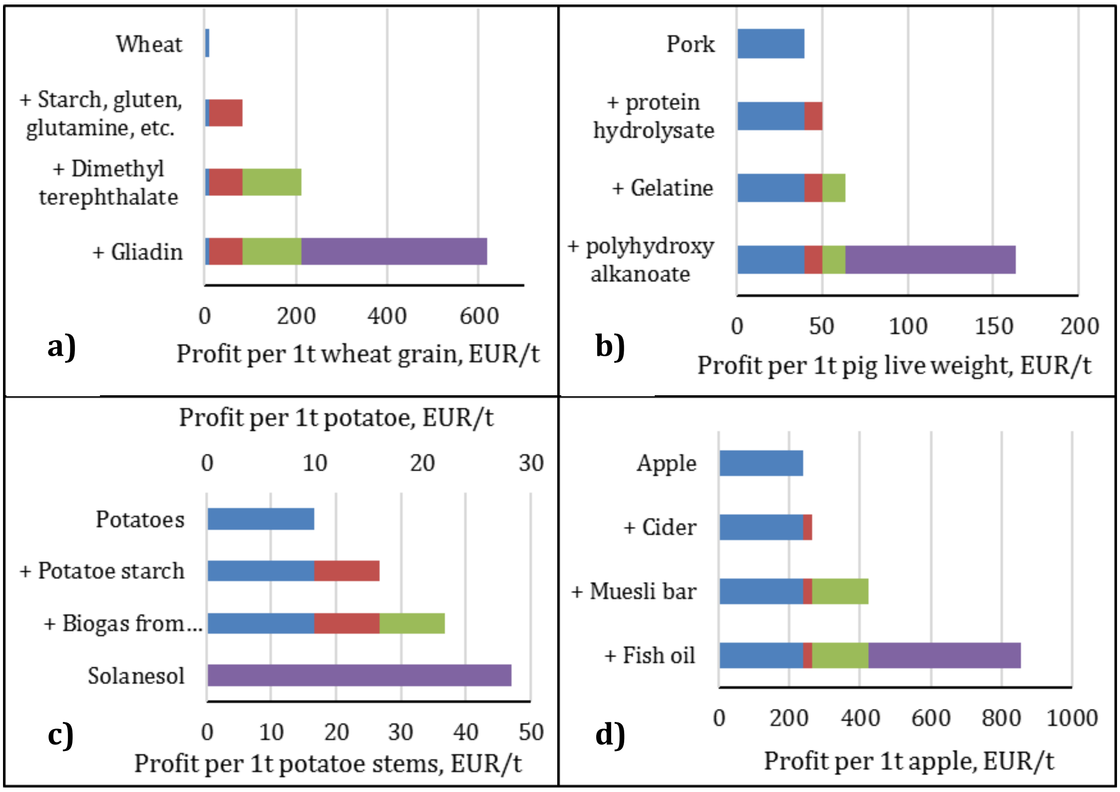


Fig. 21 Added value for agricultural activities: a) Added value for wheat products; b) Added value for pig products; c) Added value for potato products; d) Added value for apple products

At the beginning of the simulation current situation in Bauska county is taken into account, therefore no manufacturing of previously mentioned added value products is happening. Manufacturing starts together with simulation, when production capacities are slowly installed, based on available resource. It can be seen in Figure 23 that almost 80% of initial land is used for growing wheat and only 20% is used for other crops.

As economic consideration is taken into account when allocating land for certain crops. As showed in causal loop diagram (Fig. 16), relative amount of profit gained per land area determines which crop will get more land. As we are looking at the certain region, it means that land area for growing crops are limited, which works as the balancing loop of the model. At the beginning of the simulation profit for the different crops per land area have small difference between them (Fig. 24), therefore the land that gets allocated for each crop is also more similar. It can be argued that allocation coefficient in formula [1] can be higher or lower, therefore making allocation of land more or less flexible to the profit, generated by land, but this example shouldn't be taken as precise prediction, but rather to observe the behavior of the system.

As there is time necessary for farmers to observe and respond to changes in profit, and to make decision about switching to different crops, there is delay between observed profit and land allocation, which is described by 2nd reinforcing loop (Fig. 16). This delay is the main reason why the land area after first few years isn't equal for all the crops, although the profit per land area are quite similar (Fig. 24).

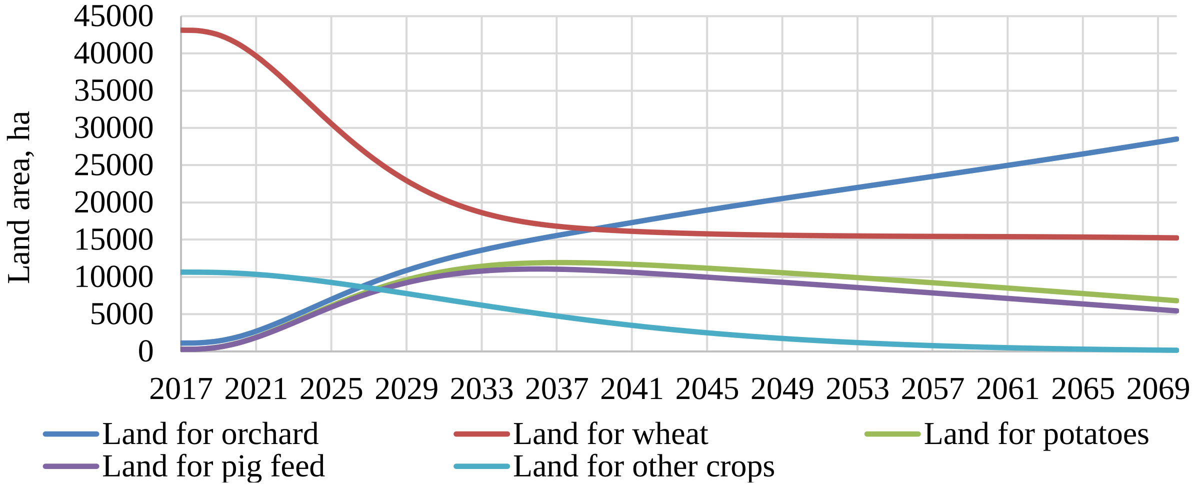


Fig. 22 Distribution of the land for different crops

As raw material stock for all the crops, excluding wheat, are increasing due to increased land area, also manufacturing capacities are expanding, therefore increasing the total value of the crops, which in turn increases the capacities of technologies even more (reinforcing loop 3 in Fig. 16). In case of wheat, although land area is decreasing, manufacturing capacities of high added value products initially are increasing due to the fact that there still is available raw material.

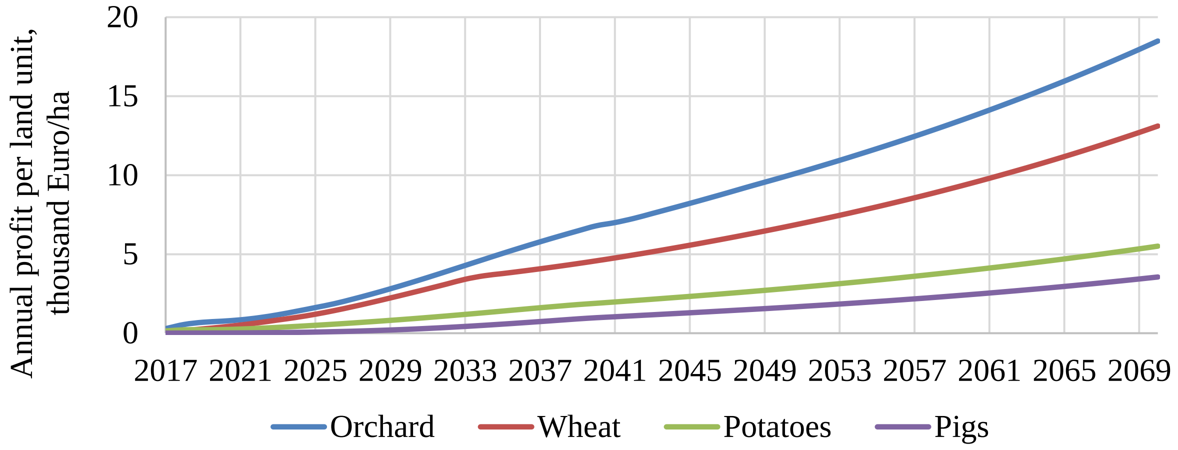


Fig. 23 Profit per hectare from agricultural products

Increase in manufacturing capacities generates more money, therefore there is also more money to invest in technology development (Fig. 16b). This means that technologies become more efficient and profit per production unit also increases, therefore increasing also profit generated per land unit. Also, not only manufacturing technology efficiency gets increased, but also cultivation efficiency, which means that in time also harvesting amount of crops per land area increases. It can very well be seen in Figure 24 that at the beginning of simulation profit value increases due to changes in land area and launching of manufacturing processes, but later when changes in land area are slower than at the beginning and manufacturing capacities have reached their limit, increase in profit value still continues. It is due to increase in efficiency and for every manufacturing process this technology development potential is different, therefore also increase in efficiency level and profit value differs.

Figures 23 and 24 shows that if looking at profit values per land area for selected crops and selected production processes, apples are the most profitable, therefore in time they would gain more land area, followed by wheat. It can be seen that area for apple orchards would be still increasing even after end of the simulation, while are for other crops are slowly decreasing. It can be argued that it is very unlikely that in real system the orchards would expand over so large area, but it should be noted that the current model is based mainly on economic considerations, which is the main driving force for industrial development. In case of different products, also land distribution will change. For example, if we would exclude fish oil production from apple seeds, profit from apple orchard and following products would be lower, therefore making the wheat and wheat products the dominant type.

What makes apples so profitable in Latvia in future is the current apple yield rate per land area, which is up to 10 times lower than in other European countries, therefore holding high development potential, which is considered in the model.

It should be noted that situation described in Fig. 22 and Fig. 23 refers to situation when all of the added value products are implemented and manufacturing technologies are operated in efficient manner. If product chains would be supplemented with additional high added value products, distribution of land for resources and profit values can change siginificantly.

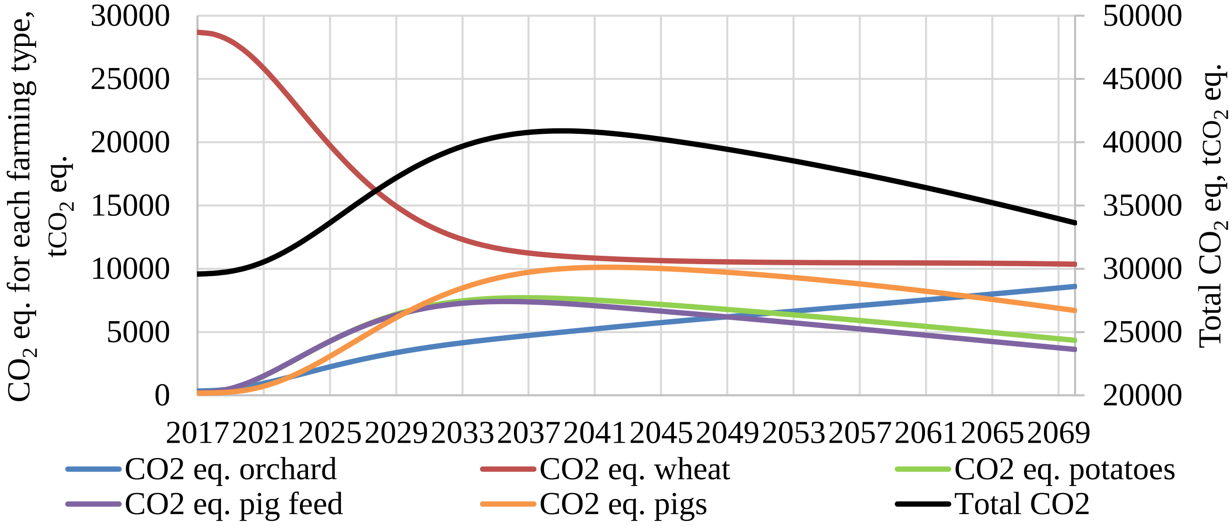


Fig. 24 CO$_2$ emmission equivalent for agricultural activities

Agricultural sector is not only responsible for a land use, but also for emissions from cultivation process. In the model, also CO$_2$ equivalent from agriculture is calculated. Only emissions from cultivation is calculated, while the emissions from manufacturing processes are left out. Agricultural sector is non-ETS sector. Depending on the crop and fertilizers used, also emission level differs. It can be seen in Fig. 25 that as predicted, at the beginning, highest emission levels are from wheat cultivation, because wheat cultivation occupies almost 80% from the total area.

It can be seen that, although the total area for the crops stays constant, emissions in the middle of the simulation are higher than at the beginning and in the end. It means that there is shift happening towards less sustainable crops. It should be noted that there is two kind of emissions for pig farming, because pig farming includes not only cultivation of crops for pig feed, but also emissions from pigs themselves. It probably is the main reason for increase in total emissions, because, it can be seen from Fig. 25 that at the beginning of simulation, due to small area occupied by crops for pig feed, there is also almost no emissions from pig farming, but by increasing the amount of pigs, the area for pig feed also increases, thereby significantly increasing the emissions from pig farming and total emissions. When the land area for pig feed are decreasing, also emission level decreases.

6. Conclusions and discussions

The model for biotechonomy development analysis has been built and applied to agriculture sector in one county in Latvia. The simulation shows how the land use is changing over time because of changes in added value of different raw materials. Simulation is purely based on market driven forces, i.e. without any policy interventions. It also shows how CO_2 emmissions are changing over time and increases due to more emitting products and activities. The behaviour of the system can be changed by means of policy tools. They have to address the main question: how to add the highest value to the bioresources in a sustainable way. There are three factors that play the main role in the development process of the biotechnomy: (1) available bioresources (based on available land area); (2) production capacity, and (3) increase of specific added value of product.

If the policy makers are interested in increasing the value of available bioresources, the following measures can be taken: (1) supporting certain types of bioresources; (2) redirecting bioresources from export to local production with higher added value; (3) increasing yield and production efficiency by means of R&D and education.

If the production capacity is addressed by the policy makers, both the investment rate in production capacity and development level of technologies have to be taken into account. The following policy tools can be applied: (1) support to R&D and education for development of biotechnologies, and competencies to adapt new technologies developed outside the count ry; (2) support to investments, e.g. subsidies.

If policy makers are aiming at increasing yield and production efficiency, support to R&D and education has to be evaluated. Innovative ideas and knowledge provide production of products that have limited supply thus increasing the price; products with high added knowledge value and low raw material consumption.

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Appendix 1.

Total land is divided among production of different raw materials based on the profit generated by one unit of the land of products produced from each of raw materials. It is calculated by means of logit function, e.g. fraction allocated for the raw material 1 is calculated based on annual total profit per 1 ha of land for competing raw materials 1,2...n:

$$LF_1 = \frac{e^{\propto P_1}}{e^{\propto P_1} + e^{\propto P_2} + \cdots + e^{\propto P_n}}, \qquad [1]$$

where *LF₁* – land fraction allocated for raw material 1;

$P_{1\ldots n}$ – perceived annual total profit per 1 ha of land for raw material, (kEUR/ha)/year;

α – coefficient which determines the rate of allocation of land from one raw material to another raw material.

The same formula is used for the calculation of fraction of allocated land for other raw materials. To change the land use requires time and the delay is calculated as the 3-rd order delay:

$$LR_1 = DELAYMTR(LF_1 \cdot TL, t, 3), \qquad [2]$$

where LR_1 – land for resource 1, ha;

TL – total land area, ha;

t – time delay, years.

Annual raw material production rate is:

$$AY = LP \cdot LR_1, \quad [3]$$

where AY – annual yield, t/year;
LP – current yield, (t/ha)/year.

Product's production rate depends on the stock of product in production process, production capacity in operation and potential production rate and is calculated as:

$$PR = MIN(PPP/dt, IF(CO < PSR, CO, PPR)), \quad [4]$$

where PR – product's production rate, t/year;
PPP – product in production process, t;
CO – capacity in operation, t/year;
PPR – potential production rate, t/year.

Product's production rate is calculated taking into account that the potential product production rate during some periods of time might be higher than the capacity in operation. To avoid overinvesting in production assets, capacity in operation is selected to be at the maximum use. MIN function ensures that the product in production stock does not become negative, i.e. it cannot be taken out of the stock more than it has accumulated, given that the stock value changes more slowly than the value of potential production rate which is numerically equal to the inflow values. Capacity in operation stock value is determined on the sub-model of infrastructure and technology. Product stored stock and product sales rate represent product sales process:

$$PSR = MIN(PS/dt, PS/TTP, \quad [5]$$

where PSR – product sales rate, t/year;
PS – product stored, t;
TTP – time to sell product, year.

Capacity order rate cannot have negative value hence it is calculated as:

$$COR = MAX(0, IOR), \quad [6]$$

where IOR – indicated order rate, (t/year)/year.

Indicated order rate depends on additional production capacity if it is demanded by potential product production rate, decommissioning rate and desired adjustment of capacity under construction:

$$IOR = ACUC + DOR, \quad [7]$$

kur $ACUC$ – desired adjustment of capacity under construction, (t/year)/year;
DOR – desired order rate, (t/year)/year.

Desired adjustment of capacity under construction is calculated as:

$$ACUC = \frac{DCUC - CUC}{ATCUC}, \qquad [8]$$

where *DCUC* – desired capacity under construction, t/year;
CUC – capacity under construction, t/year;
ATCUC – adjustment time for capacity under construction, year.

Desired capacity under construction is calculated by multiplying adjustment time for capacity under construction and desired order rate. Desired order rate (cannot have negative value) is:

$$DOR = MAX(0, DR + \frac{DCO - CO}{ATCUC}), \qquad [9]$$

where DR – decommissioning rate, t/year;
DCO - desired capacity in operation, t/year.

Desired capacity in operation is equal to potential production capacity.

Rate of increase in electricity requirement depends on electricity requirements for new technologies and commissioning rate. Rate of decrease in electricity requirements is calculated as multiplication of average electricity consumption and decommissioning rate. Average electricity consumption is:

$$AEC = \frac{EP}{DR} \qquad [10]$$

where $\bar{I}EI$ – electricity requirement, kWh/year.

Average electricity consumption is used to calculate specific electricity costs per 1 unit of production:

$$SEC = AEC \cdot EP, \qquad [11]$$

where *EP* – electricity price, EUR/kWh.

Investment rate in technologies is calculated based on capacity order rate, specific investment in technology and commissioning rate. The stock of capital costs depends on two rates – capital costs discard rate and capital costs increment rate. The capital costs increment rate is calculated as:

$$CCIR = IRT \cdot \frac{DR}{1 - \frac{1}{(1+DR)^n}}, \qquad [12]$$

where *CCIR* – capital costs increment rate, (EUR/year)/year;
IRT – investment rate in technology, EUR/year;
DR – discount rate;
n – economic life time, year.

The capital costs discard rate depends on economic lifetime of technology and pipeline delay and is calculated as:

$$CCDR = DELAYPPL(CCIR, n), \qquad [13]$$

Stock of capital costs is further used in sub-model of income, costs and profit.

in labour requirements depends on increased production capacity:

$$ILR = IF(NLR > LFP, NLR - LFP, 0), \qquad [14]$$

where *NLR* – necessary labour requirement, persons;
LFP – labour for production, persons.

Decrease in labour requirement is calculated as:

$$DLR = IF(NLR > LFP, 0, LFP - NLR)$$

Necessary labour requirement is:

$$NLR = NLRC \cdot NC, \qquad [15]$$

where *NLRC* – new labour requirement capacity, persons/(t/year);
NC – new capacity for production, t/year.

New capacity is calculated from the production capacity, capacity commissioning rate and capacity decommissioning rate. For the new labour requirement capacity, the scaling effect has to be taken into account, i.e. the higher the production capacity, the less labour is required for production of one unit:

$$NLRC = NLRC(t_0) \cdot EPLR, \qquad [16]$$

where $NLRC(t_0)$ – initial labour requirement, persons/(t/year);
EPLR – effect of production on labour requirement (see Fig. 25).

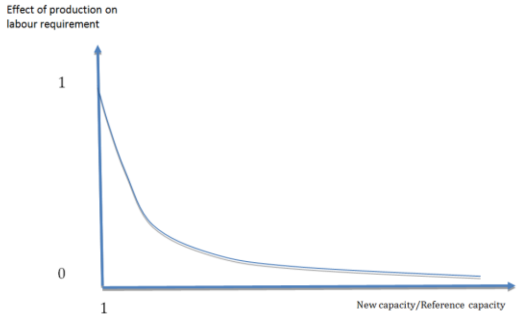

Fig. 25 Capacity effect on labour requirement

Annual labour costs are calculated as multiplication of annual average salary per person and annual labour requirement and production capacity. In the sub-model of revenues, costs and profit the specific labour costs are used (EUR/t).

Revenues from the sales of the product is multiplication of sales rate and procuct price. Unit production costs depends on both variable costs and capital costs. Emergy tax is added to the costs of production unit to show the sustainability of the product. Variable costs include specific annual labour costs, energy costs, other production costs. Unit capital costs are calculated as division of total capital costs and production rate. Total economic annual profit per land unit is calculated as (Fig. 14):

$$TEAP = \frac{TAP}{1000 \cdot LA}, \quad [17]$$

where *TEAP* – total economic annual profit per land unit, (kEUR/ha)/year;
TAP -total annual profit of land use of raw material, EUR/year;
LA – land area, ha.

Decisions about land use change are based on the profit values for last years and 3rd order information delay for 3 years is used:

$$PTAP = DELAYINF(TEAP, 3{,}3), \quad [18]$$

where *PTAP* – perceived total annual profit per land use, (kEUR/ha)/year.

Perceived total annual profit per land use is used to determine share of land allocated for particular raw material (see formula 1).