USING OF ANYLOGIC AND EXTENDSIM IN MODELLING OF BIOFUEL LOGISTIC SYSTEMS

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Abstract

Rising oil prices, national security concerns, the desire to increase farm incomes, and a host of new and improved technologies are propelling the European Union to set the directive for the year 2010 – each member state should achieve at least 5.75% biofuel usage of all used transport fuel. The report on the progress made in the use of renewable fuels shows that the average Member State of the EU has achieved only 52% of its target, and biofuels' share in 2010 will not raise much above 4%. The prices of different biofuels are still not able to compete with oil based fuel prices. One of the possible ways how to solve this problem is to optimize biofuel supply chains using different methods of systems engineering. The aims of this investigation were finding out appropriate simulation tools for biofuel supply chain modelling, development of rapeseed oil supply chains for different production types, and modelling the developed supply chains. As the result of software survey, two packages were chosen – *AnyLogic* and *ExtendSim Suite*. Modelling studies showed that rapeseed oil supply chain is very sensitive, because changing just single parameters in a short scale, the actual cost price of 1 litre of oil changes considerably. Comparing the fossil diesel fuel prices with rape oil actual cost from modelling studies, the use of oil as a fuel for farm machinery seems to be profitable. Analysis of costs distribution shows that the greatest part is composed by rapeseed growing expenses.

Key words: biofuel, rapeseed oil, logistic, supply chain, systems engineering, modelling.

Introduction

The term 'biofuel' applies to any solid, liquid, or gaseous fuel produced from organic matter. The various biomass feedstock used for producing biofuels can be grouped into two basic categories: the currently available 'first-generation' feedstock, which is harvested for its sugar, starch and oil content that can be converted into liquid fuels using conventional technology; and the 'next-generation' cellulosic biomass feedstock, which is harvested for its total biomass and whose fibres can be converted into liquid biofuels only by advanced technical processes. The two primary biofuels in use today are ethanol and biodiesel, which can both be used in existing vehicles. Ethanol is readily blended with gasoline, and biodiesel is blended with petroleum-based diesel for use in conventional diesel-fuelled vehicles. The use of pure vegetable oil and pure biodiesel in diesel engines as well as neat bioethanol in spark-ignition engines are other available alternatives nowadays, but they may require modification of engine or fuel system components.

The European Union in its biofuels directive has set the goal for the year 2010 – each member state should achieve at least 5.75% biofuel usage of all used transport fuel. Unfortunately, the report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union shows that the average Member State achieved only 52% of its target (Biofuels Progress Report, 2007), and biofuel share in 2010 will not raise much above 4%.

Concerning Latvia, the great number of different regulations has been developed since 2003, for example, the programme 'Production and use of biofuels in Latvia (2003-2010)', the decree of the Cabinet of Ministers No. 511 on the implementation strategy of the mentioned programme, and the law on biofuels accepted by the Saeima on April 2005. Regardless of that, the real situation in this country is unsatisfactory – Latvian biofuel share changed from 0.07% in 2004 to 0.33% in 2005, but in the last two years it has stayed almost the same.

The main reason of this seems to be economical by nature – the prices of biofuels are not able to be in competition with gasoline and diesel prices. If governments and others wish to expand production and use of biofuels significantly at the domestic and global levels, they will need to have an effective wide-ranging policy strategy. The most common policies supporting biofuels today are blending mandates and exemptions from fuel taxes. Other policy instruments are loan guarantees; tax incentives for agriculture and forestry, consumers and manufactures; preferential government purchasing policies; and research, development, and demonstration funding for current and next-generation biofuels and technologies (Biofuels for Transport …, 2007).

Another possible way to enlarge the production and use of biofuels is to optimize biofuel supply chains using different methods of systems engineering. Systems engineering can be defined as a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives. The most common structure of the systems engineering process is shown in Figure 1 (Bahill and Gissing, 1998).

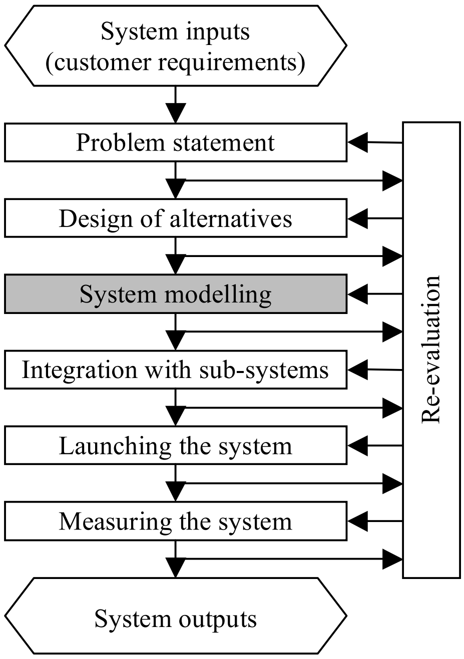

Figure 1. The systems engineering process structure.

Considering that system modelling plays a very important role in engineering process structure, it is chosen for this investigation. Before starting the modelling process, identification of the system is very important.

In this investigation the system is a biofuel logistic or supply chain. The different possible conversion routes for the production of different biofuel types play a central role in the model. These conversion routes are defined by interlinked subprocesses, which are defined by input and output. The simplified general outline of conversion route definition is shown in Figure 2 (Van Thuijl et al., 2003).

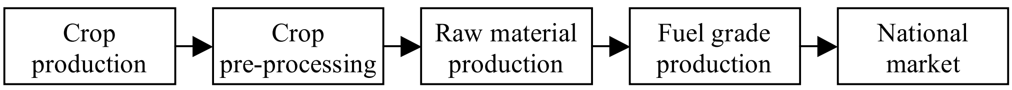

Figure 2. General outline of conversion route definition for the model.

Crop production denotes the production of biomass and biomass residues from agriculture, forestry, and industry. The pre-processing of the crop may consist of several pre-treatment steps. After pre-processing of the biomass it is converted into a raw material (for example, bio-crude or raw ethanol), which serves as an input for the production of fuel grade biofuels. Both raw material production and fuel grade production may consist of several conversion processes. Finally, the produced biofuels are transported to the national market, where distribution to end-consumers takes place (in either pure form or blends with conventional automotive fuels).

Analysing the existing solutions in modelling of biofuel supply chains, the first ones were found relating biomass fuel supply and collection correspondingly in the Netherlands and the United Kingdom (Allen et al., 1998; De Mol et al., 1997). The most valuable information from these investigations was used input and output data for modelling, but researchers didn't specify the used modelling tools. Another problem to use these models as analogues for biofuel logistic chain modelling in Latvia is different modelling input parameters, for example, raw materials, distances between objects, network of roads, etc.

The most fundamental and recent investigations in the modelling of biofuel supply chains were carried out within the European Commission-supported project 'Clear Views on Clean Fuels' (Wakker et al., 2005). The objective of this research was to develop a cost efficient biofuel strategy for Europe in terms of biofuel production, cost and trade, and to assess its larger impact on bioenergy markets and trade up to 2030. Based on the biomass availability and associated costs within EU countries, scenarios for biofuels production and cost was constructed using quantitative modelling tools. Combining this with data on biofuel conversion technologies and transport of biomass and biofuels, the lowest cost biofuel supply chain given a certain demand predetermined by the biofuels directive was designed. Two complementary models were developed in this research, the BIOTRANS model and the ChalmersVIEWLS model.

The BIOTRANS model needs the following inputs: costs and potentials of biomass resources (including organic waste fractions and residues) in individual countries, data on the possible conversion routes containing different process steps, data on the national and international transportation and handling of the different products involved and data on policy incentives. The model has been formulated as a multi commodity network flow model connected by country nodes. The ChalmersVIEWLS is a regionalised energy system model. It has three end-use sectors: electricity, transportation fuels, and heat. Specific energy demand scenarios are developed for each of the three sectors. In addition to energy demand and costs, the supply potentials, energy conversion characteristics and expansion limitations, the initial capital stock and trade parameters are exogenously defined.

Unfortunately, reports on these modelling studies don't share with used modelling equations and used computer software also. Only results in graphical and numerical form are available. Another problem is that these models are too global. For example, if the distance from Gulbene to Ventspils in European model is inconsiderable, than in modelling of biofuel supply chain in Latvia scale it is very significant.

Regardless of this, analysis of these investigations were very useful, especially studies of background document for modelling using the BIOTRANS model (Van Thuijl et al., 2003). As an example conversion route for pure vegetable oil from this document is shown in Figure 3.

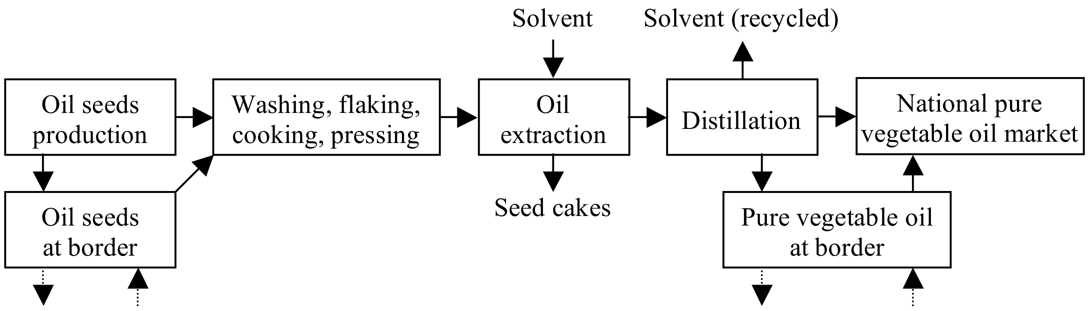

Figure 3. Conversion route for pure vegetable oil.

Since the pure vegetable oil chain is the simplest from all others and it is also the part of the biodiesel production, rapeseed oil supply chain was chosen for the modelling studies.

The choice of the most suitable modelling and simulation software is very important. Of course, for the simpliest modelling studies it's possible to use some of tools (for example, *Solver*) integrated in spreadsheet programs. The use of powerful common use modelling software, for example, *Powersim* or *Simulink* is also available, but probably other software which is specially designed for modelling of logistics would be more suitable.

Analysing existing surveys of simulation software tools as the most fundamental investigations made by Lionheart Publishing Company were found out. More than sixty different packages were compared (Simulation Software Survey, 2007; Swain, 2005; Samuelson and Macal, 2006). A lot of criteria were used, for example, typical applications of the software, primary markets for which the software is applied, system requirements, supported operating systems, model building characteristics, etc. Most of these packages can be used also for supply chain and logistic modelling, but which of them could be the most suitable for the modelling of biofuel logistic systems is not specified in these surveys.

Summarizing literature studies, the following tasks were set for this investigation:

- selection of criteria for simulation software comparison to find out the appropriate ones for biofuel supply chain modelling;
- adaptation of previously shown conversion route (Figure 3) to specific peculiarities of Latvia and development of rapeseed oil supply chains for decentralized and unitary production;
- modelling the developed rapeseed oil supply chains using selected simulation tools.

Materials and Methods

Basing on the typical applications of the software as well as on computer and operating systems requirements, eight different simulation packages were chosen for the final evaluation – *AnyLogic*, *Arena*, *ExtendSim Suite*, *Flexsim Simulation Software*, *ProModel Optimization Suite*, *ServiceModel Optimization Suite*, *ShowFlow*, and *Simul8*.

The main model building characteristics were set as the criteria for further comparison. All necessary information was obtained from vendor home pages and demo models. All of these programs include following features: graphical model construction (icon or drag-and-drop), access to programmed modules, run time debug, input distribution fitting, model optimization tools, animation, import CAD drawings, different templates, user support and discussion area, training courses, on-site training, and consulting. As the first discarded package was *ShowFlow*, because it doesn't support both modelling types (discrete event and continuous event) and real time viewing of model animation.

Seven programs satisfy other main criteria – output analysis support, presence of tools to run experimental design and to support model packaging (e.g., can completed model be shared with others who might lack the software to develop their own model?). Despite these features are included, they are different in particular programs. Not all programs are able to export animations (e.g., MPEG version that can run independent of simulation for presentation). Description of differing tools is summarized in Table 1.

Table 1

Simulation software survey

Software	Output Analysis	Batch run or experimental design	Tools to support packaging	Export animation
AnyLogic	Statistics tools, various charts, histograms, etc.	Simulation, optimization (including Monte Carlo and Sensitivity Analysis), and custom experiments	Generates Java applets and applications with full simulation-optimization functionality	+
Arena	Arena Output Analyzer for statistical analysis	Arena Process Analyzer	Seamless operation, no tools necessary	+
ExtendSim Suite	Confidence intervals are calculated at the click of a button	Automated execution of different scenarios	Free downloadable player from the web site runs the models	–

Software	Output Analysis	Batch run or experimental design	Tools to support packaging	Export animation
Flexsim Simulation Software	Flexsim Charts. Outputs to Excel and Access	Flexsim Experimenter	–	+
ProModel Optimization Suite	Output analysis reports and charts. Outputs to Excel and Access	Unlimited scenarios can be predefined to experiment on parameters	Models packaged within software; view using free ProModel Player	–
ServiceModel Optimization Suite	Output analysis reports and charts. Outputs to Excel and Access	Unlimited scenarios can be predefined to experiment on parameters	Models packaged within software; view using free ProModel Player	–
SIMUL8 Professional	Included in main product	Included in main product	Included in main product	+

To make the final decision, the pricing information and presence of academic/research versions were taken into account too because financial resources to purchase software were limited. As the result, two different packages were chosen – *AnyLogic* and *ExtendSim Suite*.

Adapting conversion route for pure vegetable oil (Figure 3) to specific peculiarities of Latvia, rapeseed oil supply chain was developed including decentralized and unitary production (Figure 4).

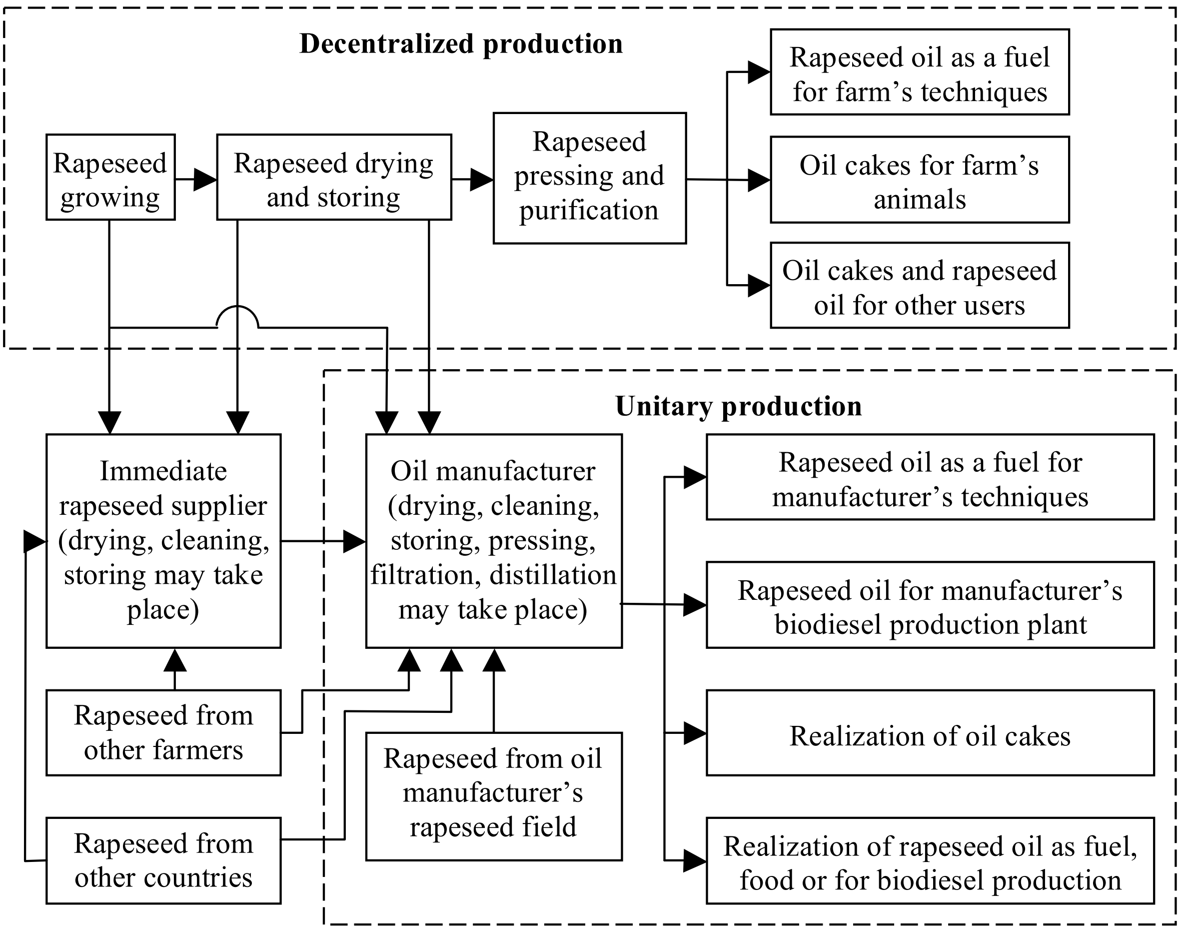

Figure 4. Rapeseed oil supply chain for decentralized and unitary production.

Transportation of intermediate products may take place between the most of two subprocesses. It can be realized by farmer, intermediate supplier or oil manufacturer transport. Biofuel or fossil fuel can be used in transportation and rapeseed growing.

A lot of different input parameters for modelling were used, for example, seed, fertilizer, herbicide and fungicide prices and norms; ploughing, cultivation, sowing, fertilizing, dusting, harvesting, transportation, cleaning and drying expenses; rapeseed yield capacities; state-aided payments; oil extraction expenses; possible oil cake sale price, average rapeseed transportation distances, etc. Besides, some of the parameters that initially seem to be constant, for example, seed price and sowing norm, are changing in practice. Thus, winter rapeseed price is 7.00 LVL kg^{-1} and 3 kg of seed is needed per 1 ha. For summer rape these numbers are correspondingly 5.00 LVL kg^{-1} and 4 kg ha^{-1}, but if only biological technologies are used on the farm ('biological rape'), 8 kg ha^{-1} of specially treated seed is needed.

Models were developed using both of previously chosen packages – *AnyLogic* and *ExtendSim Suite*.

Results and Discussion

The main questions to be answered from these modelling studies were:

- What is the actual cost of rapeseed oil for decentralized and unitary production?
- Is the price of rapeseed oil able to compete with fossil diesel fuel prices?
- What is the distribution of costs in rapeseed oil supply chain using different production technologies grouping expenses by categories – growing, transportation, cleaning/drying, and pressing/purification?

Performing system simulation different scenarios of supply chain were executed. For example, expenses for ploughing, cultivation, sowing, fertilizing, dusting, harvesting and transportation at farm (decentralized production) in the model can be assumed as external services or they can be performed by farmer's machinery. The same situation is with cleaning, drying and pressing. Oil cakes can be fed to farm animals or sold to other farmers. As an example, the results of simulation studies for decentralized production are summarized in Table 2. For technical services, neighbour machinery is used, seed pre-processing and oil extraction are done by the farmer himself, but rape cakes are sold.

Table 2

An example of the simulation results for decentralized production

Expense item	Summer rape	Winter rape	Summer rape ('biological')
Rapeseed growing, LVL ha^{-1}	-447.85	-511.52	-497.74
Transportation, LVL ha^{-1}	-8.80	-8.80	-8.80
Cleaning/drying, LVL ha^{-1}	-14.50	-21.75	-14.50
Total state-aided re-payment, LVL ha^{-1}	86.01	86.01	161.61
Total expenses, LVL ha^{-1}	-385.14	-456.06	-359.43
Average rapeseed yield (8% moisture), t ha^{-1}	2.34	3.27	1.22
Total expenses, LVL t^{-1}	-164.80	-139.39	-295.77
Pressing, LVL ha^{-1}	-101.64	-142.29	-51.11
Rape cake realization, LVL ha^{-1}	334.96	468.95	174.18
Rape oil actual cost, LVL ha^{-1}	-151.82	-129.40	-236.36
Rape oil quantity, l ha^{-1}	851.35	1191.89	442.70
Rape oil actual cost, LVL l^{-1}	-0.18	-0.11	-0.53

If only a half of oil cakes is sold, but other is used for farm's animals, rape oil actual cost for winter rape, summer rape and 'biological' summer rape changes correspondingly to 0.38, 0.30 and 0.73 LVL l^{-1}. But, in this case, economy in forage purchase for animals has to be taken into account. If the farmer uses his own machinery for technical services in this scenario, values mentioned before decrease to 0.30, 0.24, and 0.56, respectively. Rapeseed oil supply chain model is very sensitive, because changing just single parameters (for example, yield capacity, rapeseed transportation distance, or rape cake sale price) in very short scale, the actual cost price of 1 litre of rapeseed oil changes very considerably.

How do these values look in comparison with fossil diesel fuel prices? Let's assume that the diesel fuel price in the fuel tank is 0.87 LVL l^{-1}. The farmer can receive the excise tax compensation (0.19 LVL l^{-1}) and value added tax repayment (18%). In this case, the final diesel fuel price for the farmer is 0.52 LVL l^{-1}. If we compare this value with rape oil actual cost for winter and summer rape, the use of oil as a fuel for farm machinery is profitable. If only biological technologies are used on the farm, economically the use of oil as a fuel seems not so beneficial but, as the quality of final products is very high, they can be used in food (oil) and for animals (cakes), which is also very important for the farmer.

Concerning unitary production, rape oil actual cost was approximately the same when rape was grown on oil manufacturer field. On the one hand, the actual cost of growing, transportation, cleaning, drying and pressing was less than at the farm, but, on the other hand, maintenance expenses of plant infrastructure raise the prime cost. If the rapeseed is bought from the immediate supplier, rape oil actual cost is approximately 20% lower. Unfortunately, if the farmer desires to buy oil for use as a fuel from this manufacturer, purchase costs are much higher (value added tax, profit percentage, etc.).

The distribution of costs in rapeseed oil supply chain grouping expenses by categories – growing, transportation, cleaning/drying, and pressing/ purification – are shown in Figures 5 and 6 (for unitary production infrastructure maintenance and logistics expenses are assumed too).

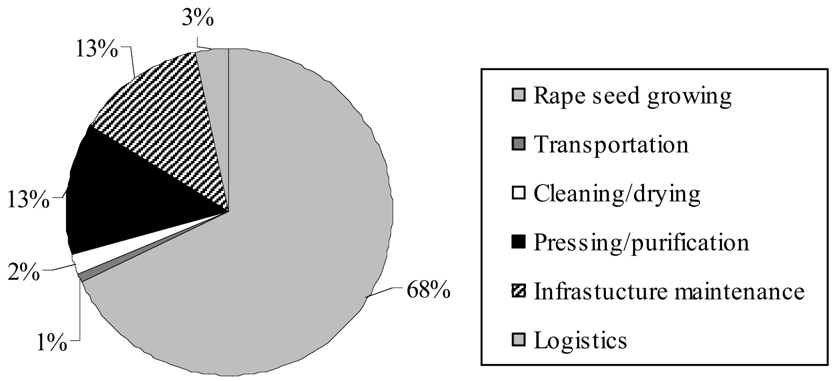

Figure 5. Distribution of costs in rapeseed oil supply chain for unitary production.

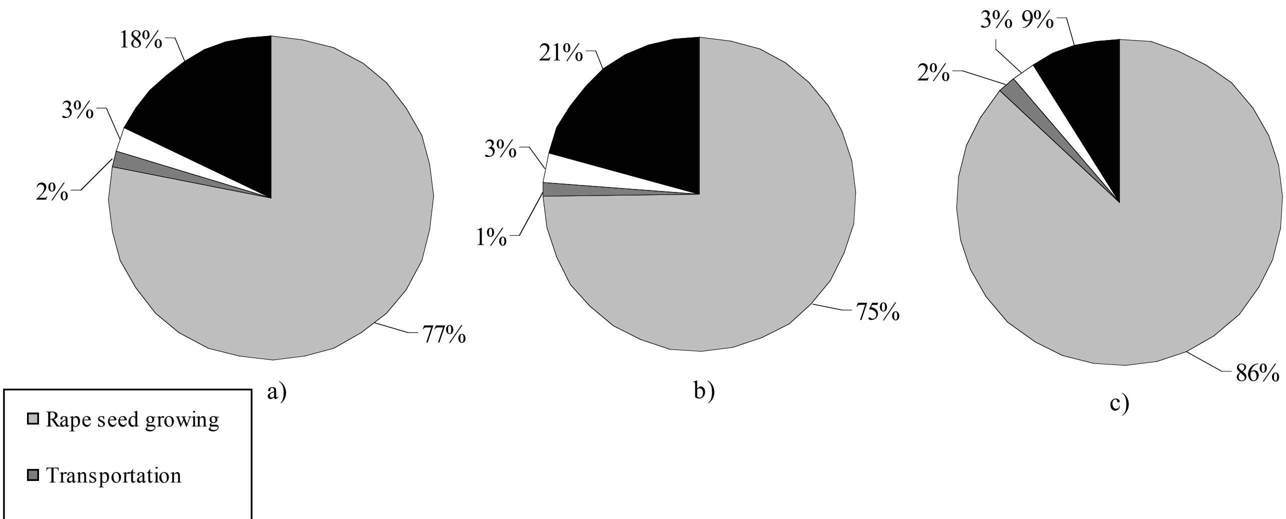

Figure 6. Distribution of costs in rapeseed oil supply chain for decentralized production: a – for summer rape; b – for winter rape; c – for 'biological' summer rape.

Distribution of costs shows that the greatest part is composed of rapeseed growing expenses. As it was mentioned before, for decentralized production this part could be reduced using own machinery with optimal productiveness characteristics as well as using rapeseed oil as a fuel for technical services as much as possible. For unitary production it's possible to buy rapeseed from the immediate suppliers or farmers.

Comparing models using *AnyLogic* and *ExtendSim Suite*, both of them showed similar results, but *AnyLogic* will be more useful from the viewpoint of sharing with others who might lack the software to develop their own model, because this software generates *Java* applets and applications with full simulation and optimization functionality.

Conclusions

1. Besides legislative initiatives, one of the possible ways how to enlarge the production and use of biofuels is to optimize biofuel supply chains using different methods of systems engineering.
2. Analysis of existing solutions in modelling of biofuel supply chains shows that existing solutions in this field are not usable for Latvia directly because this country's area, production capacities and other parameters are very different from other European countries.
3. Analysing available tools for the modelling of biofuel supply chains two different software were chosen – *AnyLogic* and *ExtendSim*. *AnyLogic* will be more useful from the viewpoint of sharing with others who might lack the software to develop their own model, because this software generates *Java* applets and applications with full simulation and optimization functionality.
4. Modelling studies showed that rapeseed oil supply chain model is very sensitive, because changing just single parameters (for example, yield capacity, rapeseed transportation distance, or rape cake sale price) in a short scale, the actual cost price of 1 litre of rapeseed oil changes considerably. That's why the future investigations in modelling of biofuel supply chains in Latvia have to be done very carefully, building models step by step and taking into account all parameters, which are affecting the final biofuel price most.
5. Comparing the fossil diesel fuel price (approximately 0.52 LVL l^{-1} after tax compensation) with rape oil actual cost from modelling studies, the use of oil as a fuel for farm machinery seems to be profitable.
6. Analysis of cost distribution shows that the greatest part (from 68% to 86% depending on production type) is composed of rapeseed growing expenses. This part could be reduced using own machinery with optimal productiveness characteristics as well as using rapeseed oil as a fuel for technical services as much as possible.

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