OPTIMIZATION MODELS FOR BIOFUEL LOGISTIC SYSTEMS

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Abstract. The short overview of the strategies and action plans in production and use of biofuels in Europe and Latvia is given. The characteristic of biofuel supply chain as a system is explained. Existing solutions in improvement of biofuel logistic systems are analysed as well as available tools for the modelling of biofuel supply chains. As the first system for modelling the pure vegetable oil from rapeseed was chosen and first results of modelling are discussed.

Key words: biofuel, supply chain, logistic, system engineering, modelling.

Introduction

Biofuels are transport fuels made from organic material. The most common biofuels today are biodiesel (made from vegetable oils) and bioethanol (made from sugar and starch crops). Research is under way to commercialise "second-generation" production techniques that can make biofuels from woody material, grasses and some additional types of waste. Biofuels have a unique role to play in European energy policy. They are today the only direct substitute for oil in transport that is available on a significant scale. Other technologies, such as hydrogen, have enormous potential. However, they are far away from large-scale viability and will require major changes to the fuel distribution system.

Europe is supporting the production and use of biofuels via several strategies and action plans:

- In 2003, the EU adopted Directive 2003/30/EC on the promotion of the use of biofuels for transport [1]. This directive urged member states to set indicative targets for a minimum proportion of biofuels to be placed on the market (2 % in 2005 and 5.75 % in 2010);
- Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity [2]. As biofuels are currently more expensive than traditional fuels, directive allows Member States to apply a total or partial exemption of taxation for biofuels;
- In view of higher oil prices and the urgency of a new debate on security of energy supply, the Commission presented a Biomass Action Plan in December 2005, setting out measures to increase the development of biomass energy from wood, wastes and agricultural crops [3];
- In February 2006, the Commission published a new Communication entitled "An EU Strategy for Biofuels" preparing the ground for a review of the Biofuels Directive by the end of 2006, which might include mandatory targets instead of the indicative ones set in 2003. The aim of the strategy was to further promote biofuels in the EU, to prepare for the large scale use of biofuels, and to explore opportunities to build plants for biofuel production [4];
- In January 2007, the Commission proposed its strategic Energy Policy for Europe. Central to the proposals is a binding target to slash the EU's greenhouse gas (GHG) emissions by 20 % in 2020 compared with 1999 levels, a binding target for 20 % of the EU's energy mix to come from renewables by 2020, and an obligation for each Member State to have 10 % biofuels in their transport fuel mix by 2020 [5].

Although the biofuels progress report [6] shows that biofuels have doubled their market share in two years, from 0.5 % in 2003 to 1 % in 2005, this growth rate is not fast enough. This situation is expected to change, because most Member States have now introduced tax exemptions for biofuels. Nevertheless, the report estimates that on present policies, biofuels' share in 2010 will not raise much above 4 %, and the biofuels Directive's 5.75 % target for 2010 is not likely to be achieved.

In order to promote the use of biofuels in Latvia, the Cabinet of Ministers has developed the programme "Production and use of biofuels in Latvia (2003-2010)" which was accepted in December 2003 [7]. On July 2004, the Cabinet of Ministers issued its decree No. 511 "On the implementation strategy of the programme "Production and use of biofuels in Latvia"", stating the competences of ministries as regards the implementation of the programme [8]. During its March 2005 session, the Cabinet of Ministers discussed the promotion of the use of biofuels, the competencies of ministries, and appointed the Ministry of Economy coordinating ministry for the implementation of the Law on Biofuels. On April 2005, the Law on Biofuels was accepted by the Saeima [9].

Regardless of the great number of different regulations, the real situation in Latvia seems to be not satisfactory. As shows report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union [6], Latvia's biofuel share in 2003 was 0.22 %, in 2004 – 0.07 %, in 2005 – 0.33 and this number was still approximately the same also in 2006 and 2007.

The reason of mentioned problems above is not so much technical nature, but economical, i.e., the prices of different biofuels are not able to compete with oil based fuels' prices. One of the possible ways how to change such situation is to optimize biofuel supply chains using different methods of systems engineering, particularly modelling. That's why it's necessary to understand main systems engineering processes and to find out the most suitable modelling and simulation tools.

Characteristic of biofuel supply chain as a system

A system is a collection of different elements that together produce results not obtainable by the elements alone. The elements or parts can include people, hardware, software, facilities, policies and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behaviour and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected [10].

In our investigation the system is a biofuel supply chain. Its structure can be various depending on biofuel kind and raw material. As examples the structures of biodiesel (from rapeseed) and bioethanol (from grain) supply chains are given on Fig. 1 and 2.

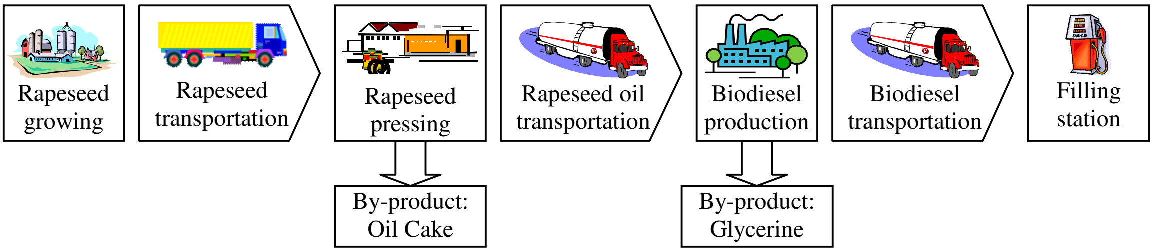

Fig. 1. **The structure of biodiesel supply chain** [11]

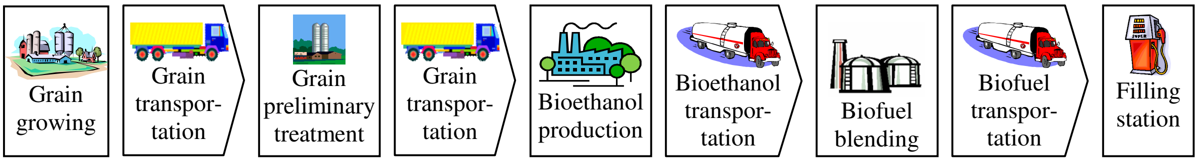

Fig. 2. **The structure of bioethanol supply chain**

<u>*Systems engineering*</u> is an interdisciplinary field of engineering that focuses on the development and organization of complex artificial systems. This process is usually comprised of the following seven tasks: State the Problem, Investigate Alternatives, Model the System, Integrate, Launch the System, Assess Performance and Re-evaluate (Fig. 3) [12].

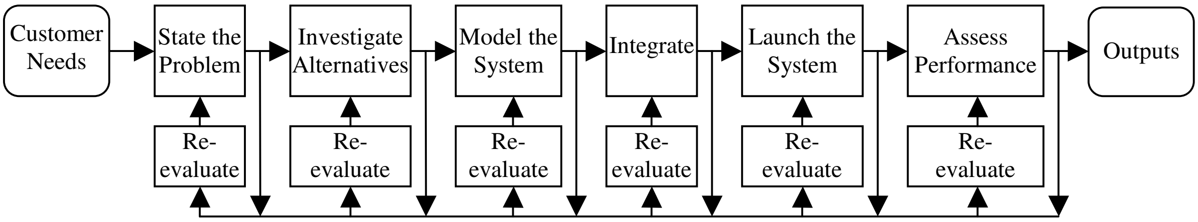

Fig. 3. **The systems engineering process**

The problem statement starts with a description of the top-level functions that the system must perform. The problem statement should be in terms of *what* must be done, not *how* to do it. The problem statement should express the customer requirements in functional or behavioural terms. It might be composed in words or as a model. Inputs come from end users, maintainers, suppliers, acquirers, owners, regulatory agencies, victims, sponsors, manufacturers and other stakeholders.

Alternative designs are created and are evaluated based on performance, schedule, cost and risk figures of merit. No design is likely to be best on all figures of merit, so multicriteria decision-aiding techniques should be used to reveal the preferred alternatives. This analysis should be redone whenever more data are available.

Models will be developed for most alternative designs. The model for the preferred alternative will be expanded and used to help manage the system throughout its entire life cycle. Many types of system models are used, such as physical analogs, analytic equations, block diagrams, functional flow diagrams, object-oriented models, computer simulations and mental models.

Systems, businesses and people must be *integrated* so that they interact with one another. It means bringing things together so they work as a whole. Interfaces between subsystems must be designed.

Launching the system means running the system and producing outputs. This is the phase where the preferred alternative is designed in detail; the parts are built or bought, the parts are integrated and tested at various levels leading to the certified product.

Figures of merit, technical performance measures and metrics are all used to *assess performance*. If you cannot measure it, you cannot control it. If you cannot control it, you cannot improve it.

Re-evaluate is arguably the most important of these functions. Re-evaluate means observing outputs and using this information to modify the system, the inputs, the product or the process [13].

The need for systems engineering arose with the increase in complexity of systems and projects. Systems engineering encourages use of tools and methods to better comprehend and manage complexity in systems. Some examples of such tools are: *Modeling and Simulation*, *Optimization*, *System dynamics*, *Systems analysis*, *Statistical analysis*, *Reliability analysis*, and *Decision making*. Taking an interdisciplinary approach to engineering systems is inherently complex, since the behaviour of and interaction among system components are not always well defined or understood. Defining and characterizing such systems and subsystems, and the interactions among them, is one of the goals of systems engineering.

Analysis of existing solutions in modelling of biofuel supply chains

Performing analysis of existing solutions in modelling of biofuel supply chains, the first ones were found relating biomass fuel supply and collection [14, 15]. These investigations were carried out correspondingly in Netherlands and UK. The main obtained information from these models is used input and output data, but unfortunately used equations and modelling tools weren’t found here. Another problem to use these models is particular countries individualities in different modelling input parameters, for example, distances between objects, network of roads, volume of output etc.

As the most fundamental and recent investigations in this field the modelling studies within the framework of the European Commission-supported project “Clear Data Clean Fuels” (NNE5-2001-00619), which was later renamed “Clear Views on Clean Fuels”, or in short, “VIEWLS”, were found. The overall objectives of this project are to provide structured and clear data on the availability and performance of biofuels and to identify the possibilities and strategies towards large scale sustainable production, use and trading of biofuels for the transport sector in Europe, including Central and Eastern European countries (CEEC) [16]. Two complementary modelling tools have been used in this research, the BIOTRANS model and the ChalmersVIEWLS model.

The BIOTRANS is a multi commodity network flow model. Inputs for BIOTRANS are regional costs and potentials of biomass resources, technology parameters on conversion processes including technological learning, transportation costs and infrastructure and vehicle adaptation costs. The model was used to generate the lowest cost supply chain from feedstock to end-use for realising a specified demand for biofuels for the WEC and CEEC following the EU biofuels Directive, with a target of 5.75 % biofuels market share in 2010 the scope of the Directive. It is assumed that the Directive is extended to a share of 20 % in 2030. The transport segments that have been incorporated in the model in each country are cars, buses and trucks. Given their characteristics, each biofuel replaces either gasoline or diesel, in blended or pure form.

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. For biofuels, for which the BIOTRANS model was used, the focus has been primarily on cost, production capacities, trade and on emissions. Other factors such as biofuel specifications, compliance with standards, end-use issues and non-economical factors such as public acceptance have not been taken into account. For bioenergy, for which the ChalmersVIEWLS model was used, focus has been on cost optimisation of the overall energy mix (consisting of biomass, renewables, and fossil sources) under a certain energy demand scenario and assumptions on CO_2 emission limits and policies.

Analysis of these investigations were very useful, especially studies of background document for modelling the EU biofuel market using the BIOTRANS model [17].

Analysis of available tools for the modelling of biofuel supply chains

Before starting biofuel supply chains' modelling available tools were analyzed. Of course, one of the solutions is to use any of powerful common use modelling software, for example, *Simulink* or *Powersim*, but probably other software which is specially designed for modelling of logistics and supply chains would be more suitable. In the first step of analysis 65 different software were compared. The main criterions in this step were typical applications of the software, primary markets for which the software is applied and system requirements, for example, minimal necessary *RAM* (*Random Access Memory*), supported operating systems etc.

After this analysis 9 different software are left:

- *AnyLogic* – set of primitives and library objects allows to model manufacturing and logistics, business processes, human resources, consumers' and patients' behaviour etc. The object-oriented model design paradigm supported by *AnyLogic* provides for modular and incremental construction of large models [18];
- *Arena* – complex, large-scale projects involving highly sensitive changes related to supply chain, manufacturing, processes, logistics, distribution, warehousing and service systems [19];
- *ExtendSim Suite* – 3-D modelling of manufacturing, logistics, business, government, education and engineering [20];
- *Flexsim Simulation Software* – a modelling software that can be used to simulate and visualize any business process, whether the process is manufacturing, logistics, or administration [21];
- *Lean-Modeler* – automotive, energy, health care, logistics, manufacturing, metals, business process re-engineering modelling [22];
- *ProModel Optimization Suite* – discrete event simulation software, used for evaluating, planning or designing manufacturing, warehousing, logistics and other operational and strategic situations [23];
- *ServiceModel Optimization Suite* – modelling of financial services, logistics, transportation, food and hotel services, entertainment, and other service industries [24];
- *ShowFlow* – the leading software product designed to model, simulate, animate and analyse processes in logistics, manufacturing and material handling [25];
- *Simul8* – manufacturing, supply chain, logistics, healthcare, financial, education processes modelling [26].

In the second step 9 software left after the initial analysis were compared using the following criterions:

- model building characteristics (for example, availability of graphical model construction, access to programmed modules, run time debug, input distribution fitting, output analysis support, presence of tools to support packaging);
- types of modelling (discrete event, continuous event or mixed);
- availability to export the model as animation and import other file formats;
- availability of support, training and consulting;
- pricing information and presence of academic/research versions.

To make the final decision, the development of the software, for example, appearance of new features since 2005 was taken in account. Impression on the individual software possibilities was obtained also from demo models which are available for most of these programs. As the result of this analysis two different software were chosen and bought – *AnyLogic* and *ExtendSim* (see acknowledgement at the end of publication). Both of them will be used in following modelling and simulation.

Results and discussion

As the first system for modelling the pure vegetable oil from rapeseed was chosen. This process is similar to the production of vegetable oils for the food industry, which is a well-established process. Solvent extraction, cold pressing, or a combination of both can do oil extraction. Here, seed cakes are produced as a secondary product. Pure vegetable oil can be used directly in automotive engines or used for the biodiesel production. Using experience from previous investigations and adapting it to Latvia's specific peculiarities, two different logistic chains were developed – for decentralized and unitary production (see Fig. 4, 5).

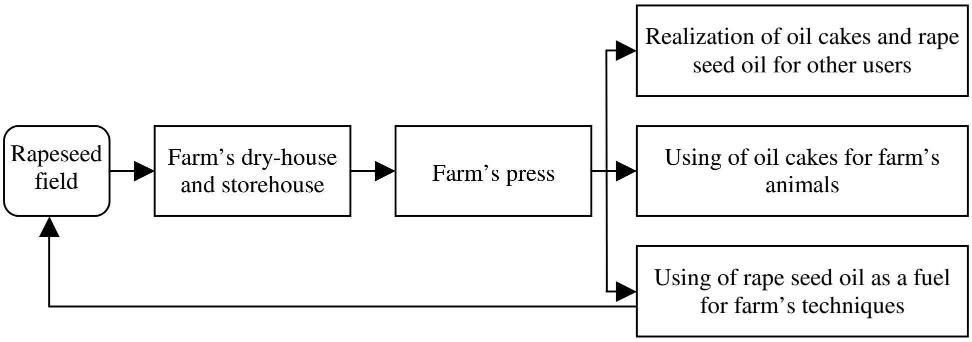

Fig. 4. **Rapeseed oil logistic chain for decentralized production**

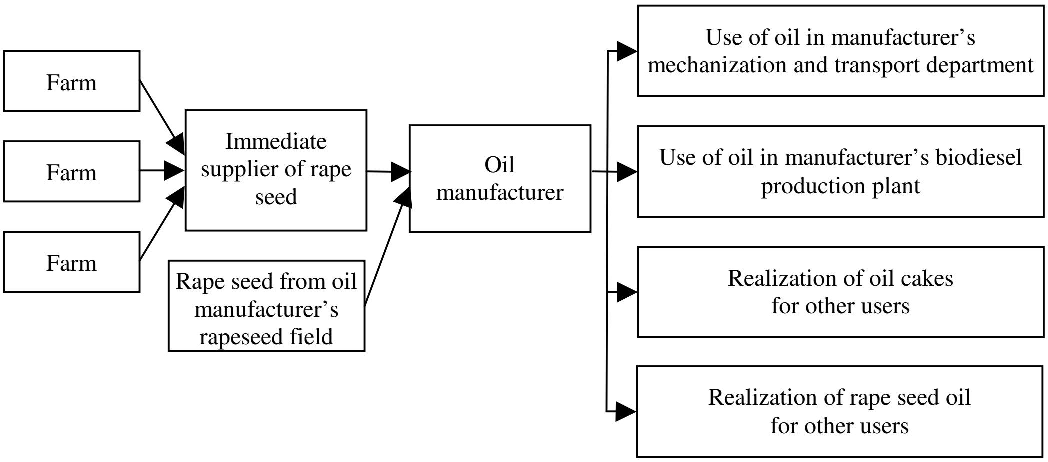

Fig. 5. **Rapeseed oil logistic chain for unitary production**

These modelling studies could be called as preliminary, because it's very difficult to include all factors in model, if the prices of raw materials, chemicals, technical services, fossil fuel etc. are so rapid changing. That's why to simplify the first investigations, the technical services, for example, expenses for cultivation of the soil, sowing, fertilizing, spraying etc. are left the constant for both models – for centralized and unitary production. A lot of different expenses were taken in account, for example, seed and fertilizer prices, rape seed and oil cake sale price, pressing capacities, average rape seed transportation distances, rape seed yield capacities etc.

The obtained modelling results varies in a very large scale, for example, the cost price of 1 litre of rape seed oil using decentralized production was from 0.22 Ls (winter rape) to 0.48 (summer rape). If at the farm only biological technologies are used ("biological rape") the price for 1 litre from summer ripe rises to 0.66 Ls. Using unitary production the price for 1 litre reached 0.76 Ls. It's explainable with high infrastructure maintenance expenses of production plants, if the production capacity is not enough high. The main conclusion of these preliminary modelling studies is that biofuel supply chain model is very sensitive, because changing just single parameters in very short scale (for example, yield capacity from 3.0 to 3.2 $t \cdot ha^{-1}$, rape seed transportation distance from 50 to 30 km, rape seed sale price from 270 $Ls \cdot t^{-1}$ to 290 $Ls \cdot t^{-1}$, oil cake sale price from 220 $Ls \cdot t^{-1}$ to 240 $Ls \cdot t^{-1}$ etc.), the cost price of 1 liter of rape seed oil changes very dramatically. It means that all existing solutions in modelling of biofuel supply chains are not usable for Latvia directly because our country's area, production capacities and other parameters are very different from other European countries. For example, if the distance from Jelgava to Ventspils in European model is inconsiderable, than in modelling of biofuel supply chain in Latvia scale it is very significant.

The same sensitivity shows also modelling of the capital investments at the farm for decentralized production. For example, if we are planning to by the oil press for 3000 Ls with using oil as a fuel of farm's technique and the fuel consumption is planned 1000 $l \cdot month^{-1}$, fossil diesel fuel price is 0.76 $Ls \cdot l^{-1}$, government's excise-duty drawback is 0.19 $Ls \cdot l^{-1}$, the cost price of 1 litre of rape seed oil is 0.40 Ls, than the period of repayment of the press is 18 months. If we reducing the cost price of 1 litre of rape seed oil only by the 0.05 Ls, the period of repayment decreases to 14 months.

The future investigations related to the modelling of biofuel supply chains particularly in Latvia have to be done very carefully building models step by step and taking in account all parameters which are most affecting the final biofuel cost price.

Conclusions

1. Regardless of the great number of different regulations in Europe and Latvia, the real situation seems to be not satisfactory – the EU consumes only 2 % biofuels for the road transport sector, but Latvia – just a little more than 0.3 %.
2. One of the possible ways how to change such situation is to optimize biofuel supply chains using different methods of systems engineering, particularly modelling.
3. Analysis of existing solutions in modelling of biofuel supply chains shows that existing solutions in this field are not usable for Latvia directly because our country's area, production capacities and other parameters are very different from other European countries.
4. Analysing available tools for the modelling of biofuel supply chains two different software were chosen and bought – *AnyLogic* and *ExtendSim*. Both of them will be used in following modelling and simulation.
5. As the first system for modelling the pure vegetable oil from rapeseed was chosen. The main conclusion of these preliminary modelling studies is that biofuel supply chain model is very sensitive, because changing just single parameters in very short scale, the cost price of 1 liter of rape seed oil changes very dramatically.
6. Finalizing these investigations, the main conclusion is that the future investigations that is modelling of biofuel supply chains particularly in Latvia have to be done very carefully building models step by step and taking in account all parameters which are most affecting the final biofuel cost price.

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