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Bioresource Value Model: Case of Crop Production

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***Abstract* – The future of sustainable development is the bioeconomy with both global and local renewable energy solutions. The updated Bioeconomy Strategy and the Green Deal serves as prove of European Commission commitment for transformation towards a sustainable and climate-neutral European Union. This process is characterized with an enormous complexity and should be studied thoroughly for designing transition pathways. Scientifically sound methods can support policymaking in dealing with uncertainty and complexity taking place within definition of transition pathways. This article reviews the existing bioeconomy development models, and presents a novel model, which focus on agriculture – one of the main directions of the national economy. The concept of model is tested within a case study of crop production sector in Latvia. The results of case study show economically viable scenario for added value target set for 2030. In the crop sector, the baseline scenario and three alternative scenarios were analysed. The highest added value and the most advantageous alternative scenario is for fibre powder produced from cereal bran (in the bioeconomy sector, food provides the highest added value).**

Keywords **– Added value; bioeconomy; biorefinery; crop production; green deal targets; optimization; TIMES**

1. INTRODUCTION

Sustainable production and consumption (SPC) can broadly be defined as encompassing any and all issues that seek to improve the way that products and materials are sourced, manufactured, and marketed and the way that products are purchased, used, and disposed of at the end of their useful lives [1]. Economy founded on biomass instead of fossil fuels represents a significant shift in socio-economic, agricultural, energy and technical systems towards sustainability. The concept of a bioeconomy, also called the 'bio-based economy' or 'knowledge-based bio-economy' (or KBBE), can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources [2].

Addressing complex agri-environmental issues calls for interdisciplinary bio-economic research that recognizes the complexity of agricultural systems, and their roles in food production, delivering ecosystem services, and contribution to rural economies. This study aims at providing a tool for bioresource value modelling and assessment, which would help to evaluate alternative scenarios of bioeconomy development at national level in crop production sector.

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2. LITERATURE REVIEW

2.1. Bioeconomy and Bioresource Value

The bioeconomy concept is becoming more prominent topic in science and policy lately. In 2012 European Commission within a strategy 'Innovating for Sustainable Growth: A Bioeconomy for Europe' defined bioeconomy concept [3]. The strategy defines that bioeconomy is based, first of all, on using renewable biomass, by using not only raw material, but also biomass residues and, second of all, producing wide range of high added value products and energy. Production of high added value products means that at first biomass is used to produce high added value products like pharmaceuticals and chemicals and then residues are used for the production of lower added value products. Therefore, the main aim of bioeconomy is to use bioresource as fully as possible and reduce waste [4].

In Latvia, innovative approaches for the efficient and sustainable exploitation of natural resources are developed and introduced in the bioeconomy industries in order to stimulate the growth of the national economy, providing higher value-added, and promoting exports and employment. This shall be achieved while simultaneously balancing economic interests with ensuring environmental quality and preserving and enhancing biodiversity [5]. The successful development of a bioeconomy based on the production of higher value-added products from bio-resources depends on the direction of policy strategies [6].

Latvia is a small country with a limited domestic market and limited resources. Economic growth and wellbeing in Latvia directly depend on its foreign trade, investment, capability to compete and produce high value-added products [7]. The current relevance of the use of biomass in the energy sector compared to other higher value-added products (e.g. composites, fine chemicals and biomedicines) highlights the need for an interdisciplinary assessment of the added value of bio-resources from various sources such as agriculture in to the circular economy [8].

2.2. Agriculture Sector of Latvia

About one-third of agricultural land in Latvia is used for crop cultivation, and about one-tenth is dedicated to pasture for livestock. Of the crops, grain (mainly rye) is the most important. Cereals account for the largest share of agricultural production (around 30 % of total final agricultural production) [9]. Potatoes, onions, carrots, and sugar beets are the main crops produced for export [10]. The role of two major sectors is becoming stronger with every year – cereal production and milk production [11].

In the last 20 years, the sector of agriculture was affected by sharp political changes: in the 90s of the last century, Latvia's land management structure changed fundamentally, collapse of collective farm system started, resulting in emerging private farms [12]. In the meanwhile, they dominated in the sector and a proportion of household plots increased. Whereas in 2004, Latvia acceded to the European Union (EU). Upon accession, Latvia transposed its basic legislation and adjusted to EU principles. Therefore, the development of Latvia's agriculture, to a large extent, is associated with the future of the EU Common Agricultural Policy (CAP). CAP objective is ensuring a stable income for farmers and at the same time facilitating production of high-quality products in accordance with the market demands as well as encouraging farmers to seek new development opportunities by diversifying types of activities [11], [13].

In agriculture, in general and in plant production, in particular one of the major sectors is production of cereals. Providing the country with a sufficient amount of cereals contributes to strengthening of its independence. Production of cereals is particularly import for animal

husbandry as neither branch of animal husbandry can exist without cereals. Particularly important production of cereals is for pig breeding and poultry farming. The year 2013 was the second distinguished year after 2012 for cereal producers. In 2013, the total yield of cereals was 175.8 thousand tonnes less than in 2012, reaching 1948.7 thousand tonnes. Total of 32.6 % of agriculture areas are accounted for cereals cultivation with the yield of least 4 t per ha. Lately, cereals are used not only for animal husbandry and food production but also in production of alternative energy, including heat production [14].

In 2013, oilseed rape sown area increased (9.1 %) however, as compared with a successful 2012, an average productiveness of oilseed rape has dropped. Thanks to enlargement of sown areas, the total yield has stayed on the level of the previous year. Basically, cereal production farms are engaged in growing of oilseed rapes because soil cultivation technologies, cereal sowing and harvesting machinery is similar to that needed for oilseed rape. However, there is a certain risk, as crop rotation on these farms goes between two crops – oilseed rape and wheat, and oilseed rape is being sown on one and the same field every second year or every 2–3 years, at best. This can lead to a situation that in a long run, oilseed rape can be affected by clubroot, resulting in a sharp reduction in yields. It is forecasted that next summer, spring oilseed rape areas could reduce considerably due to the Commission's decision to ban the use of some pesticides and treating oilseed rape with mordant [14].

The entire territory of Latvia is suitable for growing of vegetables but specialization of farms in horticulture is determined by location of markets, mainly closeness to towns and cities [14]. Horticulture farms are mainly situated in Riga neighbourhood and Zemgale region. In 2013, Latvia's vegetable area, as compared with 2012, increased by 5 %. Field areas increased by 5 % but covered areas reduced by 15 %. Although, covered area has reduced, but the total yield of vegetables in covered area increased by 7 % in 2013 as compared with 2012. It is due to introduction of new technologies in production of vegetables in covered areas resulting in higher vegetable yields. 98 % of covered areas are under tomatoes and cucumbers, leaving only 2 % to the rest of covered area species [14].

2.3. Bio-Economic Models

There is a growing interest in interdisciplinary bio-economic modelling, to provide information to policy makers and to help improve management decisions [15]. A large number of bio-economic models has been developed for different farming systems and agro-ecological conditions. Such models may link biophysical and economic models [16], but their individual components are typically developed from a single-disciplinary perspective (e.g. economics or agronomy). Bio-economic models tend to be limited in their level of integration, and often involve limited genuinely interdisciplinary teamwork. There have been increasing calls for bio-economic models that focus more on integrating knowledge at conceptual as well as technical implementation levels [15]. This section gives a review of literature on methods used in bio-economic models and assessment frameworks.

Multi-criteria decision analysis (MCDA) is a valuable tool for decision-making in complex process systems, using a number of parameters that influence embedded processes in the value chain [17]. These parameters can be assessed by different actors in the chain as 'significant factors'. In addition, by including this flexibility in the scope of this assessment, the MCDA ensures systematic investigation and transparency in its decision-making. The overall aim of the MCDA is to provide an opportunity to explore the knowledge and concerns raised by actors in the chain, to weigh them from an objective point of view, to systematically analyse them, to set key criteria and then to take decisions in complex multi-stakeholder process systems [18].

Studies are being carried out to use two-tier MCDAs to rank biological value chains based on a set of selection criteria, emphasizing the importance of respecting the principles of their circular economy. The results of the analysis highlight the importance of these selection criteria to highlight the features of any bio-based value chain / business model [19].

A mapping methodology has been developed to understand the strengths, weaknesses, opportunities and challenges inherent in the biological value chain associated with the synthesis of different bioproducts, and demonstrates the importance of bottom-up processes and material use in downstream activities (mainly post-consumption and end-of-life management). Different biological value chains have been identified in the EU. This list of tentative value chains is based on a review of the literature above, focusing on the biological value chains / products covered by the EU certification schemes and market demand [20]. The list includes organically produced value chains with (but not limited to) a variety of characteristics, including:

- From virgin food-based feedstock to bio-waste cascading;
- 100 % bio-based to partially bio-based, value chains;
- Those with a fully-functional waste management infrastructure to those that lack one;
- Diverse product functionality [21].

A recognized methodology known as GE-McKinsey Matrix [22] uses nine modules or boxes to identify aspects of the potential new bioproducts market. The methodology has been developed and tested on three existing products. The calculations combine economic data and data on technology, as well as data on product competitiveness and market data. The data analysis is based on aggregated data from information sources and is presented in two dimensions – market attractiveness and product competitive advantage. The method provides the results to allow to make recommendations for further evaluation of the production of new products in the current location or in a country where local resources are available [23].

The methodology for the GE-McKinsey Matrix can be modified to include considerations and constraints such as environmental protection, required in the manufacturing process and product sustainability [23]. Instead of the competitive position of the company, it shows the competitive attractiveness of a particular product. After obtaining results, it is possible to gain insight into market opportunities for the product. The GE-McKinsey Matrix is widely used for product portfolio management and in the analysis of competitive scenarios [24]. A similar analysis can be made using the Boston Consulting Group matrix [25], however, the GE-McKinsey Matrix can provide a broader range of factors, while the Boston Consulting Group matrix was found not to be sufficiently flexible and complexity issues are reported [26].

Life cycle analysis (LCA) is a well standardized methodology that can be applied for bioeconomy studies [27]. The LCA selects and analyses a list of key bioeconomic value chains for each pillar to identify existing and potential biomass conversion technologies and assess their environmental performance. The criteria for selecting value chains are: relevance in the global market, representativeness and / or suitability for competition with similar products of fossil origin [28].

Few studies with application of Socio-economic analysis (SEA) [29] for biorefineries have been found in the literature. Socio-economic performance in the production of various bioenergy products is divided into categories, mainly for positive, neutral or negative effects. In the study of [17] a rural biorefinery was assessed for the development of the territorial integration of economic activities in the region based on the socio-economic framework. In addition, a social life cycle assessment (SLCA) is included as one of the criteria for examining the social dimension of a rural biorefinery [30].

A specific bio-economic model called SYNERGY (cross-Scale model using complementarity between livestock and crop farms to enhance regional nitrogen self-

sufficiency) is a static non-linear programming model, which maximizes regional profit under constraints is introduced in study of [31]. It is calibrated to starting conditions using Positive Mathematical Programming. SYNERGY is applied to a particular area called 'region' that is divided into several 'sectors' to consider a variety of soil and climate conditions. SYNERGY's main originality lies in its ability to represent farm-to-farm exchanges of intermediate products (manure and crops), which occur on a local market (i.e., intra-sector or intra-region). It generates four types of indicators:

1. Structural (e.g., crop areas, numbers of animals);
2. Technical (e.g., protein self-sufficiency, application of N fertilizers);
3. Economic (e.g., regional profit, farm income, farm-to-farm exchanges);
4. Environmental (i.e., N efficiency and potential losses of N).

These outputs are provided for each farm type at the sector and regional levels [32].

Another modelling framework MOSAICA can be used for optimising individual farmer's utilities at the regional scale, considering the expected farm revenue and the risk aversion towards price and yield variations [33]. The inputs of the model are:

- The geographic database of fields that contain information about the biophysical context and the farm structure, e.g., the farm size and the land tenure,
- The database of activities that describe the cropping systems and technical-economic coefficients that can be allocated to fields, and
- The farm typology and the classification algorithm for the eight farm types.

The allocation of cropping systems is modelled through a set of equations that model the choice of cropping systems by farmers at different scales, namely the field, farm, sub-regional and regional scales. Optimization is done on a regional scale, as equations are introduced at this scale to limit the total production of some crops (due to market size or production quotas). The results of the model are estimations of sustainability range of the trimming system [34].

The SEAMLESS-Integrated Framework (SEAMLESS-IF) aims to assess the impact of agricultural and environmental policies on agricultural systems and sustainability indicators [35]. Integrated evaluation requires that the policy issues addressed by SEAMLESS-IF be translated into scenarios assessed using a set of key economic, environmental, social and institutional indicators. To model key aspects of farming systems from the field to the farm scale, SEAMLESS-IF provides an intelligent combination of crop production system model, bioeconomy farm model and indicators. This modelling chain can be used to identify which farm locations and agro-ecological technologies will be preferred in the implementation of the research policies and agro-ecological technologies and to model their impact [36].

The cropping system model *CropSyst* [37] can used to quantify the relationship between crop production and environmental effects at field scale, as the cropping system component of SEAMLESS-IF [38]. *CropSyst* implements modules capable of simulating crop response to a wide range of weather, soil and management conditions using daily time steps, for periods ranging from one year to a hundred years. *CropSyst* is a multi-year, multi-crop, daily time step cropping system model. It can simulate the soil water budget, soil–plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and pesticide fate. Crops are simulated using a generic crop simulator, in which some processes (e.g. photoperiod response, vernalisation) can be switched on or off using appropriate parameter values. *CropSyst* simulates plant growth as potential growth and under water, nitrogen, and temperature stresses [36].

A bio-economic farm model, 'MEETA' (Modelling Energy and Emissions Trade-offs in Agriculture) [39]. The objective of the MEETA model is to capture trade-offs between

different aspects of the farm system – those that are not captured by the LCA analysis [23]. The MEETA model is a linear programming optimisation model that represents multi-year cropping within a single year framework, based on combinable crops common to cereal farms. Output from crops is a product of straw and grain at representative market values; the model maximises the gross margin between total output and variable costs of seeds, fertilisers and sprays, contract costs and fuel costs. Energy inputs and outputs and emissions data are associated with the main inputs and outputs using secondary data and LCA literature. The major constraints in the model are farm size, crop rotations and availability of on-farm machinery for some operations. The model can optimise for either (maximised) farm gross margin, net farm energy or (minimised) GHG emissions, and produces the optimal crop mix, associated machinery and contract use and the farm gross margin, net energy and GHG emissions for each optimal crop mix [40]. The model structure allows trade-offs between energy, emissions and financial performance to be quantified with a specific focus on bioenergy production. The MEETA model focuses on farm level trade-offs and hence the upper model boundary includes everything that is used on farm, up to the point of sale at the farm gate. The following sections provide more detail on the levels of complexity and boundaries for specific parts of the model [40].

Lastly, the Integrated MARKAL-EFOM System (TIMES) model [41] is bottom-up, linear programming tool applied for long-term energy systems planning allowing to analyse effect of different scenarios. It optimises the whole energy system including supply and demand services by minimizing the total cost in the considered modelling period [42]. The Irish TIMES (The Integrated MARKAL-EFOM System) model is an energy system model that was developed by University College Cork (UCC) in collaboration with the Economic and Social Research Institute (ESRI), Energy Engineering Economic Environment Systems Modelling Analysis (E4SMA) and KanORS over the period March 2009–November 2011. The Irish TIMES (The Integrated Markal-EFOM System) is a model that analyses energy usage, emissions, and natural resources and was extracted from the Pan European TIMES (PET) model of Europe, and was then updated and expanded using local and more detailed data and assumptions [42].

TIMES Bioeconomy Value Model (TIMES-BVM) is developed with the aim to model bioresource flows and technologies for bioeconomy development and bioresource value-added growth to 2030. In particular, addressing the development of biorefineries from perspectives of natural boundaries for resource utilization capacity, economic feasibility in terms of cost of technologies and their operation and maintenance, and socio-economic aspect as an added value in terms of salaries and indirect taxes [43].

3. METHODOLOGY

3.1. Goal of the Study

The goal of this study is to develop and test a tool for analysis of agriculture sector bioresource utilization added value for energy and material over longer term and definition of the optimal bioresource utilization scenarios on national level. To achieve the goal of the study following tasks are performed:

1. Definition of hypothesis for agriculture sector bioresource utilization added value on national level;
2. Selection of appropriate modelling approach able to capture the scope necessary for achieving the goal of the study and test hypothesis;
3. Definition on model boundaries and scenarios under analysis;

4. Creating data inventory for the model;
5. Analysis and interpretation of results (see Results chapter).

3.2. Hypothesis and Modelling Approach

There is a certain difference in added value created from resources when they are used for energy production and materials. Historically, the development towards bioeconomy started with high emphasis on bioenergy, and now is moving towards bioresource utilization for more advanced technological and material applications. Therefore, currently a topical issue for policy planners, decision maker and other stakeholders is finding the optimal scenarios for resource utilization with the highest added value. In light of this, the proposed hypothesis for testing the developed tool is defined as achieving agricultural bio-resources utilization added value increase at the national level (by at least 30 % by 2030) by implementing new technologies. In the model, the value added of products was calculated using the total value of the product and dividing it by the volume produced. In the direction of the bioresource utilization for energy purposes one of the most recognized methods is TIMES for energy modelling. In this study TIMES modelling approach is selected and adapted for agriculture sector of Latvia. TIMES Agricultural Bioresource Value Model (ABVM) is developed to model bioresource flows and technologies for bioeconomy development and bioresource value-added growth to 2030. The selected approach is based on optimization of costs attributed to investment and operation of technologies, resource flows and final demand. Historical demand for crop products was taken from the FAOSTAT database, but for 2030 it was calculated based on future population changes. In this way, TIMES allows to evaluate optimal scenarios for bioresource use in energy sector and biorefineries for production of higher added value products. In particular, addressing the development of biorefineries from perspectives of natural boundaries for resource utilization capacity, economic feasibility in terms of cost of technologies and their operation and maintenance, and socio-economic aspect as an added value in terms of salaries and indirect taxes. The proof of model concept and the hypothesis is tested trough case study on crop production sector of Latvia.

3.3. Model Boundaries and Scenarios

The model boundaries are defined according to classification of TIMES model components. The components included are commodities and technologies that are linked with flows.

Commodities are defined as bioresource carriers, materials, products. These commodities in the model are outputs and inputs of technology (process). Commodity flows are entering the processes and are turning into other commodities in the process output (for example, production of food). In this case, flows are biomass flows and measured in mass units.

Technologies component in TIMES represents technological processes that is used to transform one type of commodities into another. Processes are divided in: 1) primary production of commodities, e.g., mining (in default) – or as in case of bioresource, it is also harvesting, import processes, and 2) transformation activities like conversion plants, biorefineries, end-use demand (in this case products). The final consumption of commodities is determined in the model by demand per end sector use.

In TIMES ABVM, model boundaries in bioresources cereals, vegetables and oils (quantities of products grown and harvested), food (fresh and cooked), feed and other products (bioethanol and biodiesel) as commodities, which are linked to respective conversion technologies with commodity flows (see Fig. 1).

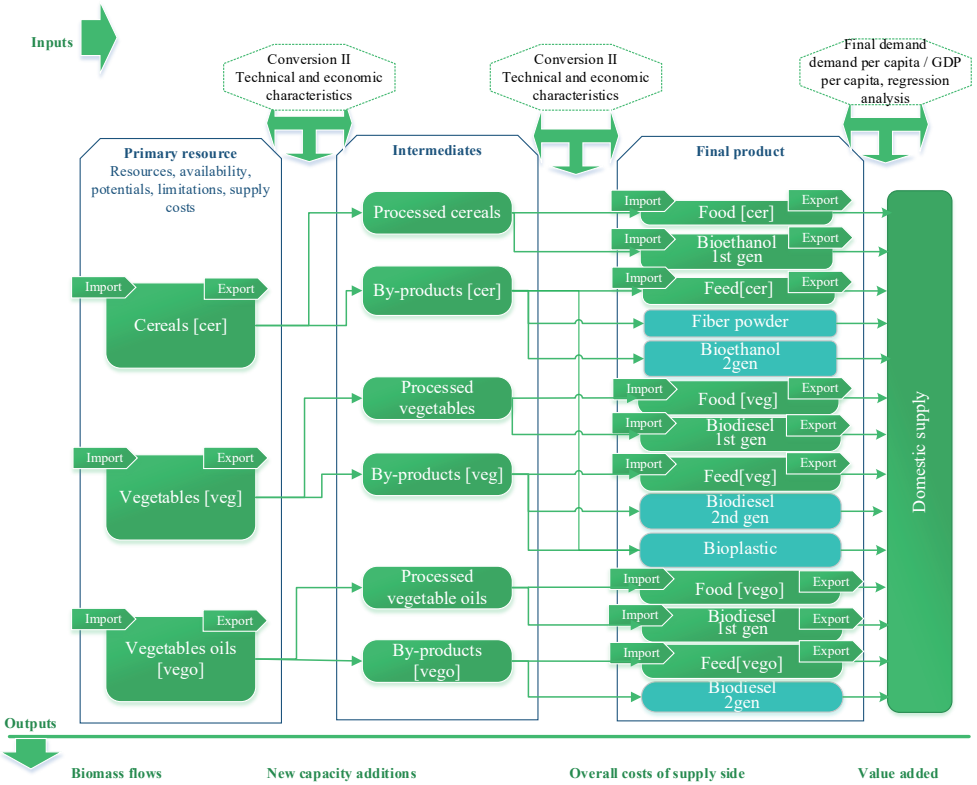

Fig. 1. Defined model boundaries for TIMES ABVM.

The definition of flows linking commodities with technologies are based on the current Latvian crop production sector, where the main extraction of crop products is locally grown products. In the processing of crop products, such as cereals, vegetables and vegetable oils are used to produce food, feed and other products (biofuels). Cereal, vegetable and vegetable oils are primarily used in food production, as well as in the production of first-generation biofuels, and the by-products are used in feed production. Novel foods as well as non-food products were considered as new products in crop products, including the production of fibre powder from grain bran, production of bioplastics from vegetable and cereals by-products, and production of 2nd generation biofuels from grain, vegetable, and vegetable oil by-products.

Based on the available information it is considered that not all crop products in Latvia are processed into food products, some are used in the production of bioethanol and biodiesel. In the process of grain processing, residues are generated, which is not used in food production (milling process). By-products from crop processing are used to produce fodder. Bread production technologies were used in the processing of cereals into food. In the processing of vegetables were considered technologies that are associated with the canning of vegetables and the production of vegetable oils. The production of bioethanol (grains) and biodiesel (vegetables and oils) was considered in other crop products.

To increase the added value of bioresources in the crop sector, four new technologies have been introduced in the model: production of fibre powder, bioplastic production, biofuel production. The total number of scenarios investigated in this study is 5, including:

1. The baseline scenario without any new technology introduction;
2. Separate scenario for each of the new technologies (3 new technologies in total);
3. Aggregated scenario with all new technologies.

Specifically, the scenario for the production of fibre powder from crops is based on the fact that the by-products of grain pre-processing – bran – are used in the production of a new product. The bioplastic production scenario from crops assumption is that by-products of grain pre-processing – bran and vegetable residues – are used in the production of a new product. As well as a new technology scenario for the production of second-generation biofuels (bioethanol and biodiesel). For the production of bioethanol assumption is that by-products of grain processing or bran are used and vegetable oil residues for the production of biodiesel.

3.4. Data Inventory

Data is collected for each commodity included in TIMES ABVM in terms of amount and costs of resources, food, feed and other products production, imports, exports and costs. Most of the data are obtained from the official statistical portal of Latvia [44], as well as the database of the Food and Agriculture Organization of the United Nations was used [45].

The historical input data from 2015 to 2019 is used in TIMES ABVM to define the upper and lower limits for amount of resources harvested, imported and exported. These limits are respected in the optimization of added value for target year 2030, in order not to exceed the expected limits for the crop products grown and minimize the potential impact of changes in imports and exports on the model output. The input data for the model's final product or industry demand is determined by a forecast based on population change for the target year 2030.

Data on respective conversion technologies are included in the model in terms of capacity, efficiency, investment, operation & maintenance (O&M) costs, lifetime and availability, and the added value of the product production process. Technological costs are taken from financial statements and reports of Latvian companies. Data on the technology capacities are obtained from the companies' pollution permits.

The added value of products is calculated from two databases. The total added value for food, feed and biofuels is obtained from the European Commission database [46]. The volumes of food, feed and biofuels produced (thousand tons) from the database of the Central Statistical Bureau of the Republic of Latvia were also considered. Value added for food, feed and biofuels was calculated by dividing total value added and output.

Literature is reviewed on new technologies in agriculture sector is performed for definition of alternative scenario input data. The new technology availability is set to 2025. The new technologies are:

1. The production of fibre powder from grain processing by-products or bran;
2. The production of bioplastics from grain bran and vegetable residues; and
3. The production of second-generation biofuels (bioethanol from grain by-products and biodiesel from vegetable oil by-products).

4. ANALYSIS OF RESULTS

The tool for analysis of agriculture sector bioresource utilization added value TIMES ABVM is developed and tested in case study on Latvian agriculture sector, considering the limitation of the method and availability data. The scenarios of the case study include baseline scenario for agriculture sector and alternative development scenarios with new technologies.

Results of are presented separately for baseline scenario separately for each of the agriculture resource group cereals, vegetable oils and vegetables, and for alternative scenarios together. The Sankey chart is used to visualize the flow of bioresources in light blue and the goods in yellow.

4.1. Baseline Scenario for Cereals

Fig. 2 shows the bioresource flows in the baseline scenario for the 2015 simulation year with fixed input commodity parameters to provide a historical view of the crop sector. The results show that most of the crop products are grown in Latvia and the imported part is smaller. The mass balance of commodity flows results in minor inconsistencies, leading to conclusions that some crop products of unknown origin are consumed by processes to satisfy the demand that do not appear in the statistics. Thus crop products of unknown origin are used in the model to fill the gap between supply and demand in the model, taking into account the efficiency of current crop processing technologies.

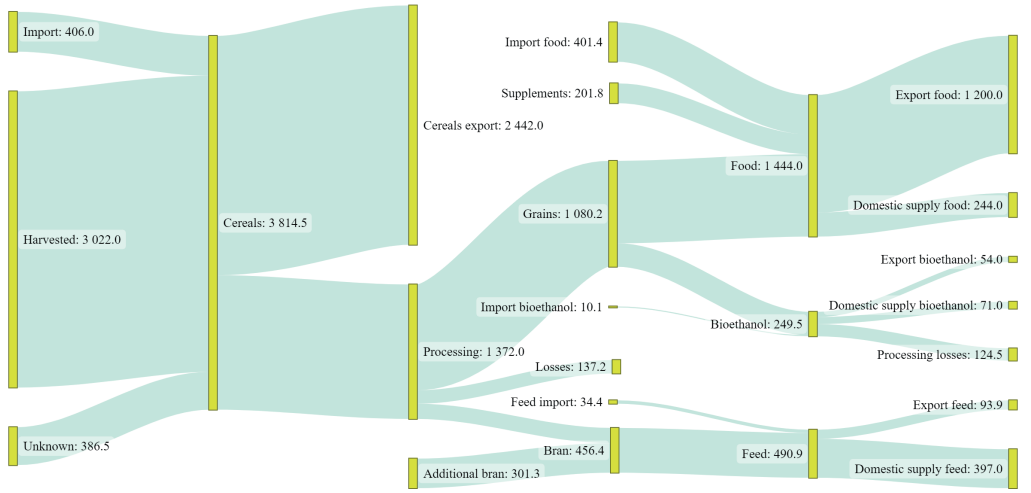

Fig. 2. Sankey diagram for bioresource flows of base scenario in 2015 for cereals, thousand tonnes.

Fig. 2 shows that the main flows of finished cereal products in 2015 are food for domestic supply and export, followed by domestic supply of feed and export of feed. Additives are added to cereal products and make up a large proportion of the final food. In the production of grain food, primary processing produces by-products from which fodder is produced. Part of the cereals is used to produce first-generation bioethanol.

Fig. 3 shows the goods flow results for the 2030 baseline scenario. The main change compared to 2015 is in the production of grain food and feed, as the demand for food has decreased by 20 %, which can be explained by the decrease in the number of inhabitants, however, given the growing world population, grain exports are increasing. Demand for feed has also declined, as total livestock numbers are projected to decline slightly, but demand for bioethanol has increased, which can be explained by an increase in demand for biofuels.

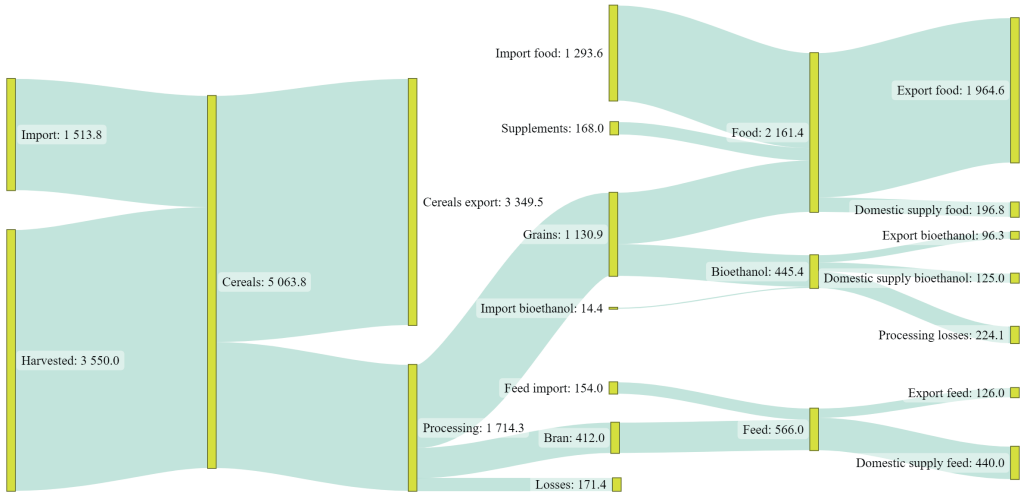

Fig. 3. Sankey diagram for bioresource flows of base scenario in 2030 for cereals, thousand tonnes.

4.2. Baseline Scenario for Vegetable Oils

In Fig. 4, the main flows of finished vegetable oil production in 2015 are for domestic supply and export of biodiesel, followed by domestic supply of feed and export of feed. In the production of vegetable food, primary processing produces by-products from which fodder is produced. Large share of the vegetable oil is used to produce first-generation bioethanol.

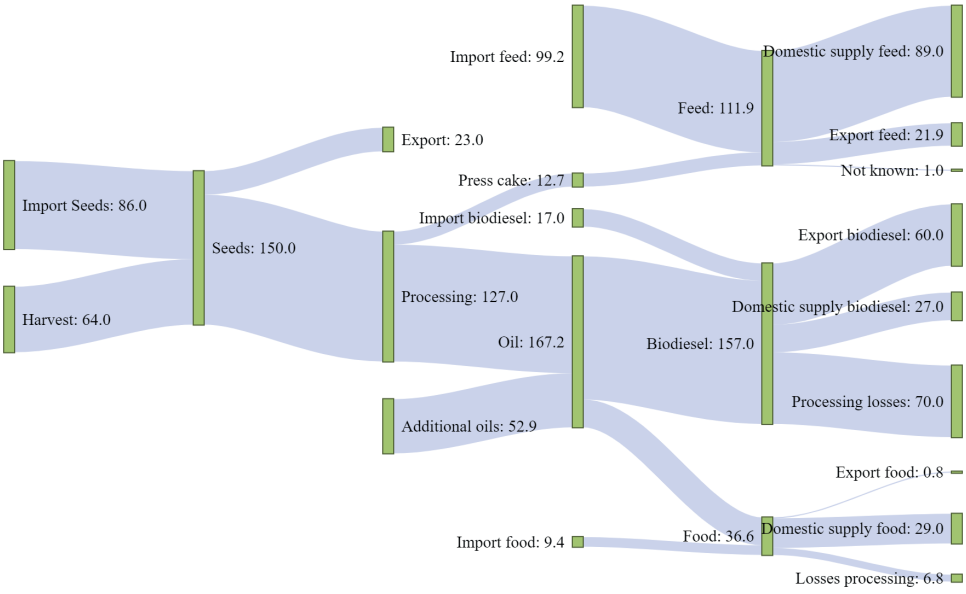

Fig. 4. Sankey diagram for bioresource flows of base scenario in 2015 for vegetable oils, thousand tonnes.

Fig. 5 shows the goods flow results for the 2030 baseline scenario. The main changes compared to 2015 are in the production of vegetable oils for food and feed, as the demand for food has decreased by 17 %, which can be explained by a decrease in the population. Demand for feed has also declined, as total livestock numbers are projected to decline slightly, at the same time demand for biodiesel has increased.

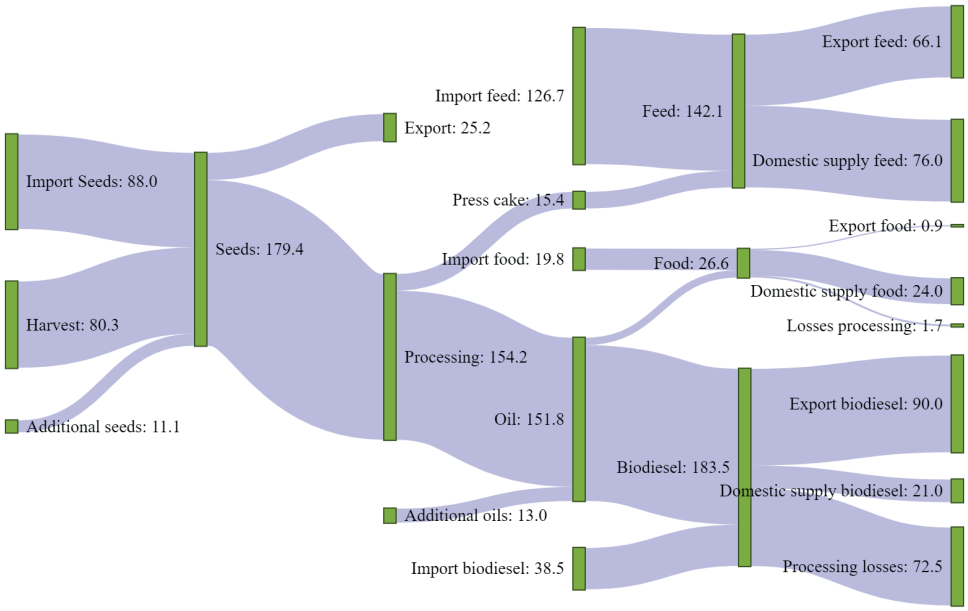

Fig. 5. Sankey diagram for bioresource flows of base scenario in 2030 for vegetable oils, thousand tonnes.

4.3. Baseline Scenario for Vegetables

In Fig. 6, the main flows of finished vegetable production in 2015 are food for domestic supply and export, followed by domestic feed supply and feed export. Additives are added to cereal products and make up a small part of the final food. In the production of grain food, primary processing produces by-products from which fodder is produced.

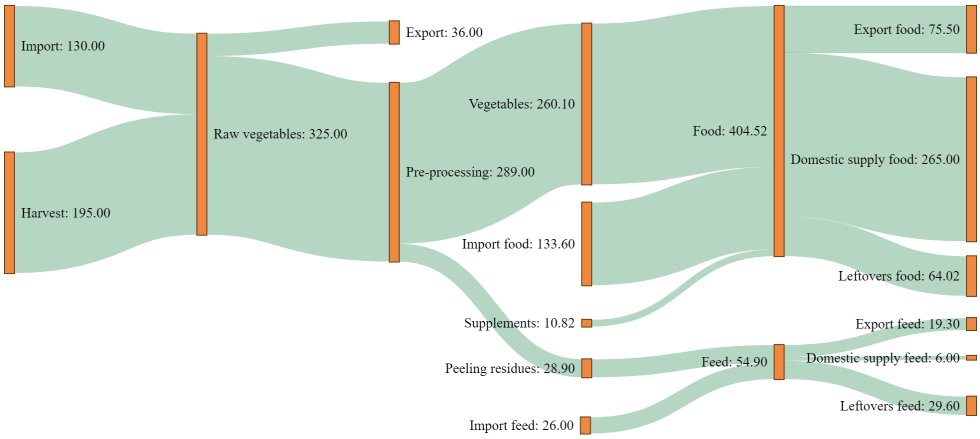

Fig. 6. Sankey diagram for bioresource flows of base scenario in 2015 for vegetables, thousand tonnes.

Fig. 7 shows the flow of goods results for the 2030 baseline scenario. The main changes compared to 2015 are in the production of vegetables for food and feed, as the demand for food has decreased by 22 %, which can be explained by the declining population, but due to the increase in the world's population, vegetable exports are increasing. Demand for fodder has also declined, as the total number of livestock is expected to decline slightly.

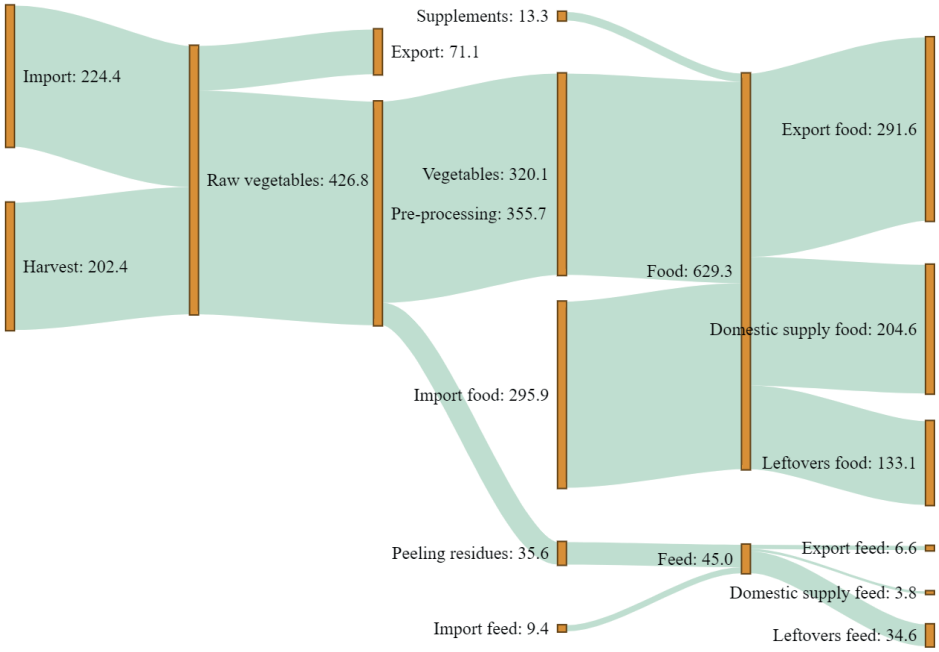

Fig. 7. Sankey diagram for bioresource flows of base scenario in 2030 for vegetables, thousand tonnes.

4.4. Alternative Scenario Analysis

In addition to the baseline scenario, four alternative scenarios are used for the crop case study with TIMES ABVM. The alternative scenario includes new technologies availability after 2025. The results of alternative scenarios are compared with the baseline scenario by added value in 2030, shown in Fig. 8.

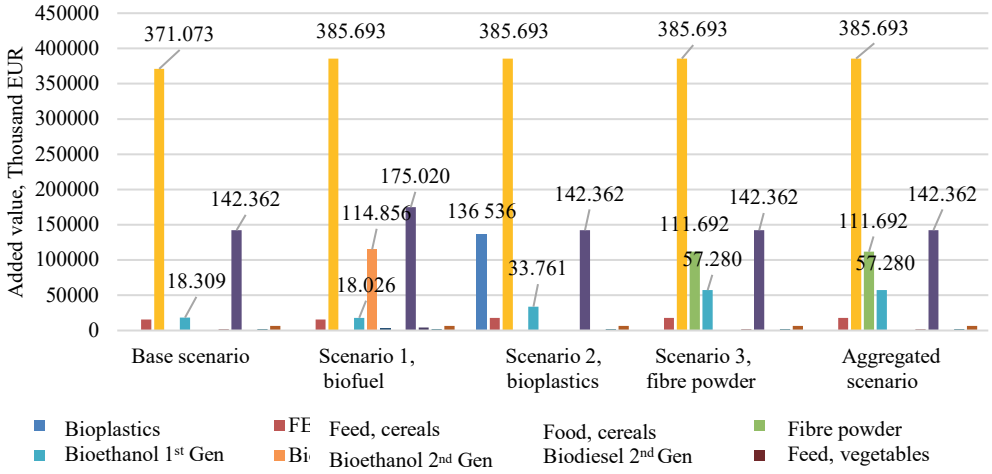

Fig. 8. Scenario analysis for new technologies in agriculture sector in Latvia, year 2030.

Base scenario shows that highest added value is reached from cereals food and vegetable food production. If the added value target is set +30 % from base scenario, in first scenario added value is reached by increasing the food production, other product production and adding new technology that is second generation biofuel production. In the second scenario added value is reached by increasing food production from cereals and bioethanol production from cereals, but most of contribution to the added value target is from bioplastic production as new technology. In third scenario food and other product production from cereals show increase and the use of new technology for fibre powder. Aggregated scenario results show that added value aim can be reached by adding fibre powder production that has higher added value than biofuel or bioplastics and is economically viable.

Cereals account for the largest share of crop production. According to statistical data, the largest amount of cereals grown is exported, as well as the largest share of grain is used in food production (all types of flour products). Vegetables and dase oils make up the smallest part of crop products. Most cereals, vegetables and oils are used for food production and feed and other products (biofuels) account for the smallest share. The model also shows losses and surpluses, which could be explained as discrepancies in the databases. New technologies were introduced in the scenarios. Cereal by-products are used in the production of second-generation biofuels, vegetable residues and by-products in the production of bioplastics. The new technology considered a scenario for the use of grain bran in the production of fibre powder. Similar as in scenario 3, the amount of fibre in the aggregated scenario is rather small, see Fig. 9, only 261 thousand tonnes. However, this amount is sufficient to meet the value-added target, as food has a higher added value in the bioeconomy compared to bioplastics and biofuels.

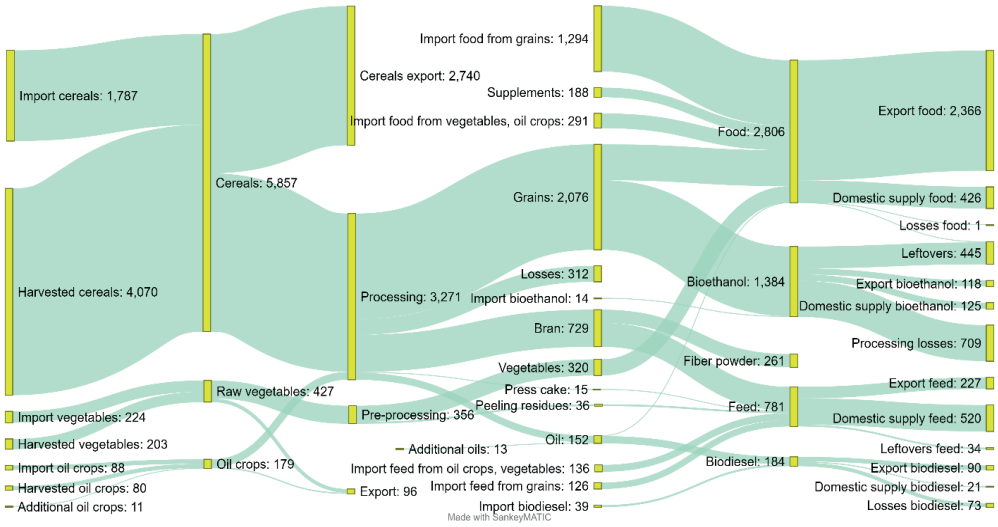

Fig. 9. Best alternative scenario modelling bioresource flow for 2030 crop farming sector, thousand tonnes.

5. CONCLUSIONS

A review of the literature on modelling tools used to optimize the value of bioresources showed that there are many choices among existing tools for bioeconomic analysis. Based on this review, BVM TIMES has been identified as the most appropriate tool to support the decision-making process, where it is important to provide detailed information on technologies and resources on both the demand and supply side. The model helps to find the best supply-demand balance scenarios in a given set of technology cost and resource limits at the national level based on linear optimization. The structure of the developed bioresource optimization model is adapted according to the available statistics from national and EU databases and reflects the multidimensionality of the sustainability pillars using environmental, economic and social criteria.

The study of the crop sector BVM TIMES proved the concept of this model as a tool for optimizing the value added of bioresources. Future studies with the BVM TIMES model should focus on improvements such as the use of new technologies and modelling at regional level.

The forecasts for food and feed demand for 2030 considered the decline in the number of people. As the demand for food decreases, it would be more important to use the amount of existing resources in the production of products with higher added value. Without reducing production and producing high value-added products, the economic situation would be improved.

The agricultural sector can strongly contribute to the development of bioeconomy. Along with food production new pathways for utilization of crops for production of higher added value products are examined in this study.

When collecting the data, it was concluded that the Latvian databases did not provide accurate and complete information, which caused discrepancies in the data. In the absence of information, assumptions were made based on historical trends.

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