Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 1179–1192
https://doi.org/10.2478/rtuect-2021-0089
https://content.sciendo.com

Bioresource Value Model. Case of Fisheries

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***Abstract* – The awareness of bioeconomy role within currently set EU policy targets towards zero carbon emissions and its contribution to achieving the sustainable development goals has been increasing during the last decade. However, it is not always straightforward how the development scenarios for bioeconomy can be evaluated on national level. Moreover, the large number of factors affecting the development of bioconomy is hard to evaluate altogether. Therefore, this study reviews currently available tools for bioresource value modelling in order to select an approach that is suitable for modelling different scenarios of bioeconomy development. As a result of the review, the study presents a methodology, which allows to estimate how higher added values of bioresource products can be achieved in different bioeconomy sectors. The concept of model is tested within a case study of fisheries sector in Latvia. The results of case study show economically viable scenario for added value target set for 2030. The concept of model is found to be adequate, and the use of the defined methodology is appropriate for bioresource value modelling.**

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

1. INTRODUCTION

Development of bioeconomy can create multiple opportunities in the industrial, economic, and social sectors within the frame of EU green deal targets [1]. The targets aim at contributing to sustainable future by implementing policies and actions for clean energy supply and develop low-carbon energy cycles across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation, and social benefits [2]. Different aspects of technologies, economics, and policies are evaluated together [3], when developing strategies for secure energy consumption, bio-economy policies, and nutrient recycling [4] and finding the optimal climate-resilient policies for the Baltic Sea Region [5].

The exiting bioeconomy strategy aims to build a strong bond with the stakeholders, policymakers, and modifications in deliverables to reach the desired target [6]. This strategy has three different following stages:

1. Short-term scenario goal till 2020;
2. Medium-term scenario goal till 2030;
3. Long-term goal till 2050 [7].

The strategy aims at:

– Reducing food waste by system approach concerning the nutritional value of food;

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- By changing the consumption pattern to reduce food waste and use of natural resources;
- Considering biomass as a feedstock to restrict the use of fossil fuel;
- Employment creation in the rural area and innovative way of using biomass resources;
- Implementing the circular to use biomass as a resource [6].

Each sector of bioeconomy (e.g. agriculture, forestry, aquaculture) provide a large amount of biomass for higher added value product production, which potentially contributes to the decrease of the overall environmental impacts [8]. However, the facilitation of higher added value production form bioresources requires legislation incentive and operational rules, and the involvement of stakeholders [9]. Also, bioeconomy development at the EU national level requires consideration of Research and Development budgets for implement the bioeconomy policy [10]. The steps towards the sustainable bioeconomy by emphasizing the research and innovation policy are also reported in [11], [12]. Thus, this research is made considering the current topicality of need for expansion of the biorefineries and development of bioeconomy.

Biorefinery is a multifunctional system at the industrial level, which converts biomass into energy, chemicals, and materials [13], and is connected the three pillars of sustainability [14], thus can be viewed as multidimensional concept. The quality of biorefineries varies in different countries and mainly depends on the amount feedstock produced [15]. In this perspective, precise evaluations of many distinct aspects related to biorefinery implementation is necessary before setting national bioeconomy targets. 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.

2. LITERATURE REVIEW

Successful development of bioeconomy, which is based on production of higher added value products from bioresources is dependent on the advancement of policy strategies. In this regard, empirical tools for complex system analysis of systems and forecasting of the development pathways of bioeconomy are very useful. The current topicality for biomass use in energy sector versus other higher added value product production (e.g. composite materials, fine chemicals and biomedical fields) [16] underlines the need for transdisciplinary evaluation of bioresource added values from wide range of sources, such as forest, agricultural, algae wastes on a way to circular economy [17]. At the same time, the competition for biomass to satisfy energy demand and food demand cannot be left out [18]. Tool that allows to evaluate these multiple aspects of bioeconomy would be of a strong advantage for national level policy planning.

Economic analysis traditionally is performed by the Econometric & Input-Output models. Econometric models can be used to estimate the effect of the alternative policy strategies, Whereas, Input-output models are used to analyse the consistency of the data set [19]. Energy-Environment-Economy Global Macro-Economic (E3ME) model is example of econometric model, which allows to assess global policy challenges with help of time-series analysis for describing economic linkages between industries [20], [21]. A similar approach is used in input-output models. The underlying disadvantage of these models is their reliance on input data for long time periods.

Geographic Information System (GIS) based Light Detection and Ranging (LIDAR) models are often used in agricultural resources management [22]. LIDAR allows to obtain 3-dimensional information of earth and its surface characteristics for agricultural resource

conversion and management in long term scale. LIDAR is a short term model used in hydrology modelling, farming facilities, and soil surveys [23].

Computable General Equilibrium (CGE) models are widely used in regional policy analysis and incorporate short-run supply chains & instant response in investment, land supply, population, and prices [24]. There are several CGE models that can be used for different purposes. The Global Trade Analysis Project is a global network of researchers and policy makers conducting quantitative analysis of international policy issues which developed CGE models for bioeconomy such as Mirage and Indirect Land-Use Changes (ILUC). More specifically, the purpose of Mirage is to assess impacts of the biobased economy including biofuels and land modules, the impact of Common Agricultural Policy, household-level impacts biofuels and land-use changes [25]. ILUC on the other hand allows to perform quantitative analysis of international economic policy, climate policy, employment, etc [26].

Modular Applied GeNeral Equilibrium Tool (MAGNET) is a global general equilibrium model with modular structure and has several key benefits for modelling bioeconomy including in the development of the agricultural market, biomass usage for energy, food sector, land supply, land transfer, feed or fertilizer requirement, agricultural activities, labour market, and non-agricultural sector [27]. The aim of this model is to detect the changes in agro-food demand activities.

Partial equilibrium also referred as optimization is another approach used for bioeconomy modelling. One of the first partial equilibrium models developed in 1990s on topic of bioeconomy is The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model [28]. IMPACT consists of several modules that describe demand commodity market with log-linear supply and demand and is used to assess changes in agricultural sector and potential yields on international and even global level [29]. Similarly, Global Biosphere Management Model (GLOBIOM) is used for assessment of trade-offs among land use and ecosystem services in agricultural, bioenergy, forestry sectors [30].

Hybrid models combine several different aforementioned models, e.g., Integrated Model to Assess the Global Environment (IMAGE) and Technology Hybridized Environmental-economic Model with Integrated Scenarios (THEMIS). Both models are used for modelling long term scenarios but have distinct criteria and properties. IMAGE is an integrated biopsychical assessment model combining MAGNET and IMPACT models for environmental impact assessment [31]. THEMIS is used for environmental and sustainability assessment to study the potential effect of global sustainable development strategies [32], [33].

Several papers [34], [35] report about interconnecting energy sector consumption and conversion technologies with other sectors through The Market Allocation-Energy Flow Optimization Model System (TIMES). The model allows integrated assessment socioeconomic, energy, and environmental issues based on partial equilibrium [36]. The main benefit of using the TIMES model finding the least-cost options through a dynamic simulation for various technologies [37]. Mostly TIMES is used to simplify the complex assessment of technologies for carbon mitigation and other energy-related problems [38], and the scope model mainly addresses the environmental emissions, materials, or energy systems and allows to perform the analysis over longer terms [39].

Developed TIMES model for energy sector of Latvia includes information about resource prices, amount, GDP, technological data in the transportation, industry, commercial, residential, and agricultural sectors [40]. Biomass is an important alternative energy source in Latvia [41], [42] and also must be considered together with the potential developments for conversion of lignocellulosic biomass into value-added products [43]. Accordingly, TIMES model currently is most appropriate choice for linking biorefinery technologies with energy

technologies in a single empirical tool able to find optimal value-performance paths for bioresources towards circular economy.

3. METHODOLOGY

3.1. Goal and Scope of the Study

The goal of this study is to develop an appropriate tool for analysis of bioresource added value increase in agricultural, forestry and fisheries, as well contributing to favouring the development of respective economic and scientific sectors. Proposed hypothesis is that faster development of the bioeconomy (by at least 15 %) and the value of the use of bio-resources (by at least 30 %) can be achieved at the national level by implementing decisions that consider the transdisciplinary of the bioeconomy.

Historically, the development towards bioeconomy started with high emphasis on bioenergy and now is moving towards technological and material and knowledge aspect. One of the most recognized methods is TIMES for energy modelling. Therefore, in this study TIMES model is adapted for bioeconomy modelling, which would allow in the future to combine biorefineries with energy sector and determine the priorities and optimal solutions for bioresource use. The choice for proposed method is based on several aspects:

1. Method allows to capture in mid to long term time scale;
2. Besides biomass flows also can include the technological aspects of biorefineries;
3. Optimization model allowing to select optimal scenario for bioeconomy development.

For purpose of the study, 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. The proof of model concept and the hypothesis is tested trough case study on fisheries sector of Latvia.

3.2. Model Structure and Boundaries

The model boundaries are defined according to classification of TIMES model components. The components included are technologies, commodities, commodity flows and scenarios (Fig. 1).

Technologies component in TIMES represents technological processes that transform one type of commodities into another (identified as conversion in Fig. 1). 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).

Commodities are defined as bioresource carriers, materials, products, and monetary flows. These commodities in the model are outputs or inputs of technology (process). Commodity flows are entering the processes and are turning into other commodities in the process output (for example, the production of food from fish). In this case, flows are biomass flows and measured in thousand tones or tones, dependent on modelling scale. The consumption of commodities can be understood also as a process component, which has not output commodity. The consumption of commodities is determined in the model by demand per end-sector use.

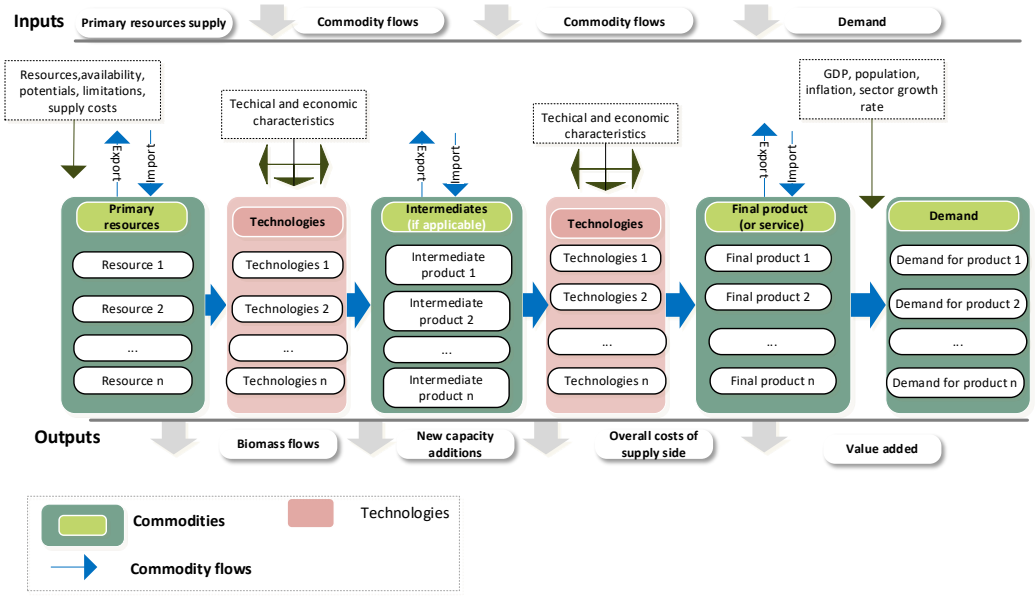


Fig. 1. Structure of the TIMES-BVM model for national bioresource optimization model.

Data for TIMES-BVM is collected from Central statistics bureau (CSB), Eurostat, Joint Research Centre (JRC) databases, companies' data, and literature. The input parameters used in the model and their reference units are given in Table 1.

TABLE.1. INPUT DATA FOR TIMES-BVM

Component	**Input parameter**	**Input measures or units**
Primary resources supply	Supply type	Domestic harvest/ import
	Reserves Cumulative Value	Thousand tons, Tt
	Cost	Euro/Tt
	Annual production	Thousand tons, Tt
	Limitations	Upper/lower
	Flow	Input/output commodity
Conversion (existing and new technologies)	Flow	Input/output commodity
	Existing Installed Capacity	Thousand tons annually, Tta
	Efficiency	0–1
	Utilization factor	0–1
	Investment cost	Euro/Tta
	Lifetime	years
	Fixed operational and maintenance costs	Euro/Tt
	Added value	Euro/Tt
	Limitations	Upper/lower
Conversion (only new technologies)	Investment costs	Euro/Tt
	Technology starting time	year
	Installed Capacity	Thousand tons annually, Tta
Demand	Demand value (for each modelling year)	Tt

For purpose of TIMES-BVM the added value of product is identified as factor costs, and is defined as the gross income of biorefineries (including salaries) for operating activities after adjusting for operating subsidies and indirect taxes. It is an indicator in the domain of structural business statistics taken from JRC database.

The input data for demand of final product or sector in the model is determined by forecast based on regression analysis for target year 2030. In this case forecasting is done prior before running the model. GDP, population, sector growth rate is selected as independent variables and the demand for final product as dependent variable in multiple regression analysis.

3.3. Case Study and Scenario Analysis

The selected modelling approach uses optimization to find the least cost solution in order to reach the target set. Bioeconomy value optimization with the developed model is performed in reference to the base scenario by applying changes in policy measures and adding new and more efficient technologies. During the optimization TIMES-BVM determines the least-cost strategy using supply – side technologies and biomass to cover the final bioproduct demand from the end-use sector models.

The approach for scenario analysis used in this study is known as backcasting – this method starts with defining a desirable future and then working backward to identify the set and amount of products necessary to reach the specified future targets. Such an approach can include analysis of different paths suitable to reach the targets, which are presented as different scenarios. The target values set in this study are indicated in Table 2.

TABLE 2. TIMES-BVM SCENARIOS FOR FISHERIES SECTOR

Scenario	Target value I	Technologies	Simulation period
Base scenario	Base value added	Existing technologies	2015–2030
Scenario 1 [Trout]	Demand for base value added +30 %	New technologies for production of trout from 2020	2015–2030
Scenario 2 [Cod]	Demand for base value added +30 %	New technologies for production of cod from 2020	2015–2030
Scenario 3 [Collagen]	Demand for base value added +30 %	New technologies for by-product bio refinery adding collagen production from 2020	2015–2030
Aggregated scenario	Demand for base value added +30 %	New technologies from scenario 1, 2 and 3 from 2020	2015–2030

Base scenario includes use of existing technologies in biorefineries for period 2015 to 2030 and the demand for final products determined by forecast. The defined base scenario is limited to the availability of input data and does not consider the cost of existing technology refurbishment until 2030. The hypothesis foresees increase by 30 % in for bioresource value by 2030 (compared to the value in 2015). The increase of 30 % is considered to be very high target and reaching this target in 2030 means having a rapid growth for bioeconomy and bioresource value. Thus, four alternative scenarios for technology development are tested under the optimization target +30 % increase in bioresource value added:

1. First scenario is production of trout in aquacultures;
2. Second scenario is cod production in aquacultures;
3. Third scenario is better use of byproducts – by producing collagen from fish skins that comes from fish processing as by-products and the rest of by-products amount is used to produce fish meal and fish oil;
4. Aggregated scenario considers all the technologies form scenario 1, 2 and 3.

Alternative scenarios in addition to base scenario setting consider optional new technologies from 2020 for production of products with higher added value (e.g., trout, cod, collagen). When target for added value increase by 30 % is set for 2030 in TIMES-BVM, the results of simulation would reflect the optimal solution for reaching this target by applying available technologies within the defined boundaries of model components.

4. Results and Proof of Concept

4.1. Model Structure for Fisheries

The developed bioresource value optimization model structure for fisheries is shown in Fig. 2 and consists of four main stages: primary resources, intermediates, final product, and end use sector. In between different processes are defined: primary resource supply contains resources (domestic, import), availability and limitations, potential yield, potential resources or land, and supply costs. There can be one or several conversion paths, depending on process described, for each conversion resource flow should be indicated and technical and economic characteristics included.

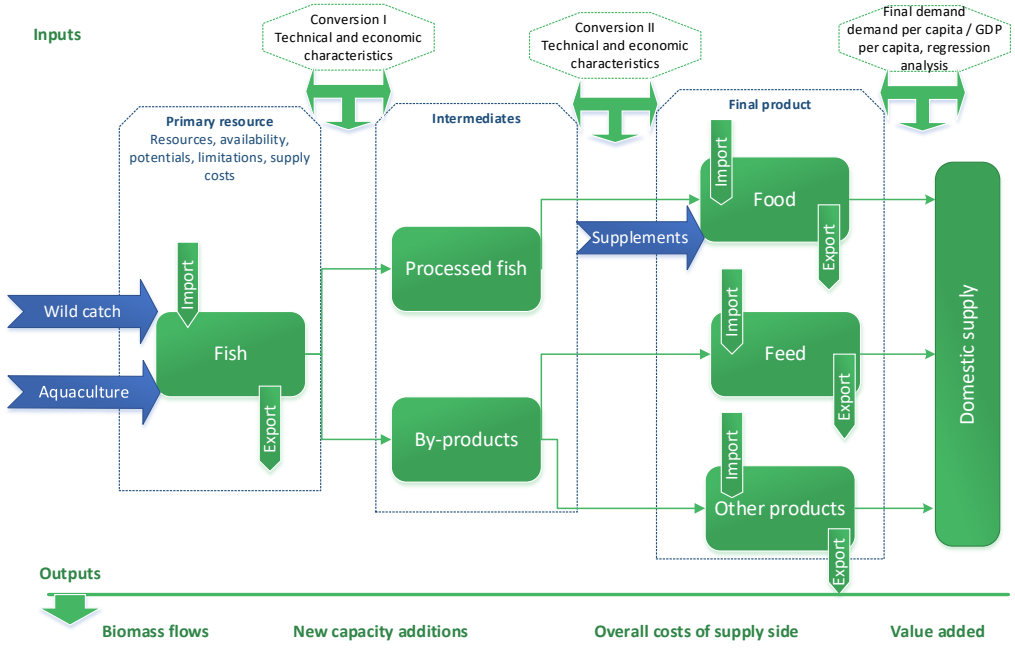


Fig. 2. Generic bioresource optimization model structure for fisheries.

Structure showed on Fig. 2 is based on the current fisheries sector in Latvia where the main sources of fish resources come from wild catch (also known as capture fisheries) and aquaculture. Within fish processing, the main stream of fish goes to production of food; the rest part of fish (by-products) are used to produce fish feed (fish meal) and other products (fish oil) that are later used as animal feed. Additionally, import and export of fish, food, feed and other products are also included in the model.

4.2. Results of Baseline Scenario

The results of baseline scenario represent the basic flows taken from statistics and used as input data for TIMES-BVM model. Sankey diagram is used for bioresource flow visualization in grey colour and the commodities in green colour. Fig. 3 shows bioresource flows in base scenario for simulation year 2015 with fixed amount for commodity input parameters to present historical view of fisheries sector. The results show most of fish in form of primary resource is obtained from wild catch, followed by imports, and a small amount of fish is supplied form aquaculture. The results of model for 2015 show that there is also an additional fish of unknown origin not reported in statistics. The fish of unknown origin is used by model to fill the gap in mass balance occurring between supply and demand reported in statistics, considering the efficiency of current technologies for fish processing.

In Latvia the most common fish products are canned fish, as well as smoked and salted fish. Unnecessary fish parts also called as fish waste or fish processing by-products are used to produce fish meal and fish oil that are further used as feed for animals.



Fig. 3. Sankey diagram for bioresource flows of base scenario in 2015.

The main flows of final fish products in 2015 are food for domestic supply and export, followed by domestic supply of feed and export of feed. Supplements are added in biorefineries to the fish products for food and have a large share in the final food product mass. Process of fish preparation for food has by-products, from which other fish products like feed and oil are produced. Productions losses for other products are accounted to loss of mass due to evaporation of water in assigned technological processing. Fish oil has a negligible amount compared in final product flow compared to food and feed.

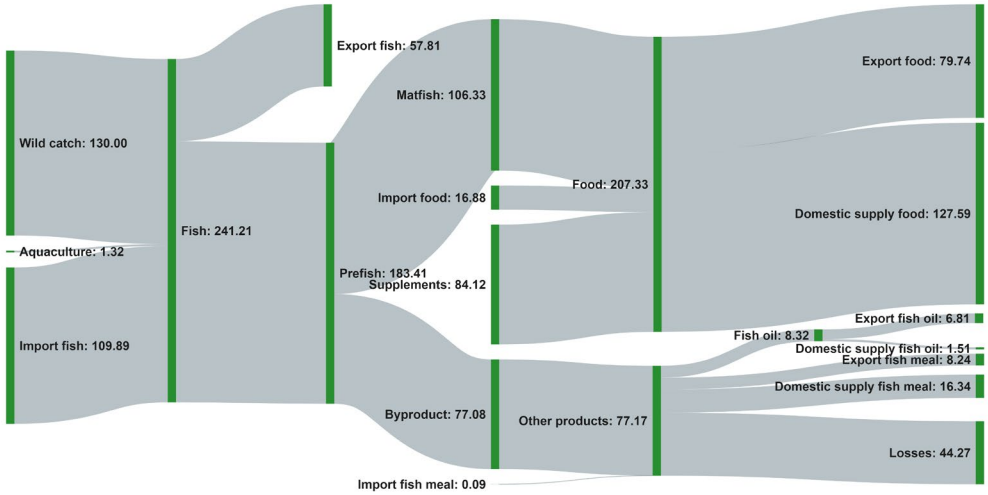


Fig. 4. Sankey diagram for bioresource flows of base scenario in 2030.

Similarly, as for 2015, historical input data also was used in model for years 2017 and 2019 without fixed commodity amounts. Only upper and lower boundaries for interpolation towards the target year 2030 are set not to exceed fisheries wild catch limits, because resource constraints are strictly defined in fisheries sector. Figure 4 shows results for commodity flows of base scenario in 2030. The main changes in comparison to 2015 are found for fish food production as the demand for fish food is increased two times (based on forecast). The demand for feed and other products slightly decreased. There is no fish of unknown origin in 2030 compared to the results for year 2015. The demand is covered mainly by wild catch and import. Only a small amount of demand is covered by aquacultures, because it is more expensive technology then wild catch and import.

4.3. Results of Alternative Scenarios

Additionally, to the base scenario, four alternative scenarios are used in TIMES-BVM for case study of fisheries. Results of alternative scenarios with new technologies available after 2020 are compared to base scenario in terms of added value in 2030 of fisheries and shown in Fig. 5. Highest added value in all scenarios is for food production from fish resources, and in all scenarios, demand is met for food supplies. Target for year 2030 is set as 30 % increase in added value compared to base scenario. Results of each scenario separately show that added value is achieved by adding new technology and boundaries considered in model are appropriate.

In Scenario 1, trout production in aquacultures is added from optional available technologies, to fulfil the set target for added value. The amount of by-products produced in scenario 1 is the same as in base scenario.

In Scenario 2, new technology production of cod in aquacultures is added to reach the added value target.

In Scenario 3, new technology replaces existing by-product use (production of fish oil and fish meal) by creating added value from the production of collagen. In this case, collagen is coming from the same byproduct flow as fish oil, fish feed, because they are made within one biorefinery. Therefore, the added value is summed for all three of the products.

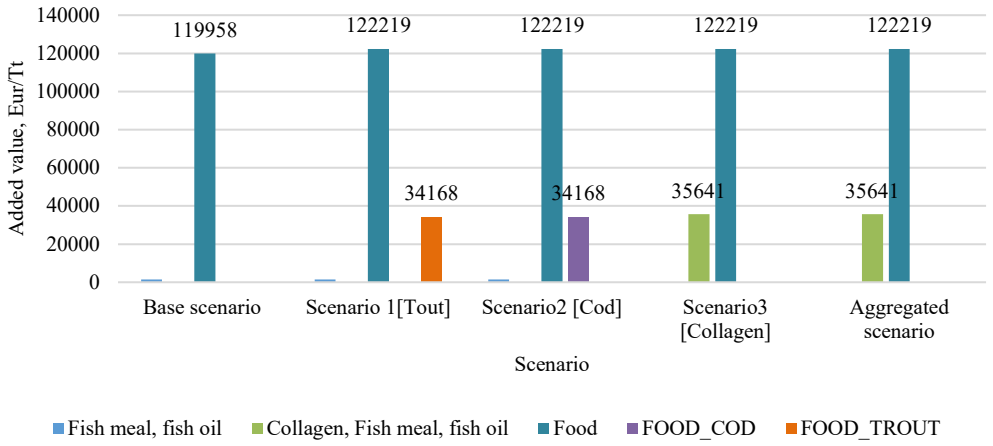


Fig. 5. Scenario analysis for new technologies in fisheries sector in Latvia, year 2030.

Finally, looking at aggregated scenario at all new technologies together in, the case of third scenario and biorefinery proves to be the best alternative to reach added value target with lower costs. The results of bioresource flows for aggregated scenario year 2030 are shown in Fig. 6.

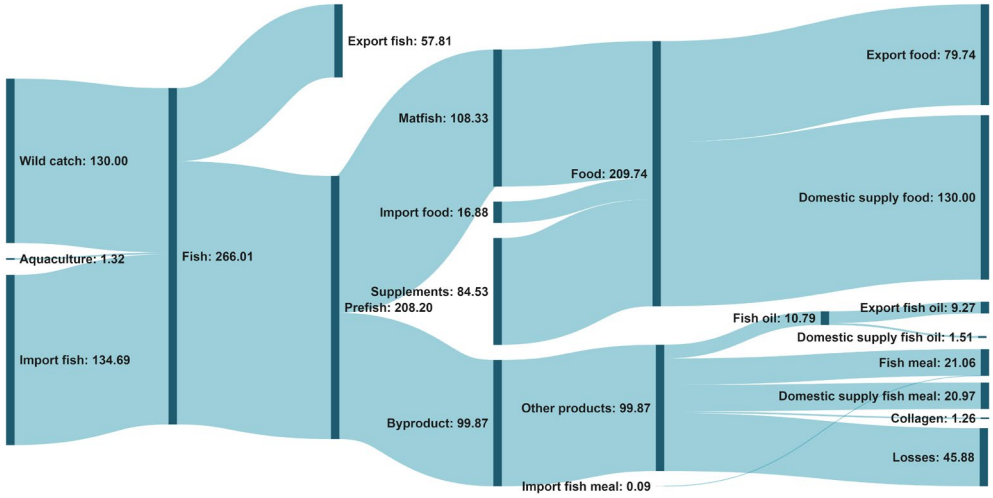


Fig. 6. Best alternative scenario modelling bioresource flow for 2030.

Collagen amount produced in Scenario 3 and aggregated scenario is rather small, only 1.26 thousand tonnes. However, this amount is enough to reach the added value target because collagen is natural polymer widely used in pharmaceutical products and nutritional supplement and has much higher added value other products of fisheries.

4.4. Cost Analysis of Scenarios

Comparison of the scenarios by annual fixed and maintenance costs for applied technologies (see Fig. 7) shows that Scenario 2 has the highest annual fixed and maintenance costs because of implementation new cod production technologies. According to results, the best alternative is Scenario 3, which considers collagen production via biorefinery, followed by Scenario 1 with trout production in aquacultures.

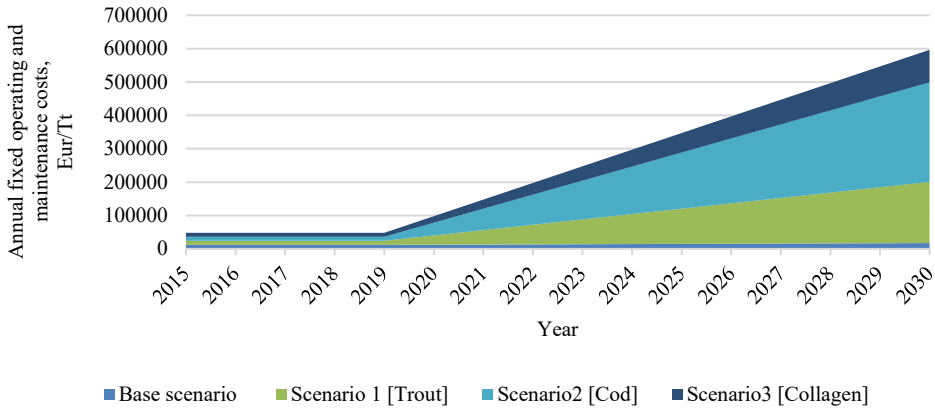


Fig. 7. Annual fixed and maintenance costs of defined scenarios.

Total costs of scenarios are examined and shown in Fig. 8(a) and Fig. 8(b). Production of cod in Scenario 2 has the highest overall cost, whereas costs for Scenarios with trout and collagen production are significantly lower.

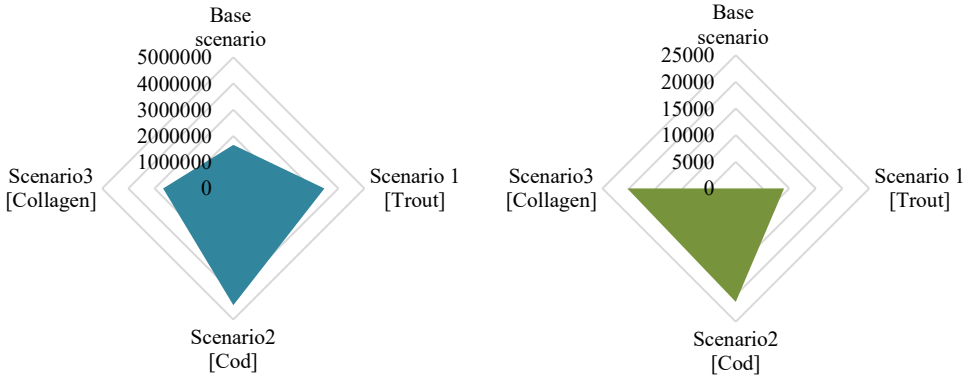


Fig. 8. a) Total costs, thousand EUR; b) Investment costs, thousand EUR.

Although the investment cost for collagen is as high as for cod production, collagen is the most viable scenario, because total costs are lower due to the existing byproduct flow in biorefinery. In base scenario, by-product share between feed and other products is 0.66 for feed and 0.34 for oil, and in new technology of production of collagen share of the process is 0.635 for feed, 0.327 for oil and 0.038 for collagen. Collagen uses a small amount from all by-products but at the same time has a very high added value, which consequently is reflected as most effective way to reach the added value target for 2030.

5. CONCLUSION

The complexity for development sustainable bioeconomy strategies lies within the large number of factors that are influencing bioeconomy sectors agriculture, fisheries, forestry. The factors include availability of technologies and resource, costs for operation of biorefineries, imports and exports, and finally the demand for products. To understand the potential pathways for bioeconomy development, these factors are analysed through a bioresource value optimization model TIMES-BVM.

Literature review of modelling tools used for bioresource value optimization showed that there is a variety of choice among existing tools for analysis of bioeconomy. Based on this review TIMES is found to be most the appropriate tool to support decision-making process in which it is important to provide detailed information on technologies and resources both on demand and supply sides. The model helps to find best supply-demand equilibrium scenarios within the given set of technology costs and resource limits on national level based on linear optimization. The created bioresource optimization model structure is customized according to available statistics from national and EU databases and reflects the multidimensionality of sustainability pillars through environmental, economic, and social criteria.

Case study on fisheries helped to prove the concept of TIMES-BVM as tool for bioresource added value optimization. With this tool is possible to model different scenarios and find most appropriate pathways that policy makers and industries should strive for in order to ensure higher added value from local resources, their sustainable use and economically viable solutions.

The future research with TIMES-BVM model should focus on improvements such as adding more flows of specific fish species, including more new technologies and scenarios, use of potential aquatic bioresources (e.g. algae, seaweeds), and modelling in regional scales. Another perspective lies towards transdisciplinary application of TIMES-BVM by linking the bioeconomy to energy sector model for development of common sustainability scenario, as these sectors have a strong interdependency within the case of Latvia. This however would also require new arrangements and coordination between representatives of research and development sector, public officials, experts of agriculture and other biorefineries.

ACKNOWLEDGMENT

This work was supported by the Latvian Council of Science, project "Bioresources Value Model (BVM)", grant No. lzp-2018/1-0426.

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