Environmental and Climate Technologies
2022, vol. 26, no. 1, pp. 1221–1233
https://doi.org/10.2478/rtuect-2022-0092
https://content.sciendo.com

Bioeconomy in the Shade of Green Deal: The System Dynamic Approach

Kristiana DOLGE[1], Girts BOHVALOVS[2], Vladimirs KIRSANOVS[3*], Andra BLUMBERGA[4], Dagnija BLUMBERGA[5]

[1–5]*Institute of Energy Systems and Environment, Faculty of Electrical and Environmental Engineering, Riga Technical University, Azenes street 12/K1, LV-1048, Riga, Latvia*

***Abstract* – At the end of 2019, the European Commission launched a new growth strategy called 'The European Green Deal' (GD), which aims to 'transform the European Union (EU) into a fair and prosperous society with a modern, resource-efficient a competitive economy with no net greenhouse gas emissions in 2050 and where economic growth is decoupled from resource use'. This study present developed system dynamic (SD) tool for determining bioeconomy development until 2030 and impact of different GD strategy activities on achieved progress. The bioeconomy index the created and used to measure bioeconomy progress for all scenarios. The optimal scenario was identified between reaching climate goals and adding value to the agricultural, forestry and fisheries resources.**

***Keywords* – Bioeconomy; bioeconomy index; Green Deal; indicators; system dynamics**

1. INTRODUCTION

1.1. System Dynamics

System dynamics is a methodology and mathematical modelling technique for understanding the nonlinear behaviour of complex systems over time [1]. The theory of SD is based on the study of causal relationships and the underlying structure of the system with the help of stocks and flows. This means that by analysing the structure of the system, a deeper understanding of the causes of the system behavior is formed, which allows to better address the problematic behavior of the observed system [2]. Rumeser *et al.* [3] proposes that the main limitation to the SD approach could be mental model perception to different audiences.

Stocks and flows are the building blocks of SD models. Stocks are the foundation of any system [4], and they are accumulating over the model time framework [2]. Stock change rate per time unit is called a flow, and the accumulation of the stocks is the result of all stock inflows minus the stock outflows. Fig. 1 left side shows a simplified model of the production inventory (a stock). This stock is increased by production rate (inflow) and reduced by sales rate (outflow). The right side of Fig. 1 shows feedback loops, also called causal loop diagrams. A feedback loop is a chain of causal links, where the level of a stock influences a flow, which in turn will change the stock. Causal links are positive (+) or negative (–). Positive links indicate that variables change in the same direction. Negative links indicate the opposite. Loops can be reinforcing (R) or balancing (B). In reinforcing loops all causal links are positive or consist of an even number of negative causal links. Balancing loops consist of

* Corresponding author.
E-mail address: vladimirs.kirsanovs@rtu.lv

©2022 Author(s). This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

negative causal links that are odd numbers [5]. Reinforcing loop R1 shows that an increase in production rate increases the number of inventory units, increasing the sales rate, increasing investments. A delay mark has been added from investment in production to production capacity, indicating that investments do not result in instantaneous production capacity increase. As capacity increases production rate increases. Balancing loop B1 shows the relation between production rate and available resources. As the production rate increases depletion rate increases, resulting in a reduced amount of resources and production rate. Balancing loop B2 shows that an increase in inventory increases the sales rate, but an increase in sales rate reduces inventory.

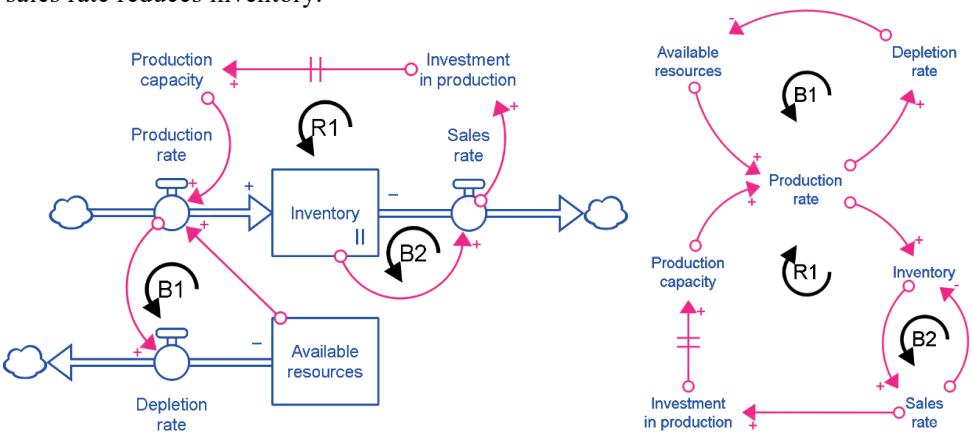

Fig. 1. Example of stock and flow model, and feedback loop diagram.

1.2. System Dynamics Application in Bioeconomy

SD methodology has been applied to various problems related to bioeconomy and biotechonomy. Blumberga *et al.* [6] created and verified the structure of a generic framework model for a biotechonomic sectors that had been applied to the forestry birch-derived products. Azis *et al.* [7] found that forest biotechonomic sectors can indicate significant improvements to the prospect of high-added value economic growth in Latvia and that it should have a lower impact on climate and environment with more efficient usage of resources [8]. Gravelsins *et al.* [9] analysed economic feasibility of 3 different bio-products from wood. Economic feasibility could be increased by expanding the production process with other co-products from leftovers. Runge *et al.* [10] analysed fisheries bio-products and how the study of innovative technologies and co-operation with scientific institutions can lead to high-added value products. Musango *et al.* [11] developed SD for South Africa analysing the impact of investment allocation scenarios on the transition towards a green economy.

1.3. The Essence of the Bioeconomy, Its Role in the EU and Latvia

Satisfaction of demand and increase in production can be met in two ways: by increasing land yields or by increasing the land area cultivated with crops for food or biofuel production. Both of these solutions have environmental costs [12]. However, bioeconomy offers innovative solutions in technology and policy regarding natural resources. Bioeconomy refers to economic activity involving the use of biotechnology and biomass in the production of goods, services, or energy [13]. EU bioeconomy objectives is to ensure food and nutrition security, manage natural resources sustainably, reduce dependence on non-renewable,

unsustainable resources, limit and adapt to climate change, strengthen European competitiveness and create jobs [14]. For Latvia in 2015 bioeconomy sectors amounted to 54 % of the added value of all manufacturing sectors. Development of bioeconomy in Latvia would result in economic development and employment, spatial development in rural areas, and sustainability of surrounding environment [15].

This study aims to investigate the development of bioeconomy at the national level and find an optimal solution between reaching climate goals and adding value to the agricultural forestry and fisheries resources. The hypothesis has been proposed that by being aware of interdisciplinary interactions and making sustainable decisions to achieve the GD goals, it is possible to secure bioeconomy development at least 10 % over the next 10 years. The hypothesis will be validated or rejected by a SD model comparing the baseline (representing the current bioeconomy situation) with different development scenarios and their impact on future bioeconomy development, where the key variables will be the quantifiable value of bioenergy utilization, tools used and GHG emissions. The result of the SD model will be quantified as an bioeconomy index at the national level scale.

2. METHODOLOGY

2.1. Description of Selected Approach

A mathematical model of bioeconomy sector was created using SD approach. SD based is a 'white box' modeling method, where the model structure is transparent to all users, mathematical relationships are available and they are used to explain the results of model simulations. The model was developed based on data from scientific publications and scientific studies, as well as information provided by recognized industry experts and statistic data. The developed model considers three main sectors of the bioeconomy in Latvia: agriculture, forestry, and fisheries. The most important raw materials of bioresources were identified based on statistical data about raw material the amount of raw materials available in Latvia, as well as the importance of these raw materials and the products produced from them to the country's gross domestic product, as well as products that are currently produced or have the opportunity to be produced from these raw materials (see Fig. 2). Selection of produced product depends from economical aspects.

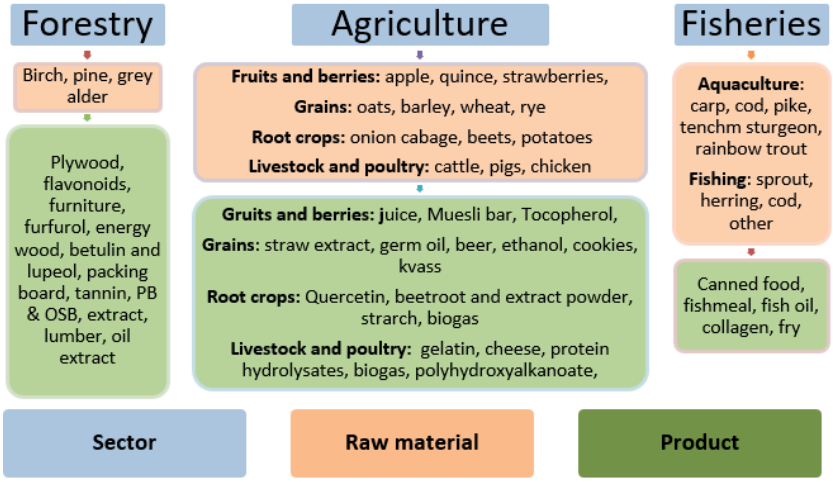

Fig. 2. Bioeconomy sectors, raw materials and products at SD model.

Considering the guidelines, aims, and objectives of the Green Agreement, the model includes some of the tools that are relevant to this strategy. As a result, the SD model serves as a tool to determine the impact of the EU's Green Agreement strategy on the development of the bioeconomy at a national level. They make it possible to find the most effective solution between achieving climate goals and adding value to agricultural, forestry and fisheries resources.

To analyse the impact of the included tools and assess the development of the bioeconomy in general, the SD model includes an index of bioeconomy development. The previously developed bioeconomy index [16] was revised and adapted to the structure of the SD model and available output data. To calculate the bioeconomy index in Latvia, an innovative method was chosen, which includes a combination of multi-criteria decision analysis (MCDA) and fuzzy cognitive map (FCM) analysis methods [17]. FCM is method to present relations between the different system elements. Bioeconomy is complex system effected by many factors. Many factors have mutual connection and influence. FCM method was used to draw bioeconomy development map with influencing parameters and the significance of their connection. FCM map was developed based on 20 expert using Mental Modeler tool. Experts identify 196 variables which were aggregated into 7 indicators representing 6 different dimensions from the created FCM. Based on expert developed connection the weight of each indicator were founded. The weight of selected FCM indicators were normalized using the classical MCDA methodology. The higher is normalized factor weight the higher is significance of impact indicator. Indicators in the SD model were assigned a weight equal to the determined weight using the FCM method and normalized weight (see Table 1).

TABLE1. INDICATORS OF THE BIOECONOMY INDEX IN THE SD MODEL

Indicator	Description	Unit	Category (FCM)	Weight (FCM)	Normalized factor weight
Added value to turnover ratio	Added value/turnover	EUR/EUR	Macroeconomics	0.78	0.14
Location quotient	Number of people employed/total number of people employed	people/ people	Social	0.71	0.13
Labour productivity	Turnover/number of people employed	EUR/people	Macroeconomics	0.78	0.14
GHG Emissions	Value added/generated GHG	EUR/t	Emissions	0.33	0.06
Energy	Value added/energy consumed	EUR/MWh	R&D	1.04	0.19
Resource	Value added/used raw materials	EUR/t	Resources	1.03	0.19
Generated waste	Value added/generated waste	EUR/t	Waste	0.72	0.13

2.2. Description of SD Model

The developed SD model continues previous research and developed model described in [6]. At the same time, the newly developed model has been significantly supplemented. The previous model was improved, but its structure was simplified while increasing the amount of output. Input data were updated to newer ones, previous assumptions in the model were revised and the limits of possibilities were replaced with real data. The fisheries sector was added to the existing agricultural and forestry sectors. Fisheries include 2 sub-models named fishing production, and aquaculture growth and production. For all of the model's

subsidies for production chains, carbon dioxide (CO_2) tax, investment subsidies, and production cost reduction policy has been added. For each model graphical function related to required workforce decrease per capacity increase has been changed from extrapolated to continuous e.g. as capacity increases from the initial value the production process becomes more automated, and fewer workers are required for production. In the case of extrapolated function workforce could result in negative values. Therefore, switching to continuous function prevents the workforce from resulting in negative values as the workforce required per capacity stays constant after capacity in operation reaches 30 times larger value than the initial capacity in operation. The developed bioeconomy SD model framework consists of 7 interrelated modules. Each sub-model follows a similar structure to the general framework with differences related to raw material production of sub-models.

Production of derivatives.

The raw material from bio-production is sold to the market as it is. Although, fractions of certain raw materials can go through additional processing. For example, apples can be sold after harvesting, but derivates from apples can be produced such as cider, muesli bar, and tocopherol creating a production chain, but such chain will take place only if it is profitable. Derivative production will add value to the products, over and beyond the value of the raw material. For derivative production capital investments and labor are required.

Capital investments.

The profitability of a certain product is indicative of the volume to be produced and thus the investments made in that production. Investments are going to be made according to the production goal, which depends on the raw material available.

Turnover, added value, and profit.

Turnover gained from selling the product is determined by the volume sold and the price of the product. All product prices are assumed constant. The turnover must justify the costs associated with production. These costs include capital costs, labor costs, energy costs, and other costs (including raw material costs). From capital costs, profit, and labor costs added value is obtained.

Labour.

The required workforce is determined by the production capacity in operation. The more land is used for production, the more workforce is required for production. Labor annual salary reflects the level of education to be held by the workforce and is set constant.

Research and development.

Research and development increase the effectiveness of production enabling product improvements. Resulting in higher raw material production yield and reduced energy consumption per production unit.

2.1.1. Forestry Model

Bio-product production is not possible without land available. Reinforcing loop R1 in Fig. 3 shows that an increase in forest land area increases the reforestation rate. Therefore, increasing forest land area even more. As forest area increases absorbed CO_2 amount increases. Also, raw material production increases, but as more raw material is produced, a larger forest area must be harvested resulting in the reduced forest area. Creating a balancing loop B2. Raw material can be sold without refining for a lower cost, but the goal of bioeconomy is to create high added-value products. Therefore, a fraction of raw materials go through the refining process resulting in derivative production. The larger the raw material amount is available the larger production capacity for derivatives is possible. Production capacity requires raw materials to produce derivatives reducing the raw material amount available and creating balancing loop B1. Larger production capacity increases investment

required for production, which results in increased capital costs, also increase in production energy consumption and labor required. An increase in production costs results in decreased profit. At the same time, production capacity increases the volume of derivates produced and production profits may be justified by the unit value of derivates. The larger the production volume and unit derivate value, the larger turnover and the profit obtained from production. Research and development play a vital role in the reduction of production energy consumption. Research increases potential technologies available for production and development using the latest available technologies creating a balancing loop B3.

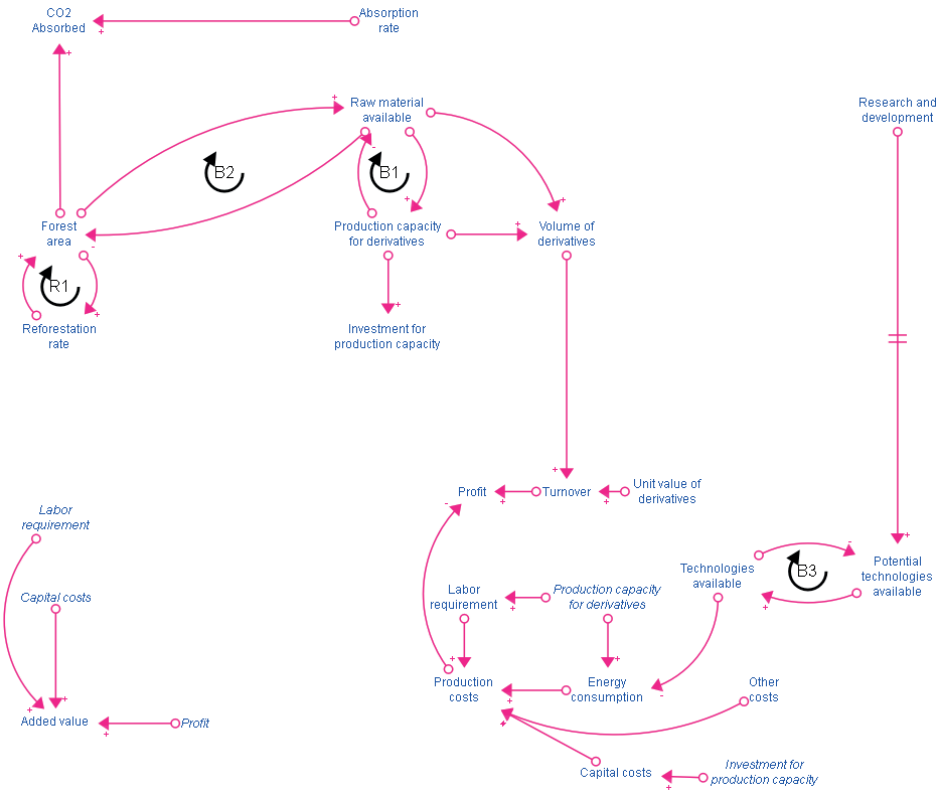

Fig. 3. Forestry causal loop diagram.

2.1.2. Agriculture Model

Reinforcing loop R1 in Fig. 4 shows that the larger the amount of raw material is available, the larger volume of derivatives can be obtained. Each derivative has its value, the larger the value and production volume, the larger turnover resulting in increased profit. As profit increases, the total profit per land area increases, and more land is allocated to the production chain increasing raw material production even more. Land allocation fraction increases after time delay since agriculture producers can't adjust to market changes instantly. Increase in raw material production results in the increase of production capacity for derivatives. Production capacity requires raw materials for production, therefore reducing the amount of raw material available and production capacity for derivatives resulting in balancing loop B1. For raw material, production land area is required and the more land area is used the less area

is available for further allocation resulting in balancing loop B2. Seen from reinforcing loop R1 land area increases the profit from production chains, but at the same time in balancing loop B3, land increase decreases profit per used land area. These loop interaction results in a wave-like behavior in production chains due to delay in land allocation based on profit per used land area. Balancing loop B4 shows the interaction between current land yield and potential land yield. As the current land yield increases the potential for increase decreases. Research and development increase potential land yield and potential technologies available. Technologies available deplete the potential technologies available stock increasing technologies available creating a balancing loop B5.

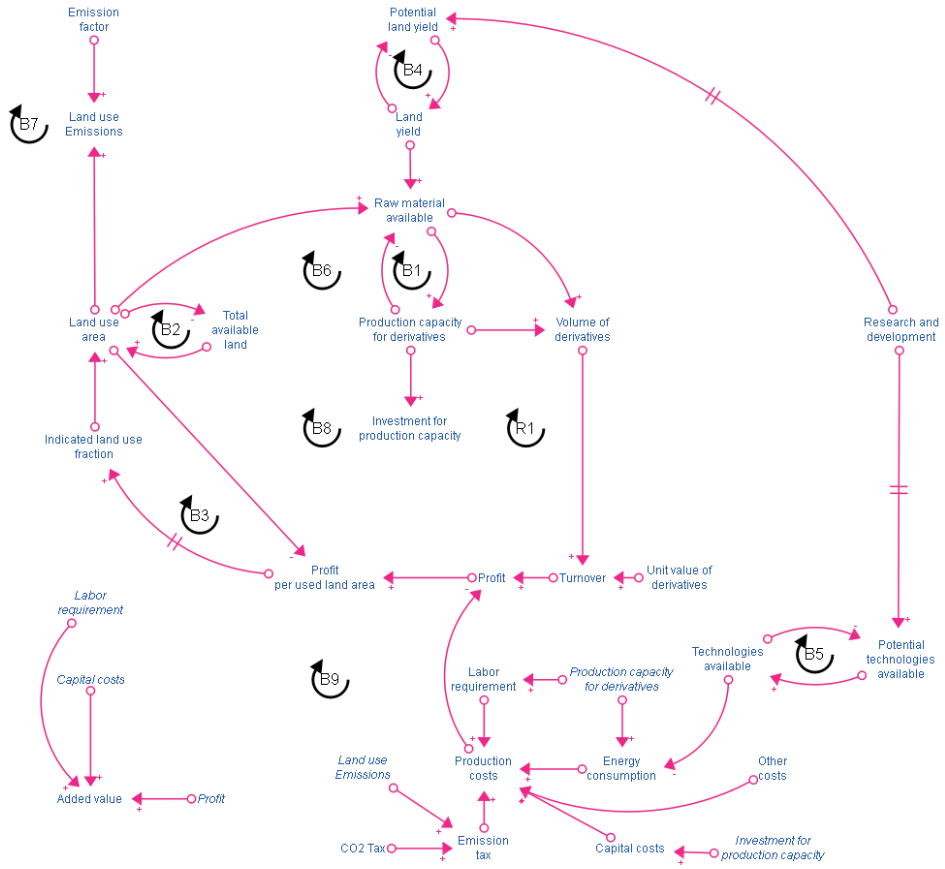

Fig. 4. Causal loop diagram of agriculture bio-production.

Balancing loop B6 shows the interaction of investment for production capacity to profit. As production capacity for derivatives increases investment for production capacity increases that resulting in increased capital costs and production costs. An increase in production costs decreases profit. Therefore, reducing profit per used land area, land allocation, land available, raw material available, production capacity for derivates, and investment for production capacity. Balancing loop B7 shows how emissions tax affects the entire system. Increased land usage results in increased emissions and emission tax paid. Emissions tax results in increased production reduced profit, profit per used land area, allocated land fraction, land

area used, and reduction in emissions. Balancing loops B8 and B9 are similar to loop B6. Instead of investment for production capacity, the production capacity results in increased energy consumption and labor requirement resulting in higher production costs, lower profit, etc. Biomethane production has been added in comparison of the previous model.

2.1.3. Fisheries Model

The aquaculture bio-production causal loop diagram is similar to agriculture Fig. 5. The main differences are that instead of land area pool volumes are used and land yield is removed.

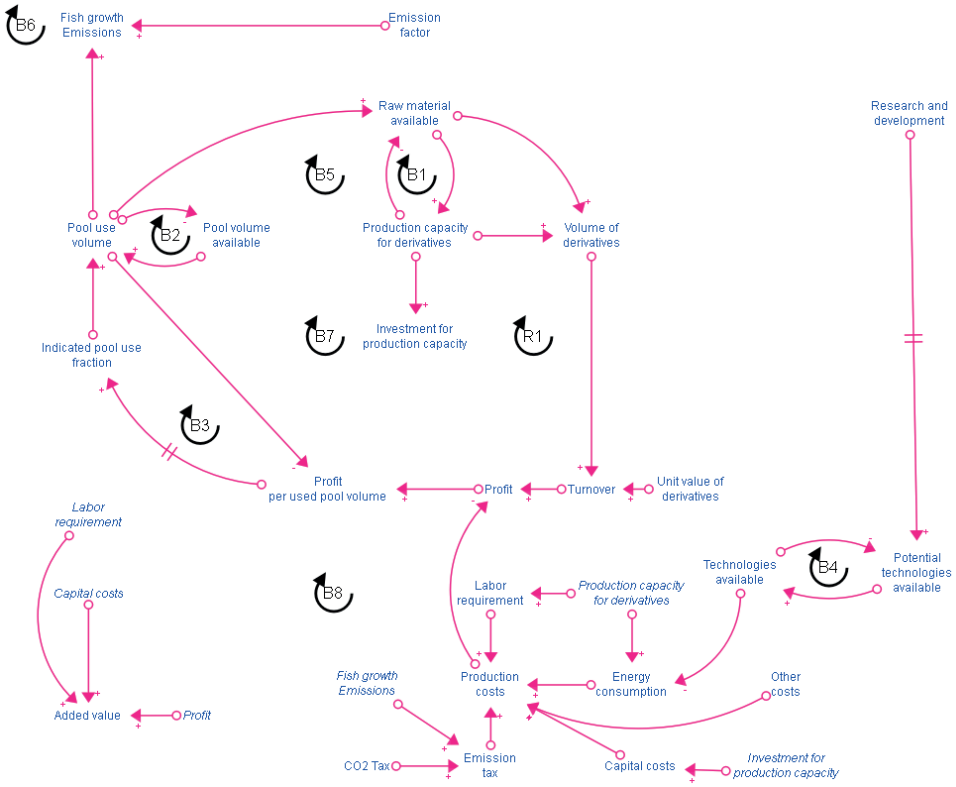

Fig. 5. Aquaculture causal loop diagram.

The fishing sub-model starts with the annual fishing rate Fig. 6. Depending on the annual fishing rate raw material is used production and to increase production capacity for derivatives, which depletes raw material available stock creating balancing feedback loop B1. Similar to other models increased production volume results in larger turnover and profit. An increase in production capacity increases production costs and reduction of profit. Research and development reduce production costs by the increase of potential production technology availability. Fisheries SD model structure includes 10 section:

1. Capital investment sector;
2. Finance sector;
3. Aquaculture emissions from fish farming;
4. Aquaculture pool use;

5. Production sector;
6. Production capacity sector;
7. Fish farming and fishing;
8. Labor requirement for the production sector;
9. Production emergy;
10. Production energy consumption sector.

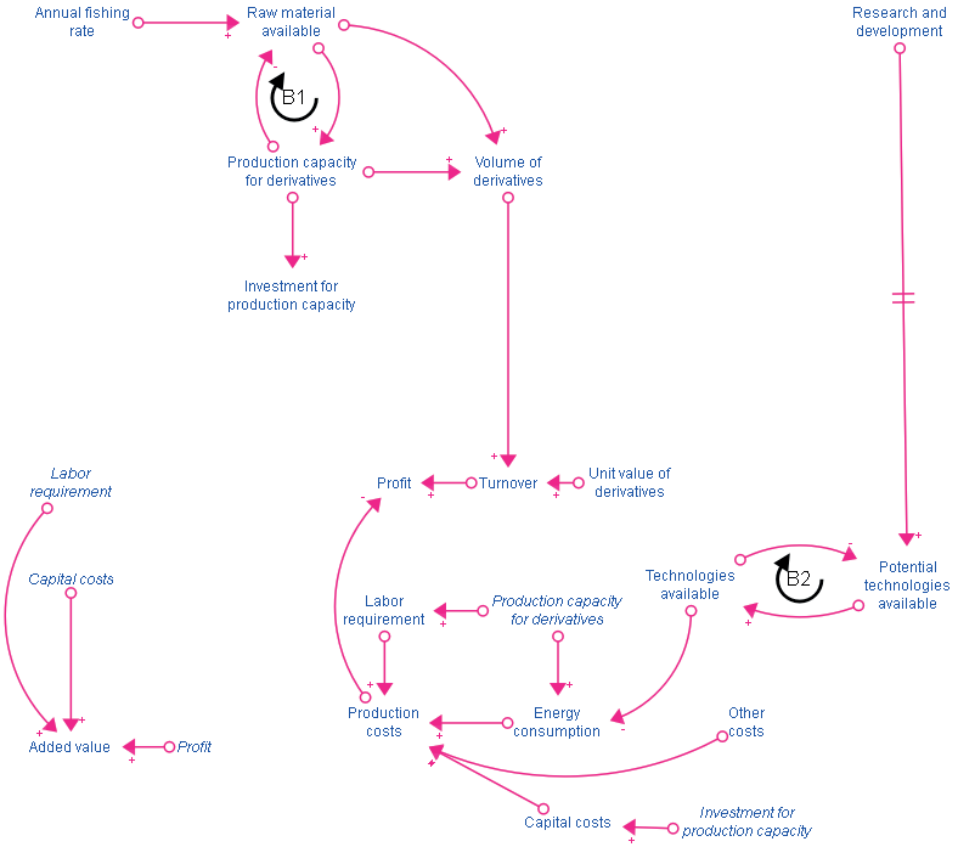

Fig. 6. Fishing causal loop diagram.

2.3. Scenarios

A literature review and a detailed analysis of the Green Agreement identified key instruments in line with the drive to achieve climate neutrality and added value. It was identified three policy instruments that have been thoroughly evaluated using developed bioeconomy index. Each of these tools was analysed separately, although an additional scenario was considered when all three tools were used simultaneously:

- Baseline scenario. Describes the current situation in the bioeconomy sector and the projected development without the use of additional support mechanisms;
- Alternative scenario 1 provides support for industry, tax incentives, investment attraction and other bonuses. The scenario takes the form of a reduction in all costs by 40 % in form of subsidies.

- Alternative scenario 2 takes the form of a reduction in the consumption of energy and other raw materials due to increased production efficiency, which in turn reduces production costs by 75 % in form of production cost decrease.
- Alternative scenario 3 takes the form of a tax on one tonne of CO_2 produced and an increase in the tax rate until 100 EUR/t and increase rate 10 %.
- Alternative scenario 4 is a combination of all the above mentioned instruments: subsidies (20 %) + production cost decrease (50 %) + CO_2 tax 50 EUR/t

3. RESULTS

Bioeconomy development was simulated using 5 selected scenarios. Table 2 present value of 7 selected bioeconomy indicators for each scenario in the year 2030. The ratio of added value to turnover in the baseline scenario increases from 0.74 to 0.89 between 2016 and 2030. The highest indicator value was achieved in Scenario 4 and is 0.97, an increase of 8.6 %. The location quotient growth trend in the baseline scenario is similar to the employment growth trend. The value of this indicator increases from 0.11 to 0.22 in the period from 2016 to 2030. The maximum value is reached in Scenario 4 and is 0.22. The increase compared to the baseline Scenario is only 1.5 %. The laboratory productivity indicator reflects the relationship between turnover and the number of people employed in the bioeconomy. In the baseline scenario, the value of this indicator increases from 43.7 thousand EUR/person to 124 thousand EUR/person in the period from 2016 to 2030. The highest indicator will be achieved in Scenario 4 and amounts to 134 thousand EUR/person, which is an increase of 8.1 %.

TABLE 2. BIOECONOMY INDICATOR VALUE AT SELECTED SCENARIOS

	Baseline scenario	**Alternative scenario 1**	**Alternative scenario 2**	**Alternative scenario 3**	**Alternative scenario 4**
Added value to turnover ratio	0.89	0.96	0.94	0.91	0.97
Location quotient	0.22	0.22	0.22	0.22	0.22
Labor productivity	124 487	133 374	131 233	125 390	134 616
GHG Emissions	5801	7024	6776	5810	7201
Energy productivity	3420	4009	3844	3516	4100
Resource productivity	111	122	121	116	125
Generated waste	668	721	776	677	761

The GHG emission indicator shows the difference between added value and GHG emission. In the baseline Scenario, the value of this indicator increases from 0.9 to 5.8 EUR/thousand tons in the period from 2016 to 2030. The energy productivity indicator reflects the difference between value added and energy consumption in the bioeconomy sector. The highest indicator will be reached in Scenario 4 and amounts to 4.1 EUR/thousand tons, which is an increase of 19.9 %. The resource productivity indicator shows the relationship between added value and resource consumption. The generated waste indicator shows the difference between the added value and the amount of waste produced. Compared to the indicators discussed above, there is an inverse trend here. Significant fluctuations in the value of the index in the period from 2016 to 2018 are related to the impact of the applied policy instruments. As production capacity increases and added value increases not immediately, but with a delay. Overall, this indicator shows one of the most significant discrepancies between the bioeconomy and the GD. Added value is important in the bioeconomy, but one of the guiding principles of the GD

strategy is to reduce waste. Therefore it is important to be proactive and to make significant progress in reducing landfills to achieve both directions.

Taking into consideration the changes in the values of all the above indicators, the bioeconomy index was calculated. It is important that in the baseline scenario, even without the use of additional tools, the value of this indicator increases from 0.17 to 0.60 in the period from 2016 to 2030 (see Fig. 7) statistical data. The highest indicator in 2030 will be reached in Scenario 4, where the index is 0.69 (an increase of 15.8 %).

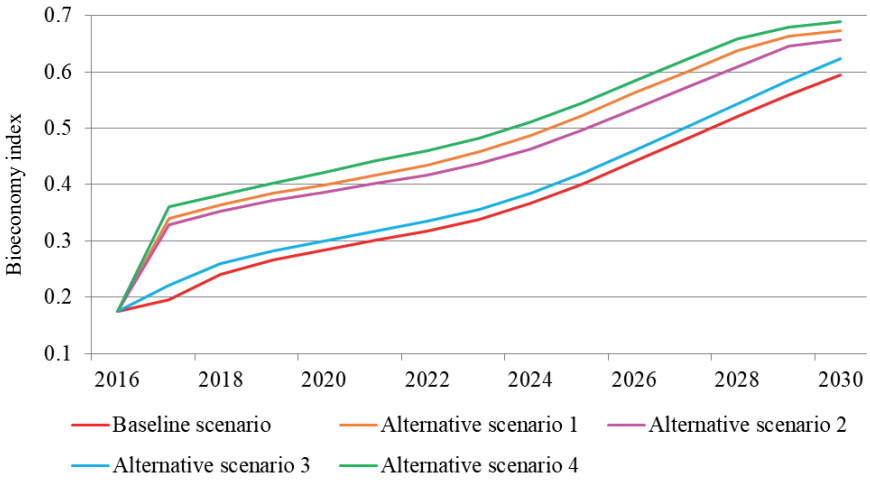

Fig. 7. Bioeconomy index changes for simulated scenarios

The value of the bioeconomy index for each scenario in 2030 is shown in Fig. 8. The figure shows the proportion of each of the seven indicators to achieve the current value. Indicators such as resource productivity and energy productivity have the greatest impact on the final value. The indicators added value to turnover ratio, labor productivity, and location quotient play a very important role. The role of GHG emissions and generated waste indicators is low.

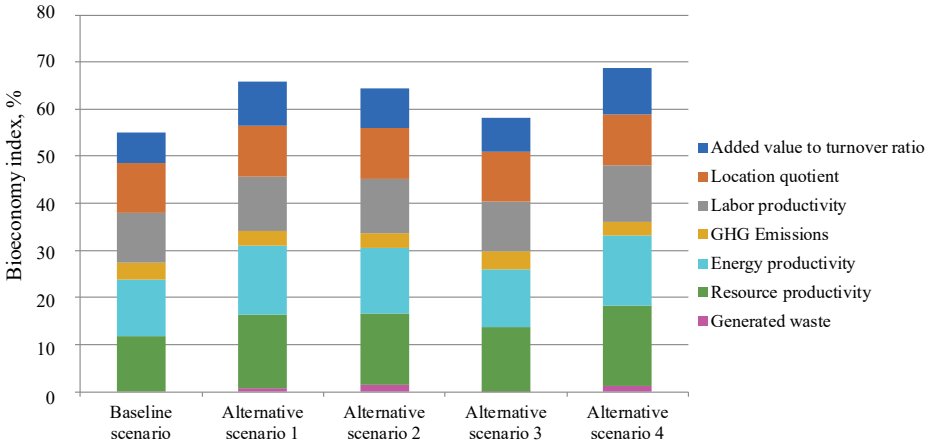

Fig. 8. Bioeconomy index for simulated scenarios at 2030 by indicator weight.

4. CONCLUSION

The SD model which represents the Latvian bioeconomy sector was developed. The model includes three main bioeconomy sectors: agriculture, forestry, and fisheries. Several policy instruments linked to the tasks and directions of the GD were added to the model. The development of bioeconomy sector until 2030 depending on selected policy instruments and sceneries is represented in the model as bioeconomy index based on 7 indicators.

The obtained results confirm that with the help of various policy or support mechanisms it is possible to achieve the development of the bioeconomy above 10 % in comparison with the baseline scenario. Assessing the results of the alternative scenarios, it can be concluded that the best results were achieved by combining all three policy instruments: subsidies, production cost reduction, and CO_2 tax. In this case, the instruments complement each other by working on different aspects of the bioeconomy.

There is a strong link between the GD and the bioeconomy. Sustainable and circular bioeconomy development helps to address all objectives set out by the EGD and vice versa. The aim of the GD is to ensure no net emissions of greenhouse gases by 2050. The EGD includes key policy areas: clean energy, sustainable industry, building and renovation, farm to fork, eliminating pollution, sustainable mobility, biodiversity, and sustainable finance. These policy areas are largely in line with the European strategy for the development of the bioeconomy. The bioeconomy does not appear to be a separate line in the GD, but in fact the idea and principle of the bioeconomy are clearly visible in several of these elements.

ACKNOWLEDGEMENT

This research is funded by the Latvian Council of Science, project Bioeconomy in the shade of Green Deal (BioDeal), project No. lzp-2020/2-0321.

REFERENCES

[1] System Dynamics Society. What is System Dynamics? [Online]. [Accessed: 15.03.2022]. Available: https://systemdynamics.org/what-is-system-dynamics/

[2] Blumberga A., *et al.* Sistēmdinamika vides inženierzinātņu studentiem (System dynamics for environmental engineering students.). Riga: Riga Technical University, 2010. (in Latvian)

[3] Rumeser D., Emsley M. Key Challenges of System Dynamics Implementation in Project Management. *Proc. - Soc. Behav. Sci.* 2016:230:22–30. https://doi.org/10.1016/j.sbspro.2016.09.004

[4] Meadows D. H. Thinking in Systems. Chelsea: Chelsea Green Publishing, 2008.

[5] Blumberga A., *et al.* Sistēmdinamika biotehonomikas modelēšanai (System dynamics for modeling biotechonomics). Riga: Riga Technical University, 2016. (in Latvian)

[6] Blumberga A., *et al.* System dynamics model of a biotechonomy. *J. Clean. Prod.* 2018:172:4018–4032. https://doi.org/10.1016/j.jclepro.2017.03.132

[7] Azis R., Blumberga A., Bazbauers G. The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: A system dynamics approach. *Energy Procedia* 2017:128:32–37. https://doi.org/10.1016/j.egypro.2017.09.011

[8] Azis R., Blumberga A., Bazbauers G. The role of forest biotechonomy industry in the macroeconomic development model of the national economy of Latvia: An in-depth insight and results. *Energy Procedia* 2018:147:25–33. https://doi.org/10.1016/j.egypro.2018.07.029

[9] Gravelsins A., *et al.* Economic analysis of wood products: System dynamics approach. *Energy Procedia* 2017:128:431–436. https://doi.org/10.1016/j.egypro.2017.09.023

[10] Runge K., Blumberga A., Blumberga D. Bioeconomy Growth in Latvia. System-dynamics Model for High-value Added Products in Fisheries. *Energy Procedia* 2017:113:339–345. https://doi.org/10.1016/j.egypro.2017.04.075

[11] Musango J. K., Brent A. C., Bassi A. M. Modelling the transition towards a green economy in South Africa. *Technol. Forecast. Soc. Change* 2014:87:257–273. https://doi.org/10.1016/j.techfore.2013.12.022

[12] Wesseler J., Spielman D. J., Demont M. The future of governance in the global bioeconomy: Policy, regulation, and investment challenges for the biotechnology and bioenergy sectors. *AgBioForum* 2010:13(4):288–290.

[13] Smyth S. J., *et al.* Sustainability and the bioeconomy: Synthesis of Key themes from the 15th ICABR conference. *AgBioForum* 2011:14(3):180–186.
[14] European Commission. Bioeconomy strategy [Online]. [Accessed 15.03.2022]. Available: https://research-and-innovation.ec.europa.eu/research-area/environment/oceans-and-seas/bioeconomy-strategy_en
[15] Ministry of Agriculture Republic of Latvia. Latvian Bioeconomy Strategy 2030. Riga: ZM, 2018.
[16] Kubule A., *et al.* Country Level Sustainability Evaluation of Bioeconomy. *Proceedings of the 28th European Biomass Conference and Exhibition* 2020:745–751. https://doi.org/10.5071/28thEUBCE2020-4AV.1.4
[17] Kirsanovs V., *et al.* Bioeconomy sustainability index: a fuzzy cognitive mapping approach. *Environmental and Climate Technologies*, 2022 (in press).