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BIORESOURCE TRANSITION TOWARDS SUSTAINABLE BIOECONOMY

Doctoral Thesis

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ANNOTATION

Doctoral thesis "Bioresource transition towards sustainable bioeconomy", author Lauma Žihare, scientific supervisor Professor Dagnija Blumberga, *Dr.habil.sc.ing*. consultant leading researcher Anna Kubule, *Dr.sc.ing* is carried out in Riga Technical University, Institute of Energy Systems and Environment.

The aim of the Doctoral Thesis is to develop an integrative methodology for the assessment towards sustainable bioeconomy through bioresource transition assessments using top-down and bottom-up approaches, transdisciplinarity analysis, and underused biomass potential use. The main contribution of the Thesis ascends from an integrated multi-level approach, that takes into account technical, socio-economic, environmental and market aspects. In order to reach the aims of the Thesis, the fallowing tasks were set:

1) to assess bioeconomy understanding and create consolidated view on bioeconomy;
2) to assess disciplinarity approaches towards sustainable bioeconomy;
3) to identify bioeconomy affecting factors, their interlinkages and propose possible nexus assessments;
4) to identify factor characteristic indicators;
5) to create factor nexus benchmark;
6) to create methodology for bioeconomy efficiency measures;
7) to identify potential bioresources that are underused and asses their potential value towards effective resource transition proposing new or existing bioresource value chains and their priorities;
8) to provide innovation transfer with market and economic analysis framework to determine if innovative bio-based product or technology would have the potential of entering market successfully;
9) to validate bio-resource potential with experimental analysis.

The research presents several novel approaches not previously used in bioeconomy. In this thesis three main levels of bioresource transition assessment have been presented with methodology and case studies to approbate those methodologies.

The outcome obtained in this Thesis extends the existing knowledge in bioeconomy for multi-level approach with transdisciplinary analysis. The results are beneficial for national and local and sectoral level governmental authorities, stakeholders and scientists.

ANOTĀCIJA

Promocijas darba “Bioresursu pāreja uz ilgtspējīgu bioekonomiku” autore Lauma Žihare, zinātniskā vadītāja profesore Dagnija Blumberga, *Dr.habil.sc.ing.* konsultante vadošā pētniece Anna Kubule, *Dr.sc.ing* tika veikts Rīgas Tehniskajā universitātē, Elektrotehnikas un vides inženierzinātņu fakultātē.

Promocijas darba mērķis ir izstrādāt integrējošu metodoloģiju ilgtspējīgas bioekonomikas novērtēšanai, izmantojot bioresursu pārejas novērtējumus, izmantojot augšupējas un augšupējas pieejas, transdisciplināru analīzi un nepietiekami izmantoto biomasas potenciālu. Darba galvenais ieguldījums izriet no integrētas daudzlīmeņu pieejas, kurā ņemti vērā tehniskie, sociālekonomiskie, vides un tirgus aspekti.

Darba mērķu sasniegšanai ir izvirzīti šādi uzdevumi:

1) Novērtēt bioekonomikas izpratni un izveidot konsolidētu skatījumu uz bioekonomiku
2) Izvērtēt disciplinaritātes pieejas ilgtspējīgai bioekonomikai
3) Identificēt bioekonomiku ietekmējošos faktorus, to savstarpējās saites un ierosināt iespējamos saistību novērtējumus
4) noteikt faktoru raksturlielumus
5) Izveidojiet faktoru saistību līmeņatzīmi
6) Izveidot bioekonomikas efektivitātes noteikšanas metodiku
7) Identificēt neizmantotos bioresursus un novērtēt to potenciālo vērtību efektīvai resursu pārejai, ierosinot jaunas vai esošās bioresursu vērtību ķēdes un to prioritātes
8) Nodrošināt inovāciju nodošanu ar tirgus un ekonomiskās analīzes sistēmu, lai noteiktu, vai inovatīvam bioloģiskam produktam vai tehnoloģijai ir potenciāls veiksmīgai komercializācijai
9) Validēt bioresursu potenciālu veicot eksperimentālo analīzi

Pētījums piedāvā vairākas jaunas pieejas, kuras iepriekš nav izmantotas bioekonomikā. Šajā darbā ir aprakstīti trīs galvenie bioresursu pārejas novērtēšanas līmeņi ar metodoloģiju izveidi un gadījumu izpēti, lai aprobētu šīs metodoloģijas.

Šajā darbā iegūtais rezultāts paplašina esošās zināšanas bioekonomikā daudzlīmeņu pieejai ar starpnozaru analīzi. Rezultāti ir labvēlīgi valsts, vietējā un nozaru līmeņa valdības iestādēm, ieinteresētajām personām un zinātniekiem.

ACKNOWLEDGMENT

I would like to express my gratitude to everyone that has supported me during the time of doctoral studies. I sincerely thank my scientific supervisor Professor Dagnija Blumberga and professor Jūlija Gušča who empowered me to start doctoral studies and encouraged to persistently work towards the target. There were a series of doubts and willingness to walk side path and to take more and more into the work of thesis that could exceed the capacity of four years. Professor Dagnija Blumberga and Anna Kubule helped to overcome these doubts and to finish the thesis, so the continuous work can be done by helping others to go this path.

Special thanks to Indra Muižniece for encouragement and long discussions about bioresources and bioeconomy in the start of my path and along the way. For brainstorming and collaboration in several projects that resulted in co-authorship.

Thanks to my colleague Raimonda Soloha and student Ieva Laganovska for interesting work in laboratory.

Special thanks to Krišs Spalviņš for knowledge support and motivation to keep on going and substantive discussions during the road trips to conference and lectures and collaboration in projects.

Thanks to my family for moral support and friends, especially former pentathlon athlete Ieva Siļķe, that managed to prove and to believe my inner and physical strength gaining personal growth with ability to hold more than half a ton in a storm.

“Sometimes nature reflection can be an actual picture. But if you want to change the reflection you have to change the nature.” L.Zihare

CONTENTS

ABBREVIATIONS

EU – European Union
EC – European Commission
UK – United Kingdom
JRC – Joint Research Centre
IAP – Invasive Alien plants
IAS – Invasive Alien species
NPV – net present value
MCDA – multi criteria decision analysis
AHP – Analytical hierarchy process
TOPSIS - The Technique for Order of Preference by Similarity to Ideal Solution
DMC – domestic material consumption
DMI – direct material input
IRR – Internal Rate of Return
NPV – Net Present value
OECD - Organisation for Economic Co-operation and Development
R&D – Research and development
R&I – Research and Innovations
RD&D - Research, development and demonstration
GDP – Gross domestic product
GE – General Electric
SDG - Sustainable Development Goal
TRL - Technological readiness level
CO_2 – carbon dioxide
SO_2 - sulphur dioxide
NOx - nitrogen oxide
ISO - International Organisation for Standardisation
X_{ij} – normalized value (AHP)
A_{ij} – pairwise matrix elements (alternatives)
W_{ij} – *priority vector*
n - *number of alternatives*
n_{ij} – normalized value (TOPSIS)
v_{ij} – is weighted normalized value
d_i^+ - is distance to ideal solution
d_i^- - is distance to negative solution
R_i - relative closeness to the positive ideal solution
I_{act} is the actual value of an indicator (raw data)
I_{min} is the minimim value from the data set of the specific indicator
I_{min} is the maximum value from the specific indicator's data set
$I_{N,ji}^{\pm}$- the normalised value (positive +, or negative -) of individual indicator i for dimension j
$I_{S,j}$ – weighted sub-indicator, in dimension j
W – weight of variable i in dimension j
I_{CSI}- complex index of alternative I
M_a – market attractiveness total score
Z – estimated rating score
k – coefficient
f – number of factors
B_{max} – max rating score
R – relative indicator of product competitive advantages
B – new product score estimation
B_{comp} – strongest competitor score estimation
P - patent indicator: applications to the European Patent Office per million inhabitants
c - gross domestic expenditure on R&D by sector
NMMO - N-methylmorpholine-N-oxide
CAGR - compound annual growth rate
CIS - Commonwealth of Independent States
L1 –lyocell for export market
L2 - lyocell for local market
B1 – bio-oil for export market
B2 bio-oil for local market
X1 – xylitol for export market
DAISIE - Delivering Alien Invasive Species Inventories for Europe
NOBANIS - The European Network on Invasive Alien Species
GISD - Global invasive species database
MedPAN - network of Marine Protected Areas in the Mediterranean
EASIN - European Alien Species Information Network
Sc – *Solidago Canadensis*
Hs – *Heracleum Sosnowkyi*
PPW – potato peel waste
CG – coffee grounds
C - carbon
H - hydrogen
N - nitrogen
S – sulphur
A_d – Ash content, wt% (wt - Wet basis moisture content (designated MW in the text) is described by the percentage equivalent of the ratio of the weight of water (WW) to the total weight of the material (Wt))
m_1 - mass of empty dish, g
m_2 - mass of dish plus the test portion, g
m_3 - mass of dish plus ash, g
M_{ad} - moisture content of the test portion used for determination of ash content, w-% *(after ISO 18122)*
m_1 – mass of the empty dish plus lid, g
m_2 – mass of the dish, lid and test portion before drying, g
m_3 – mass of the dish, lid and test portion after drying, g
Q_a^d - gross calorific value at constant volume, J g^{-1}
m – mass of sample, g
$Q_{N,S}$ - correction of heat, considering formation of nitric acid, J
Q_S - correction of heat, considering formation of sulphuric acid, J
H_0 – gross calorific value of the analysed fuel, J/g
S^d- sulphur content in the analysed sample (on dry basis), %
$Q_{V,gr,d}$ – gross calorific value of dry mass at constant volume, J/g
M_{ad} – moisture content of general analysis sample, wt% *(after ISO 1825)*
$Q_{p,net,d}$ – net calorific value of dry mass at constant pressure, J/g
H^d – hydrogen content in the analysed sample (on dry basis), wt%

CF_0 - initial investments
$CF_{1,2,\ldots n}$ – cash flows
N – period
CF_{NPV} - Cash flow net present value
IRR – internal rate of return
R_t = Net cash flow during single period
i – discount rate
t- time period
WACC - Weighted Average Cost of Capital
PI - Profit index

O^d – oxygen content in the analysed sample (on dry basis), wt%
N^d – nitrogen content in the analysed sample (on dry basis), wt%
$q_{p,net,ar}$ – net calorific value for sample as received at constant pressure, J/g
M_{ar} – total moisture content, wt%

INTRODUCTION

Topicality of the Doctoral Thesis

After rapid fossil economic development an estimation of resource insufficiency is evident. After global economic crisis in 2008, responsive actions by national governments rise, tightening credit markets lead to subsequent increase in borrowing costs that reduces the amount of capital available for investing in biotechnology research and development, that could lead to high-risk start-up firms and cause another global economic crisis. Therefore, it has become a push towards bioeconomy and necessity for research and infrastructure for alternative energy and sustainable agriculture. Combining resource depletion with climate change mitigation aims bioeconomy share an exponential growth towards more sustainable economy all over the world. A global trend that bases on biological resource use is in the centre of scientific researchers’, policy makers’, different stakeholders’ and society behaviour. However, bioeconomy cannot substitute fossil resources with bioresources to the same extent to ensure the consumption of existing demand. Initial aims towards sustainable European bioeconomy were largely diverted towards bioenergy direction. Updated European bioeconomy strategy emphasizes not only bioenergy, but also creation of products with higher added value.

There are several limitations for bioresource production, therefore a methodology for smart bioresource selection, production and processing should be initialized within different levels of development.

The transition to sustainable bioeconomy with a holistic approach on a global level would benefit national bioeconomy development, climate change mitigation and innovation transfer.

There is still no common international method for determining, measuring, and comparing the extent of bioeconomy sustainability.

Composite indexes have been applied for evaluation of various complex phenomena, e.g. sustainable development, company sustainability [1], biorefinery complexity [2], and rural sustainable development [3], [4]. One of such indicators related to environmental dimension is the eco-innovation index that is used to describe the eco-innovation progress in EU member countries. Eco-innovation index is composed of 16 indicators that are grouped into five major groups: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency, and socio-economic outcomes. Eco-innovation progress is described by the eco-innovation scoreboard [5]. However, there are no studies exclusively regarding composite index for bioeconomy. Like the concept of sustainability, a sustainable bioeconomy must be assessed at several levels: resources, products, companies, industries, national and global based on main pillars of sustainability (environmental, social, and economic).

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The Aim and Tasks of the Doctoral Thesis

The aim of the Doctoral Thesis is to develop an integrative methodology for the assessment towards sustainable bioeconomy through bioresource transition assessments using top-down and bottom-up approaches, transdisciplinarity analysis, and underused biomass potential use. The main contribution of the Thesis ascends from an integrated multi-level approach, that takes into account technical, socio-economic, environmental and market aspects. Output of the Thesis consists of: the assessment of bioeconomy factor interlinkages that could be further used for composite sustainability index creation and development of bioeconomy effectiveness index that helps to determine how effectively the bioeconomy is developing at a national level; several underused biomass potential use cases for Latvia; technology and product innovation commercialization framework and transdisciplinary market and economic assessment for cases done with collaboration with different stakeholders; experimental analysis for specific case of invasive species application. A case of triple factor nexus is also presented: policy, research and innovations, and technology nexus for European Union countries. As a result, the empirical model presents the mathematical description of policy, research and innovation, and technology link benchmark.

In order to reach the aims of the Thesis, the fallowing tasks were set:

1. to assess bioeconomy understanding and create consolidated view on bioeconomy;
2. to assess disciplinarity approaches towards sustainable bioeconomy;
3. to identify bioeconomy affecting factors, their interlinkages and propose possible nexus assessments;
4. to identify factor characteristic indicators;
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6. to create methodology for bioeconomy efficiency measures;
7. to identify potential bioresources that are underused and asses their potential value towards effective resource transition proposing new or existing bioresource value chains and their priorities;
8. to provide innovation transfer with market and economic analysis framework to determine if innovative bio-based product or technology would have the potential of entering market successfully;
9. to validate bio-resource potential with experimental analysis.

Research Methodology

The research methodology is based on three interconnected parts according to the proposed multi-level approach for assessing bioresource transition to sustainable bioeconomy development, through innovation and a transdisciplinary approach. The research methodology is divided into three main levels that permeate this transition – macro-level, which determines the global trend in economic development (the emphasis in this work is on the European level); meso-level, which is the institutional level; and micro-level, which determines a specific niche, in this case specific bioresources and their potential. Several methods, factor analysis, indicator analysis, benchmarking, triple-helix, and multi-criteria analysis methods have been used in this work.

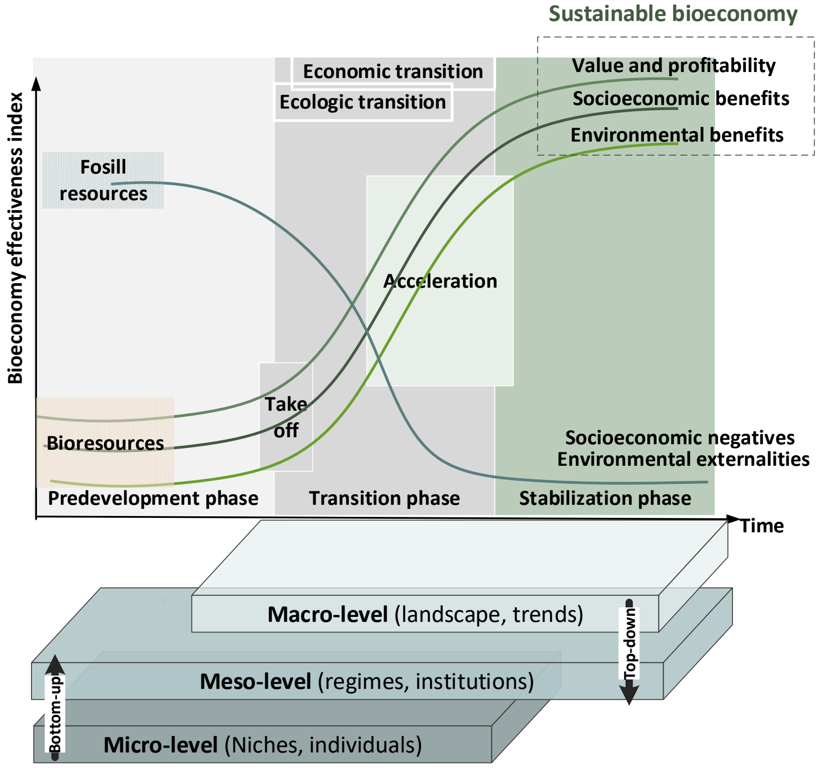


Fig. 1. Generic description of the bioresource transition (author representation)

The aim and the process are shown in Fig. 1, where the main emphasis is on bioresource use promotion towards sustainable bioeconomy, that results in value and profitability, socioeconomic benefits and environmental benefits. The assessment that helps this transition and understanding of situation goes through three levels:

Macro-level (top-down approach) is focused on bioeconomy development assessment based on factor analysis, case of European Union triple factor nexus through indicator approach is applied as case study to determine benchmark. A composite indicator for bioeconomy effectiveness for international comparison is created.

Meso-level focuses on transition phase through innovation transfer framework, market and economic analysis, and transdisciplinary approach, taking into account different stakeholder requirements and opinion.

Micro-level (bottom-up approach) focuses on estimation of potential value of different underused bioresources and management system. This part applies decision analysis and experimental analysis.

Scientific Significance

The Thesis is of high scientific significance in the Latvian and international contexts due to the fact that the investigation and analysis of bioresource transition is a topical research area of bioeconomy development. Three innovative methods have been developed and approbated within this Thesis. The first method is intended for bioeconomy efficiency measurement, the second can be used for innovation transition assessment and the third – for bioresource value assessment. This Thesis can be used as guidelines for further scientific studies towards bioeconomy development and bioresource assessments for bioresource value evaluation with holistic analysis approach.

Practical Significance

The Thesis is of high practical significance in the Latvian and European context. The research results provide a novel multi-level approach, which can provide a significant contribution a) for several bioeconomy stakeholders at national, sectoral, and international level; b) for policy makers in more effective bioeconomy development path determination; c) at a regional level for municipalities with invasive species new management plan and bioresource value notion; d) for entrepreneurs and different stakeholders; e) for society in effective use of resources; f) for scientific and research community in the agricultural and forestry fields who carry out research on related topics and can employ the scientific findings from this project in their further research.

Approbation of the Study

The results of the Doctoral Thesis have been presented at 6 conferences and in 19 scientific publications and 2 monographs.

The research results have been discussed and presented at the following conferences.

1. International scientific conference "EUBCE 2020 28th European Biomass Conference & Exibition", with paper "Country level sustainability evaluation of bioeconomy" 2020, Marseille, France
2. International scientific conference "Biosystems Engineering 2019", paper "A holistic vision of bioeconomy: the concept of transdisciplinarity nexus towards sustainable development" 2019, Tartu, Estonia.
3. International scientific conference "Conference of Environmental and Climate technologies 2019", papers "New vision on invasive alien plant management system", "Obtaining the factors affecting bioeconomy", "Case Study of Aizkraukle Region in Latvia", and "Priorities determination of using bioresources. Case study of *Heracleum sosnowskyi*" 2019, Riga, Latvia.
4. International scientific conference "Conference of Environmental and Climate technologies 2018", papers "Multi criteria analysis for products derived from agro-industrial by-products", "Analytical framework for commercialization of the innovation: case of thermal packaging material" 2018, Riga, Latvia.
5. International scientific conference "Biosystems Engineering 2018", papers "The potential use of invasive plant species as solid biofuel by using binders", "Evaluation of reed biomass use for manufacturing products, taking into account environmental protection requirements" 2018, Tartu, Estonia.
6. International scientific conference "Conference of Environmental and Climate technologies 2017", papers "Bioeconomy mapping indicators and methodology. Case study about forest sector in Latvia", "Market opportunities for cellulose products from combined renewable resources", "Single cell protein production from waste biomass: comparison of various agricultural by-products", "Invasive Species Application in

Bioeconomy. Case Study *Heracleum sosnowskyi* Manden in Latvia", "Carbon storage in wood products", "Methodology for estimation of carbon dioxide storage in bioproducts" 2017, Riga, Latvia.

Scientific publications

1. **Zihare, L.,** Kubule A., Dolge K., Muizniece I., Blumberga D., "Country level sustainability evaluation of bioeconomy", 2020, EUBCE proceedings (submitted).
2. **Zihare, L.,** Kubule, A., Vamza, I., Muizniece, I., Blumberga, D. Bioeconomy triple factor nexus through indicator analysis. *New biotechnology*, 2020 (submitted).
3. **Zihare, L**., Blumberga, D. Bioeconomy investments: market considerations, *Environmental and Climate Technologies*, 2020 (in press). (Scopus, WoS)
4. Muizniece, I., **Zihare L**., Pubule J., & Blumberga D. (2019). Circular Economy and Bioeconomy Interaction Development as Future for Rural Regions. Case Study of Aizkraukle Region in Latvia, *Environmental and Climate Technologies*, *23*(3), Pages 129-146. doi: https://doi.org/10.2478/rtuect-2019-0084 (Scopus, WoS)
5. **Zihare L.,** Muizniece I., & Blumberga, D. (2019). New Vision on Invasive Alien Plant Management System, *Environmental and Climate Technologies*, *23*(2), Pages 166-186. doi: https://doi.org/10.2478/rtuect-2019-0062 (Scopus, WoS)
6. Muizniece I., **Zihare L**., & Blumberga D. (2019). Obtaining the Factors Affecting Bioeconomy, *Environmental and Climate Technologies*, *23*(1), Pages 277-291. doi: https://doi.org/10.2478/rtuect-2019-0018 (Scopus, WoS)
7. **Zihare L.,** Muizniece I. and Blumberga D. A holistic vision of bioeconomy: the concept of transdisciplinarity nexus towards sustainable development *Agronomy Research* 17(5), Pages 2115- 2126, 2019 https://doi.org/10.15159/AR.19.183 (Scopus, WoS)
8. **Zihare L**., Gusca J., Spalvins K., & Blumberga D. (2019). Priorities Determination of Using Bioresources. Case Study of *Heracleum sosnowskyi*, *Environmental and Climate Technologies*, *23*(1), 242-256. doi: https://doi.org/10.2478/rtuect-2019-0016 (Scopus, WoS)
9. **Zihare L.,** Spalvins K., Blumberga D. Multi criteria analysis for products derived from agro-industrial by-products, *Energy Procedia*, Volume 147, 2018, Pages 452-457, https://doi.org/10.1016/j.egypro.2018.07.045 (Scopus, WoS)
10. Spalvins K., **Zihare L**., Blumberga D. Single cell protein production from waste biomass: comparison of various industrial by-products, *Energy Procedia*, Volume 147, 2018, Pages 409-418, https://doi.org/10.1016/j.egypro.2018.07.111 (Scopus, WoS)
11. **Zihare L.,** Soloha R. and Blumberga D. The potential use of invasive plant species as solid biofuel by using binders Agronomy Research 16(3), Pages 923-935, 2018 https://doi.org/10.15159/AR.18.102 (Scopus, WoS)
12. **Zihare L**., Muizniece I., Spalvins K., Blumberga D., Analytical framework for commercialization of the innovation: case of thermal packaging material, *Energy Procedia*, Volume 147, 2018, Pages 374-381, https://doi.org/10.1016/j.egypro.2018.07.106 (Scopus, WoS)
13. Muizniece I., Kazulis V., **Zihare L.**, Lupkina L., Ivanovs K. and Blumberga D., Evaluation of reed biomass use for manufacturing products, taking into account environmental protection requirements, *Agronomy Research* 16(S1), Pages 1124-1132, 2018 https://doi.org/10.15159/AR.18.077 (Scopus, WoS)
14. **Zihare L**., & Blumberga D. (2017). Market Opportunities for Cellulose Products From Combined Renewable Resources, *Environmental and Climate Technologies*, *19*(1), Pages 33-38. doi: https://doi.org/10.1515/rtuect-2017-0003 (Scopus, WoS)

15. **Zihare L**., Blumberga D., Insight into bioeconomy. Solidago canadensis as a valid resource. Brief review, *Energy Procedia*, Volume 128, 2017, Pages 275-280, https://doi.org/10.1016/j.egypro.2017.09.074 (Scopus, WoS)
16. **Zihare L**., Blumberga D., Invasive Species Application in Bioeconomy. Case Study Heracleum sosnowskyi Manden in Latvia, *Energy Procedia*, Volume 113, 2017, Pages 238-243, https://doi.org/10.1016/j.egypro.2017.04.060 (Scopus, WoS)
17. Kalnbalkite A., **Zihare L**., Blumberga D., Methodology for estimation of carbon dioxide storage in bioproducts, *Energy Procedia*, Volume 128, 2017, Pages 533-538, https://doi.org/10.1016/j.egypro.2017.09.002 (Scopus, WoS)
18. Blumberga D., Muizniece I., **Zihare L**., Sniega L., Bioeconomy mapping indicators and methodology. Case study about forest sector in Latvia, *Energy Procedia*, Volume 128, 2017, Pages 363-367, https://doi.org/10.1016/j.egypro.2017.09.053 (Scopus, WoS)
19. Kazulis V., Muizniece I., **Zihare L**., Blumberga D., Carbon storage in wood products, *Energy Procedia*, Volume 128, 2017, Pages 558-563, https://doi.org/10.1016/j.egypro.2017.09.009 (Scopus, WoS)

Monographs

1. Scientific monograph **“**Sustainable Energy Sources”, Barisa, A., Blumberga, A., Grāvelsiņš, A., Rochas, C., Blumberga, D., Dace, E., Vigants, E., Romagnoli, F., Galindoms, G., Vigants, Ģ., Veidenbergs, I., Ziemele, J., Rošā, M., Sarmiņš, R., Kalniņš, S., Prodaņuks, T., Kirsanovs, V. Editor **Lauma Zihare**, RTU Press, 2018, 146 p. ISBN 978-9934-22-017-3.
2. Scientific monograph “Development of Energy Planning in the Local Municipalities of Latvia”, Kamenders, A., Barisa, A., Blumberga, A., Rochas, C., Blumberga, D., Pakere, I., Dzene, I., Burmistre, I., Muižniece, I., Veidenbergs, I., Ziemele, J., Kļavenieks, K., Kašs, K., **Žihare, L**., Sniega, L., Žogla, L., Rošā, M., Kalniņš, S. Riga: RTU Press, 2020, 172 p. ISBN 978-9934-22-062-3.

Structure of the Doctoral Thesis

The Doctoral Thesis is written in English and consists of introduction, 3 chapters, 3 annexes, and references. The introduction looks at the topicality of the work, the aim of the research and general methodology, as well as the importance of the results of the research.

The first chapter is based on overall description of bioeconomy development, bioresource role and holistic framework with transdisciplinary approach for bioeconomy assessment based on literature. This chapter is included only in full thesis not summary.

The second chapter of the Thesis given a description of multi-level methodology applied in research.

The third chapter of the Thesis introduce to the results for all level assessments and case studies.

The conclusions section summarizes the main points of the research.

The Doctoral Thesis consists of 145 pages, 71 images, 18 tables, 25 mathematical formulas and a reference list with 271 literature sources.

1. LITERATURE REVIEW

1.1. Bioeconomy Historical Development

Bioeconomy from scientific perspective

Sustainability has become a global trend that is theoretically sought by all sectors and countries. Another widespread tendency in recent years is the shift towards the use of knowledge-based bio-resources within the economy for the production of higher value-added products, and the subsequent development of the bioeconomy with sustainability objectives in mind [1]. Although the basic principles of the bioeconomy may be considered as an instrument to approach real sustainability, critical views on how truly sustainable the bioeconomy is have been raised in scientific publications [1][2]. Thought there is a general consensus that sustainability should be evaluated on social, economic and environmental levels [3]–[5], there is still is no unanimous view on what should be the sustainability metric criteria for evaluation of sustainable biomass use [4].

Bioeconomy development comes from large base of scientific research, therefore a literature analysis of scientific publications related to bioeconomy has been assessed.

Boolean string of "bioeconomy" or "biobased economy" or "bio-economy" or "bio economy" were performed in timeframe from 1992 -2020.

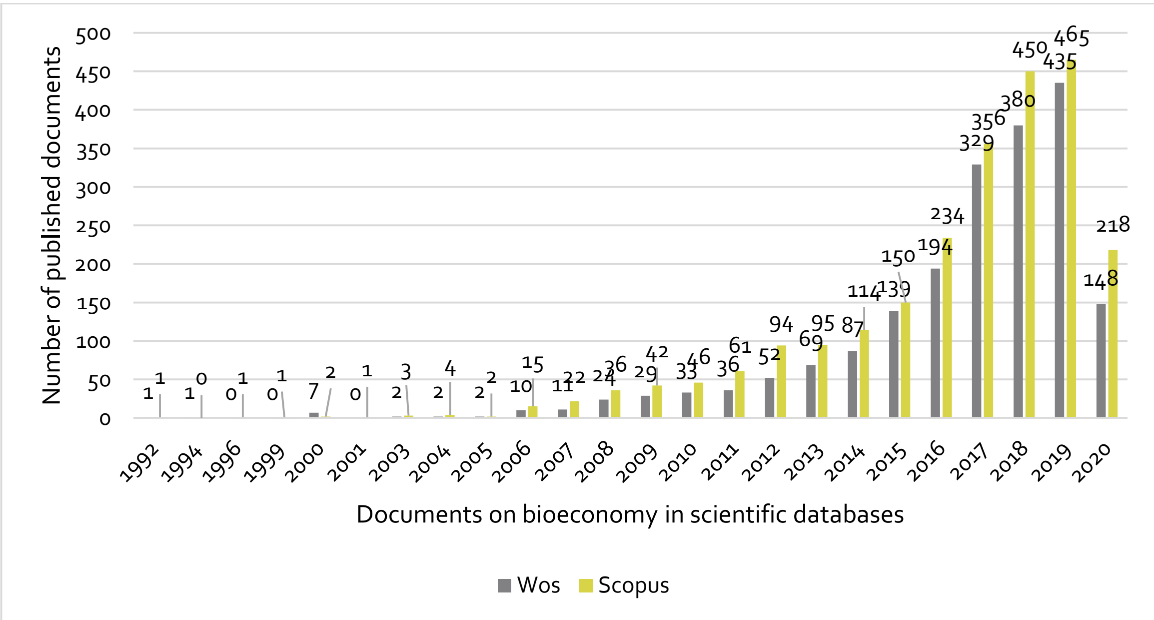


Fig. 1.1. Number of documents per year on bioeconomy topic based on Web of Science data (n=1’991) and Scopus data (n = 2’415)

The results show that Bioeconomy has been developed exponentially after number of articles published in Scopus and Web of science databases. Year 2020 data is incomplete, extracted on April 2020, therefore there is not complete year presented. The bioeconomy take off is seen from year 2006.

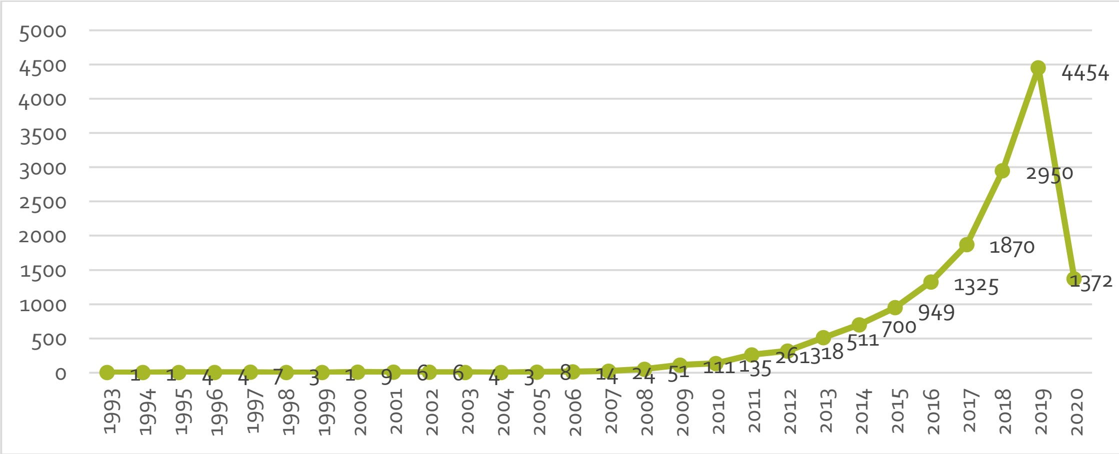


Fig. 1.2. Number of citations per year on bioeconomy topic based on web of science data (n= 15’102 citations)

Amounts if citations show the tendency of research importance, that also has grown exponentially over years 1993-2020 (year 2020 data is till April).

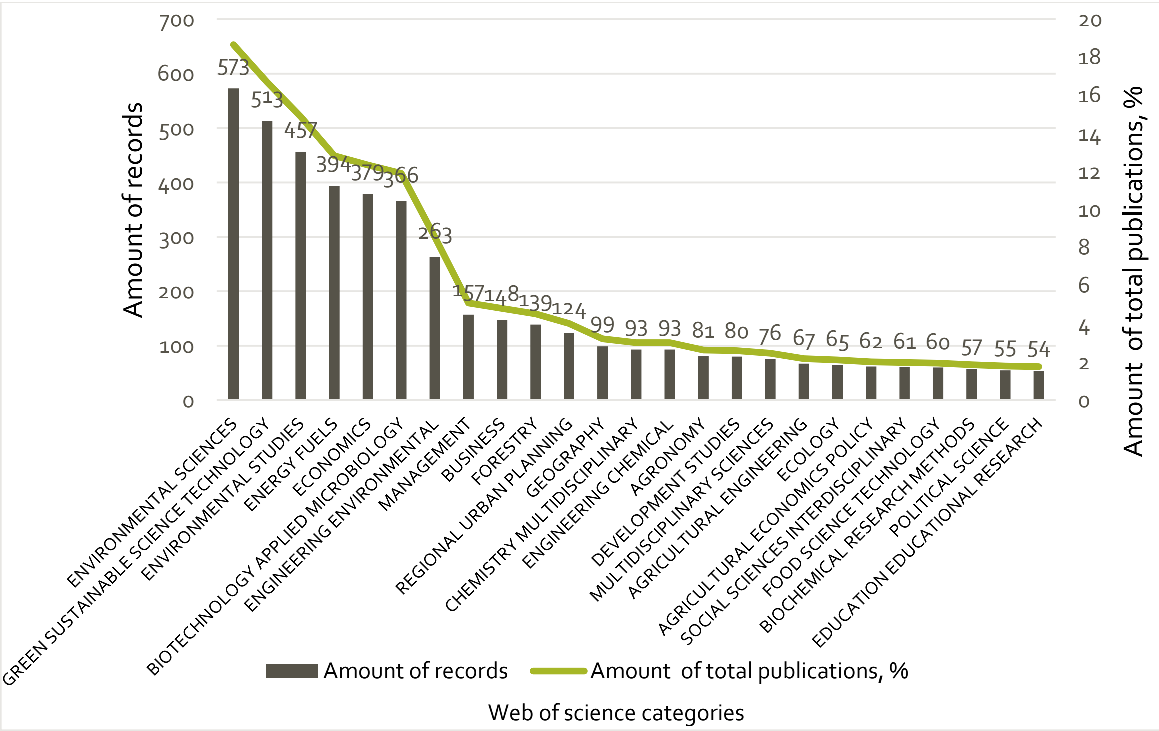


Fig. 1.3. Main bioeconomy research fields based on Web of Science data

The amount of records based on research fields differs between Scopus (Fig.1.4.) and Web of science (Fig.1.3.) data, although highest importance of this area takes environmental science fields, in Web of science next leader fields is green sustainable science technology, environmental studies and energy fuels, as for Scopus it is social sciences, energy, agricultural and biological sciences and economics.

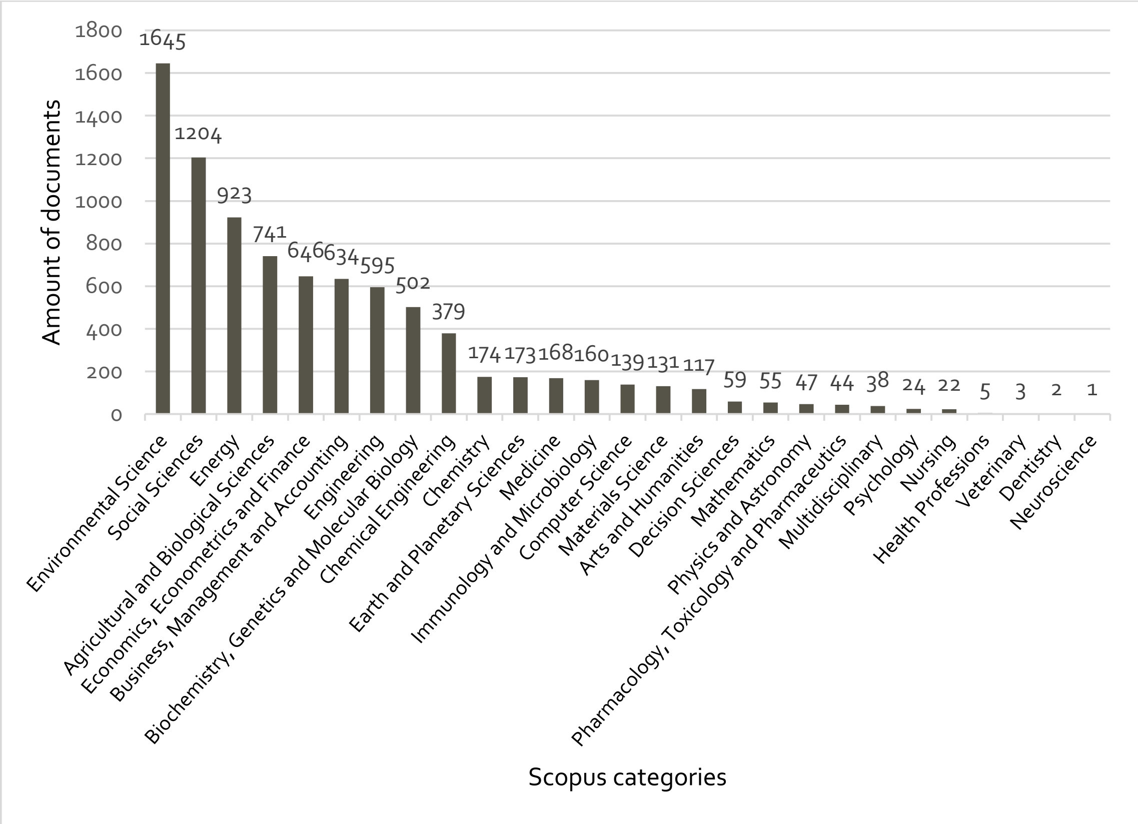


Fig.1.4. Main bioeconomy research fields based on Scopus database

Bioeconomy historical development

In 1993 European Commission published White Paper on Growth, Competitiveness and Employment that similarly to bioeconomy nowadays is the observation of knowledge-based investments and biotechnology necessity (Fig.1.5.). Next fallowed global conference hosted by European Commission "New perspectives on the knowledge based bio economy" that united 400 stakeholders from different countries and commenced bioeconomy as global phenomenon. Cologne paper in 2007 promoting bioeconomy concept and two dimensions of bioeconomy: biotechnology innovations and use of biomass for product production acknowledging the importance of governmental support. Already the biorefinery concept was raised [6].

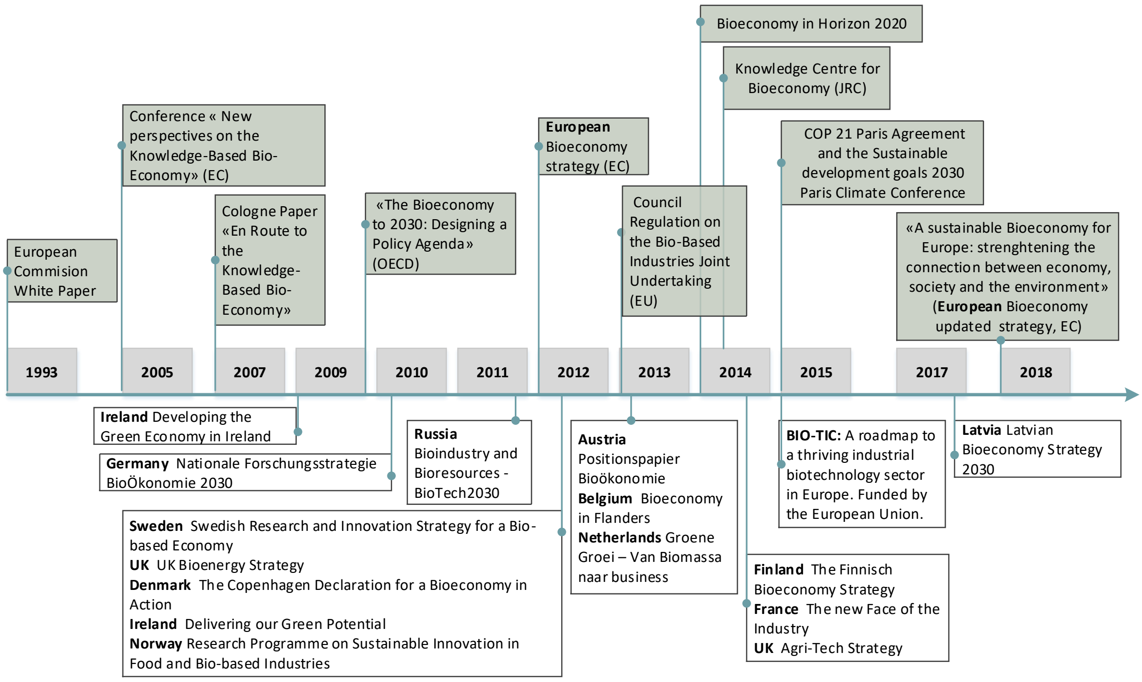


Fig. 1.5. Bioeconomy historical development main pathway (author representation based on national documents)

Overall 49 countries developed bioeconomy strategies on national and regional level till 2018, majority in Europe, but also USA, South Africa and Thailand. Latest bioeconomy strategies Finland, France, Italy, Latvia, Norway, Spain and UK raised a new approach combining bioeconomy and circular economy emphasizing circular bioeconomy concept towards sustainable development [7].

Bioeconomy in figures

One of the two main bioeconomy performance indicator is bioeconomy turnover, as seen in figure 1.6. development of turnover of total bioeconomy (including food and beverages and the primary sector of agriculture and forestry) in timeframe of 2008 – 2016, the highest turnover comes from forest-based industry and agriculture.

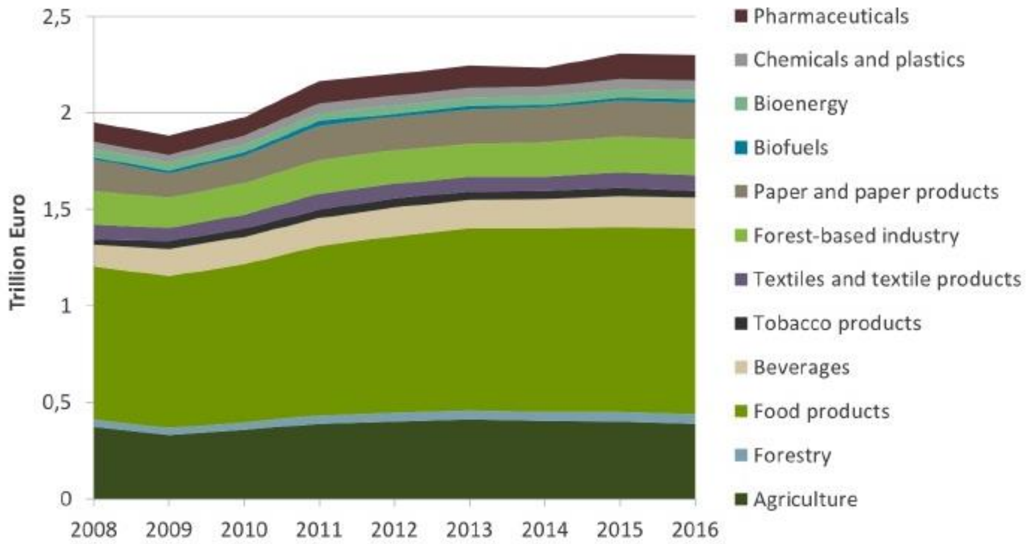


Fig.1.6. Turnover in the bioeconomy in the EU-28, 2008-2016 [7]

Not counting the recession in 2009, the data show a steady increase from less than € 2 trillion euros in 2008 to around 2.3 trillion euros in 2016. An important factor in the increase in turnover was especially in the food, feed and beverages sector (NACE division 10). About half of the € 2.3 trillion in 2016 comes from food and beverages sector, almost a quarter of turnover is accounted for by primary sectors (agriculture and forestry), while the second quarter is produced by so-called organic industries (such as chemicals and plastics, pharmaceuticals, paper and paper products, forest industries, textiles industry, biofuels and bioenergy). trillion euros. Note that the food industry always refers to NACE division 10 here. If primary biomass production is excluded from analysis, the biofuels and bioenergy counts approximately 8% corresponding ~60 billion euro of the EU industrial sectors that are referred to bioeconomy. The sectors paper and paper products (27%) and forest-based industry (wood products and furniture, 27%) make up for the largest shares of turnover: together they amount to approximately 380 billion Euro. Bio-based chemicals and plastics accounted for 55 billion Euro. The total turnover of the bio-based industries reached about 700 billion Euro in 2016), up from about 600 billion Euro in 2008 [7].

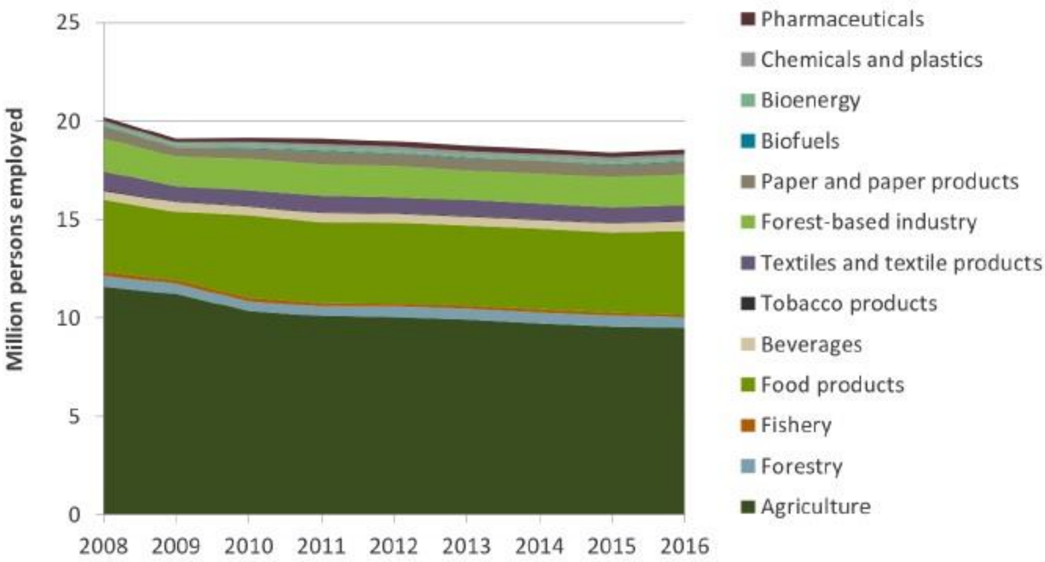


Fig.1.7. Employment in the bioeconomy in the EU-28, 2008-2016[7]

Fig. 1.7. shows the development of employment (total number of employed persons) in bioeconomy in the EU in timeframe of 2008-2016. Contrary to overall turnover, overall employment of the EU bioeconomy is declining. However, as this decline of employment of the total bioeconomy is mainly due to the decline of the agricultural sector while the other sectors have been stable or even increased their employment. In 2016, the total number of employed persons in the EU bioeconomy amounted to 18.6 million.

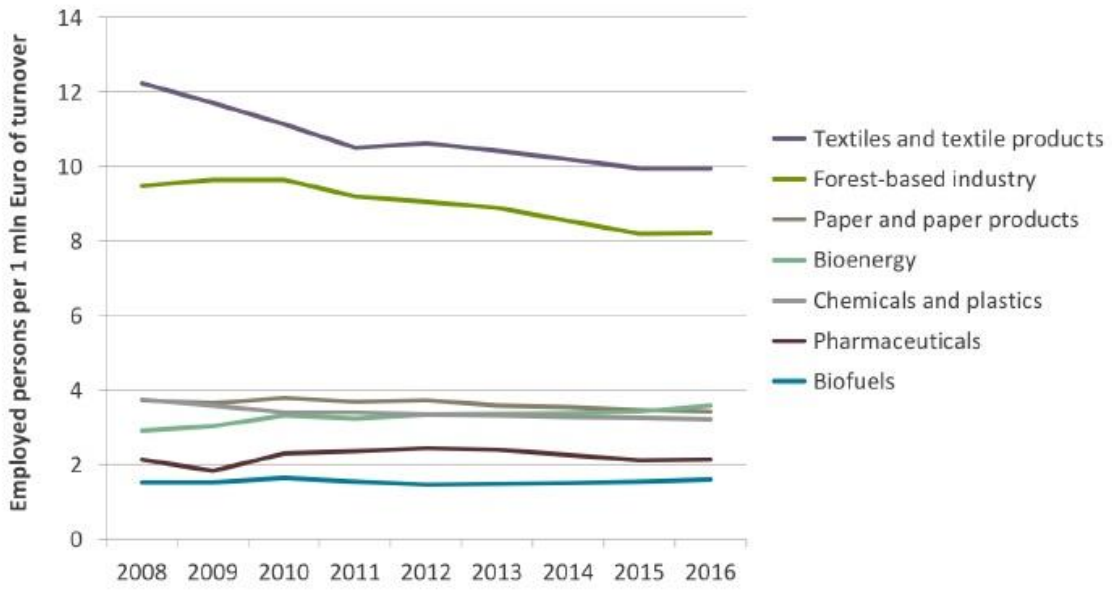


Fig.1.8. Employment per turnover in sectors of the bio-based economy, 2008-2016 [7]

Bioeconomy performance indicator of employment per turnover, figure 1.8., shows that textile and forest – based industries are labour intensive sectors. In contrary biofuels with lowest employed person number generate higher turnover, similarly with pharmaceuticals. Employment and turnover refers to the end product manufacturing stage [7]. The overall decrease in the ratio between employment to turnover indicates improved productivity, revealing a continued competitiveness of Europe. Strongest is the decrease of this ratio in the forest-based industry and the textile industry, which can be explained by the overall economic crisis following the year 2008, and partly by increases in productivity [7].

1.1.1. Understanding of the Bioeconomy

From the definition of bioeconomy and the analysis of different understandings, bioeconomy concept is summarized and graphically illustrated in Figure 1.9. Bioeconomy is stated as knowledge and technology driven [8] and biotechnology is set as first priority [9]. Bioeconomy covers different science fields, including, but not limited to – life sciences, agronomy, ecology, engineering and management sciences [8]. According to OECD, bioeconomy is an innovative approach of transforming knowledge into new sustainable and eco-efficient product that is also competitive [10].

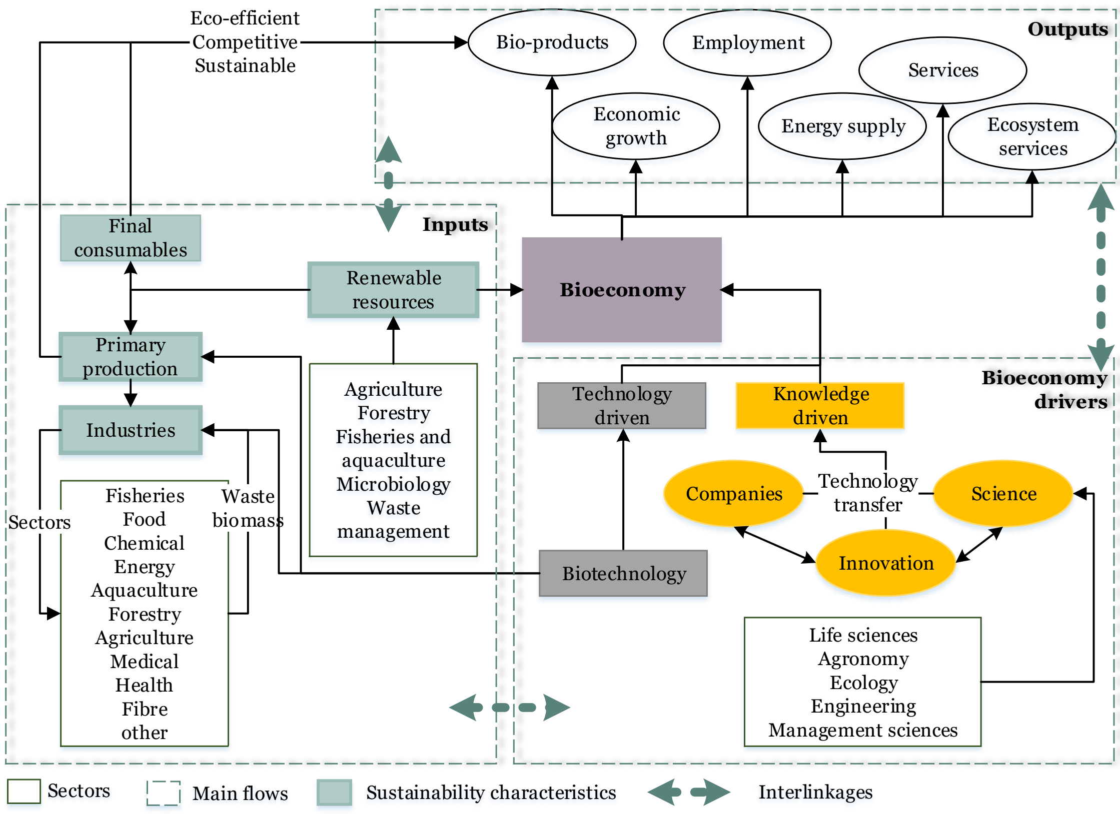


Fig. 1.9. Bioeconomy schematic representation (author representation based on bioeconomy definitions)

Bioeconomy interconnect with different topics such as primary resources – forestry, agriculture, fisheries and aquaculture, and sectors- industrial, such as food, chemical, energy, ecosystem services of nature like recreation and wellbeing [11]. The main outputs from bioeconomy is sustainable bioproducts, economic growth, energy supply, employment, services (such as health services) and ecosystem services [12]. Bioeconomy also implies the sustainable exploitation of biological resources to produce new bio-based products [13], providing conditions for increased standard of living [14]. Bioeconomy knowledge drivers is not only science, but also innovative companies with large knowledge on bioproducts and services offer [12].

The main bioeconomy system is driven by three main flows – bioeconomy drivers, inputs and outputs, which all are interconnected. It means that changes in one part of the system would have an impact not only on each other, but also directly on the development of the bioeconomy. This demonstrates the crucial role of bioeconomy extensive coverage, which has long exceeded the level of one industry or country. Therefore, it is essential to understand how transdisciplinarity of the bioeconomy is manifested. First of all, it is necessary to understand the essence of transdisciplinarity, which, like the concept of bioeconomy, is interpreted very differently.

1.1.2. Measuring the Sustainability of Bioeconomy

Unfortunately, there is still no common international method for determining, measuring and comparing the extent of sustainability [3]. However, several techniques have been developed for calculating sustainability. For example, the use of various sustainability indicators (e.g. EUROSTAT SDG indicators), creating specific indices (e.g. Sustainability index, Global green economy index, Environmental performance index), methods (e.g. Social accounting matrix [15]), benchmarks, audits, emergy analysis [16][17], various footprints [15][18]. What all these techniques have in common is that they are based on the three main pillars of sustainability - environmental, economic and social. But the exact criteria and factors used in each sustainability assessment method are different and the results are not comparable. It is clear that each of these methods has its own advantages and disadvantages, so only a utopian would hope to create one ideal method for sustainability evaluation that would be appropriate in all cases. Hence, various researches focus on development of specific methods to evaluate the sustainability of narrow topics. For example, measuring transport sustainability at a regional level industrial sustainability of small and medium-sized enterprises [19], sustainability indicators for economic evaluation of tourism investments in the islands [20], sustainability of manufacturing industry [21] . In addition, the sustainability evaluation is also hindered by the multidimensional nature of sustainability, which can manifest itself at different scales, such as resource [22], enterprise [23], industry [24], country, global. The same applies to the bioeconomy assessment, as it also does not have a uniform evaluation method. There have been several attempts to select bioeconomy characterizing indicators [5], [25], calculate life cycle impacts of biomass use [26] or measure the extent of the bioeconomy [27], but there is still no common understanding of the definition of bioeconomy [2], [28]. Similarly, sustainability is also defined in different ways [29]. Respectively, sustainable bioeconomy is like a loud slogan that everyone aspires to, but do not have a common understanding of it [30]–[33] and that cannot be measured and quantified at the moment. That is why the evaluation of bioeconomy sustainability also requires the development of a specific methodology, which can produce comparable results with quantitative data. The development of such methodology is the aim of this research. Such methodology is required to identify and compare the current situation and evaluate different development scenarios in order to select the best possible solution. The methodology would also take into account the transdisciplinary nature of the bioeconomy [8], [34]–[38] and the different levels at which bioeconomy can manifest. Like the concept of sustainability, a sustainable bioeconomy must be assessed at several levels: resources, products, companies, industries, national and global.

Innovations in bioeconomy (types of innovations)

Innovations in biotechnology faces three challenges: 1) a complex knowledge base, 2) converging technologies, and 3) issues concerning commercialization and market diffusion. Holistic innovation approach includes co-creation, innovation systems and open innovation.

Transition to bioeconomy innovation stages:

- Incremental, gradual innovations (product and processes)
- **Diverse, radically new and disruptive innovations**: redesigned business models, reconfigured supply chains, setup of new value chains – development of new sustainable products and technologies needs knowledge and skills outside their fields of expertise. Universities and research institutions will be cornerstone to accomplish radical innovations [39][8].

1.2. Transition Through Transdisciplinary Approach

In order to understand the meaning of bioeconomy on global scale (not only in terms of international but also of ecosystems), it is necessary to identify the bioeconomy area. According to the literature, there are nine planetary boundaries [40]–[42], which are close related to three bioeconomy main pillars – resource scarcity, climate change and food security, [34]. Planetary boundaries are not system that could show development of society, but it can clearly show the boundaries of safe development area and risk zone.

Planetary boundaries interlink with bioeconomy pillars, that show the global necessity for sustainable system development, taking into account safe development zone, therefore it shows complexity of the system required and bioeconomy transdisciplinary is suspected, but there should be clear division between disciplines and vision on development.

In 2013 - 2015 there were addressed a pathway for need to look on bioeconomy from interdisciplinary point of view, mostly because of novel technologies and need to use side streams, therefore engineering, environmental and socioeconomic challenges affect products and processes. Also integration of knowledge from different disciplines is necessary[8]. In 2018 the vision of bioeconomy pathway is determined more complex and one–dimensional approaches are not suited, therefore more holistic and systemic perspective and solutions are needed [43]. According to [44] categories that has been researched in bioeconomy are: biotechnology & applied microbiology, energy & fuels, environmental science, chemistry, multidisciplinary, environmental engineering, food science & technology, chemical engineering, forestry, applied chemistry, agronomy, agricultural engineering, plant sciences, social sciences, biomedical, multidisciplinary sciences [44]. Three bioeconomy visions are set in this article – biotechnology vision (research, application and commercialisation), bio-resource vision (RD&D, biological materials in agriculture, marine, forestry and bioenergy) and bio-ecology vision (potential for regionally circular and integrated processes and systems) [44]. In 2009 OECD (Organisation for Economic Co-operation and Development) has created an analysis of future developments of bioeconomy on three sectors – agriculture, health and industry. It has been stated as interdisciplinary research. Implementation pathways determined technology –based approach and socio-ecological approach, where the second includes inter- and transdisciplinary approach in research [45]. In other article multi-, inter- and transdisciplinary environment is stated as "social process of knowledge production" [46].

Current issue of bioeconomy development has been largely addressed on a linear or interdisciplinary level. But the future development of the bioeconomy should be viewed more widely, not as limited system. It involves many, sometimes very radically different, disciplines, both tangible and intangible, which are interrelated and can have an impact on the development of the bioeconomy, both directly and indirectly. Including mutual interaction. The increasing demand of food and feed, population growth and climate changes require new holistic vision on bioeconomy, bringing together various stakeholders. It has been acknowledged that holistic view of bioeconomy requires a transdiciplinary system analysis [43]. There is some evident need for interdisciplinary approach for bioeconomy [8], so it is important to understand if there is really a need for transdisciplinary approach or interdisciplinary approach.

Systemic approach will be achieved by nexus thinking and the concept of transdiciplinary approach in bioeconomy. Nexus thinking is based on factor and their interrelationships analysis.

Transdisciplinary research encompasses broad, deep and equal opportunities with different interests, which usually do not evolve in the study of policy. There is a need to align the principles of circular economy and bioeconomy involving system approaches across sectors and macro regional nexus thinking. This research gives a comprehensive view about holistic vision in bioeconomy and clear concept with a graphical representation of transdisciplinarity nexus. It should be noted that the development of the bioeconomy cannot be promoted in all regions at the same structure, but it is essential to understand the discipline and which factors should be considered in the assessment.

The aim of this task is to clarify the difference between interdisciplinary, multidisciplinarity and transdisciplinary in bioeconomy and to develop the concept of bioeconomy transdisciplinarity approach. Therefore, understanding is the bioeconomy transdisciplinary and what are the essential components of this system. Therefore, critical literature analysis was carried out and holistic approach used to analyse and aggregate the information. Different bioeconomy disciplines are defined and the obtained results are represented graphically. The obtained results can be used for further research as a transdisciplinary basis of the bioeconomy, studying specific systems, factors influencing them and evaluating potential scenarios and their impacting tools.

First to have a clear vision on bioeconomy disciplines and transdisciplinary, it is important to clarify bioeconomy definition, discipline definition and disciplinary definition in context of nexus interlinkage, then it should be clear how the disciplinary approach connects to bioeconomy.

1.2.1. Discipline relations in nexus context

Nexus approach is generic-conceptual approach with the aim to find interactions among different processes, that depends on the impact of various factors [35]. There are many illustration options on discipline levels, the one that is closest in order to understand nexus, is chosen.

Crossdisciplinary *(Fig.1.10.a)* concept is viewing one discipline from the perspective of another, crossdisciplinary involves associative relations between different methods that are primarily comparative [47]. Here one discipline, for example agriculture farming interacts with other discipline, for example agriculture economics, to find solution on one issue. Results are solution – oriented.

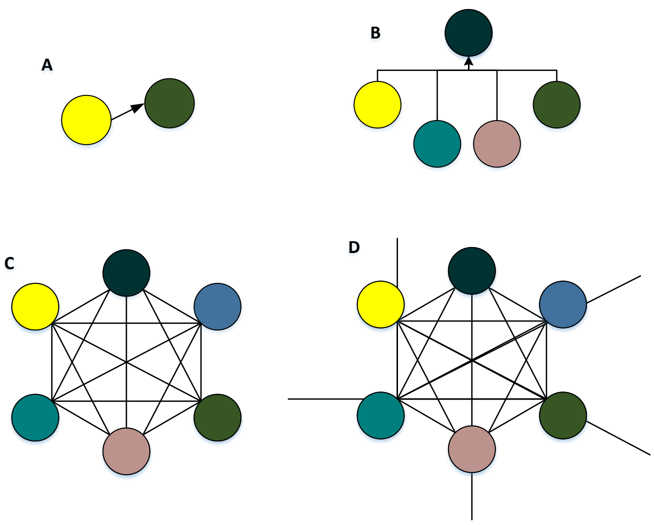


Fig. 1.10. Illustration of discipline levels [47]

Multidisciplinary *(Fig. 1.10. b*) is where people from different disciplines working together, each use their disciplinary knowledge**.** In multidisciplinary, relationship is usually centralised and hierarchical – it uses the power to define 'discipline' in research, in the language of this word. Thus, a particular discipline (in the academic terms, along with related methods) investigation is a privileged development of other methods of ordering and the final results of the general interpretation. [47]**.** As for bioeconomy point of view, would be different discipline experts, that are working on the same bioeconomy issue, for example, on issue of using agriculture waste, microbiologist can give his knowledge and expertise on how to add value to agriculture waste, engineer can find solutions for most effective equipment on various solutions and economist can give his expertise on solutions that he believes is the most cost effective. In this stage, they do not interact with each other. Or interaction is stated as weak link. Results is more subjective.

Interdisciplinary *(Fig. 1.10. c)* integrates knowledge and methods from different disciplines, using real-world approach of synthesis**.** In contrast, interdisciplinary has more symmetrical relationship between disciplines, and different methods can be used to address the contrasting aspects of the existing problem. However, even if participatory practice is used in subsequent parts of the process, non-academic interests are often excluded in the most important research, development and interpretation processes [47]**.** Here the disciplines that interacts are from different basis, they interaction are solution- oriented and with strong links, for example, issue on how to add value on agriculture waste, is a policy question, will it give social benefits and improve national economic situation and on what scale, microbiologist, that can help to find solution, that would give highest added value, economics, that help to find the most cost effective solution and computer science, that can perform modelling on different solution scenarios and their impact to various economic, socioeconomic, health and environmental processes.

Transdisciplinary *(Fig.* 1.10. *d)* creates the integrity of intellectual systems beyond a disciplinary perspective. Only in the field of transdisciplinarity, research or evaluation engages in broad, deep and equal ways with different interests, which are usually left outside the formal processes of policy research. Transdisciplinary engagement not only takes place in disciplines, nor is it the case that certain methods are implemented in a way that is subject to wider involvement [47]. According to J.A. Bergendahl et al. nexus projects are going to be more successful if transdisciplinary approach is applied [48]. If previous disciplines focused only on academic disciplines, this approach interacts with non-academic disciplines (society) as equals, broadening the view of issue and solution. If we look at previous mentioned example, in this case it would be supplemented with non-academic disciplines – different non-governmental organizations, local communities, local people, industries and also government agencies, etc. It means, we take into account opinions not only on previous mentioned disciplines on agricultural waste management with high added value, but also e.g. farmer's opinion, local communities' opinion, municipalities opinion and industries opinion on different solutions and possibilities to create a new path for bioeconomy development, in this case adding value to agriculture waste by new product production, that is feasible not only in theoretical level, but also realistic on implementation stage, economic and environmental aspect and with market potential.

1.2.2. Transdisciplinary bioeconomy

In order to research, demonstrate and define transdisciplinary approach of the bioeconomy, it is necessary to understand not only the bioeconomy on a largest scale, but also understand what is transdisciplinary nature. Therefore, a broad analysis of the scientific literature was carried out and various opinions on transdisciplinary definition were compiled. Some of them are summarized in Table1.1.

Table 1.1.

Evolution of transdisciplinary definition

Definition of transdisciplinary	Reference
'Transdisciplinarity is the incorporation of a broad set of scientific and policy disciplines, including industries and actors, for addressing broad and complex problems, e.g., sustainability. Transdisciplinarity is meant to address concerns of traditional scientific methods relying on reductionist, reasoned, studies that investigate a phenomenon or research question typically from a single disciplinary perspective.'	[48]
'Transdisciplinary is the ontological specification of knowledge constructs on a higher, boundary-transcending, level of abstraction.'	[49]
'The science of team science: assessing the value of transdisciplinary research problems; meaningful collaborations, particularly between academic researchers and non-academics'	[50]
'Transdisciplinarity is seen as a specific methodology of efficient utilization and a way to relay knowledge from practice and science to the management of complex sustainable transitions.'	[51]
'Transdisciplinarity is a reflexive research approach that addresses societal problems by means of interdisciplinary collaboration as well as the collaboration between researchers and extra-scientific actors; its aim is to enable mutual learning processes between science and society; integration is the main cognitive challenge of the research process.'	[52]
'Transdisciplinary studies incorporate interdisciplinary integration and add additional research dimensions by (a) addressing problems that are user inspired and context driven, (b) embracing complexity; and (c) acknowledging and incorporating multi-stakeholder perspectives and values…'	[53]
'TR deals with problem fields in such a way that it can: (a) grasp the complexity of problems, (b) take into account the diversity of life-world and scientific perceptions of problems, (c) link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good […] We define TR by these four requirements for knowledge production.'	[54]
'Transdisciplinarity is a new form of learning and problem solving involving cooperation among different parts of society and academia in order to meet complex challenges of society. Transdisciplinary research starts from tangible, real-world problems. … Ideally, everyone who has something to say about a particular problem and is willing to participate can play a role. Through mutual learning, the knowledge of all participants is enhanced … The sum of this knowledge will be greater than the knowledge of any single partner. In the process, the bias of each perspective will also be minimized.'	[55]
'Transdisciplinarity represents a move from science on/about society towards science for/with society.'	[56]

All definitions show (see table 1) that transdisciplinary approach is the transition from science to practice, seen as complex and sustainable way to meet complex challenges of society. Transdisciplinarity itself is complex and consists of four dimensions (Fig. 1.11.).

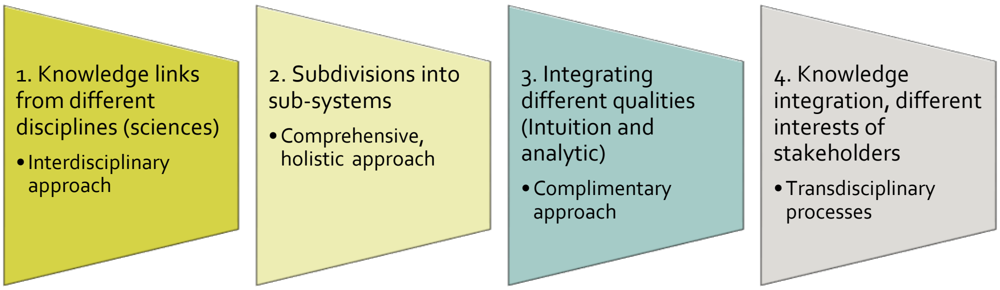


Fig.1.11. Transdisciplinary approach dimensions [56]

Transdisciplinarity processes is way from unsustainable management moving towards sustainable management, covering four dimensions with the aim to connect science (disciplinarities) with practice (stakeholders) [51]. According to [57], knowledge that has to be implemented to preceptors go through four dimensions:

1st dimension – helix approach - this dimension brings together different fields from natural – life sciences (biology, medicine, chemistry), economics, applied sciences. It should ensure interdisciplinarity [57].

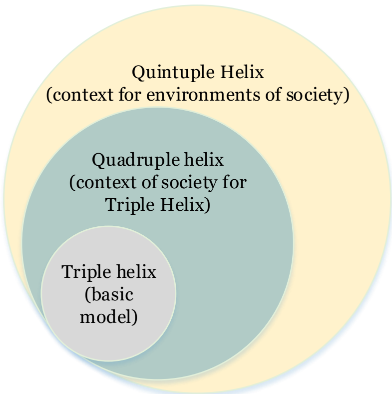


Fig. 1.12. Helix approaches [58]

Different types of helix approach could be implemented: triple helix, quadruple helix or quintuple Helix [58], see Figure 1.12.

2nd dimension – Systems: dividing in subsystems, for example in environmental study can separate regions water, air, soil systems and their interlinkages. For stakeholders it is management, financial and equipment as individual systems or complex systems. Needs to be integrated and related to the soft factors – gives circumstances [57].

3rd dimension Interests: Interests of research or practical perspective. For example, different interests of farmers, residents, policy, different interests of stakeholders. Methods are socially integrating and mediating [57].

4th dimension Modes of though; cognitive or epistemological perspective analysis or understanding. Methods that integrate different cognitive representations, for example experience of a farmer and the expertise of a scientist [57].

Transdisciplinary processes connect science with society, adapted *Brunswikian Lens* model [57] in Figure 1.11. [51], to adapt this processes for sustainable bioeconomy, that not only replace fossil resources with biobased resources, but strengthens different disciplines, taken into account interlinkages, knowledge, and stakeholders and limitations set by planetary boundaries, different dimensions should be included in transition towards sustainable bioeconomy. Syntheses is application of methods of knowledge integration[57], [59].

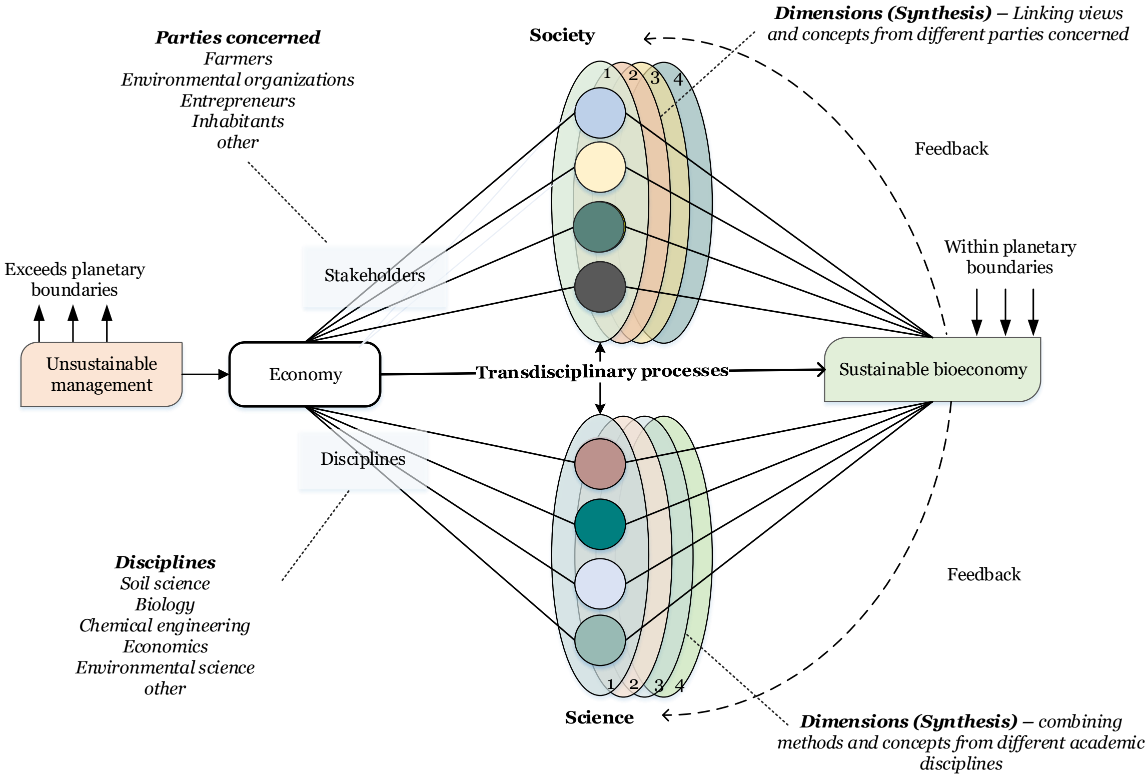


Fig. 1.13.Transdisciplinary process towards sustainable bioeconomy (modified [51])

The concept of how to view and should act in order to achieve a transdisciplinary approach and outcome for sustainable bioeconomy development (see Fig. 1.13.). This type of approach can be used as a basis for developing the research issue into quantitative results, which would allow comparing the situation in different regions of the world and evaluating different development of scenarios, taking into account the views and actions of the various stakeholders. For example, this graphical representation can be used as a basis for creating a system dynamics model.

By carrying out critical analysis of literature on various bioeconomy perceptions, it was found that bioeconomy is essentially of transdisciplinary nature. An analysis of the understanding of transdiciplinarity was also carried out to prove this. By interconnecting these two ideas that are not directly related to each other, an appropriate approach to expressing the bioeconomics of transdiciplinarity using the *Brunswikian Lens* model was found.

Developed graphical representation is applicable to further case studies. Methods that is applicable to use in order to achieve best possible result, still need to evaluate and verify. Further research in the context of bioeconomy should be carried out directly through the prism of transdisciplinarity and a solution should be found to quantify this view. It is clear that bioeconomy should be looked as complex system through transdisciplinary approach, but advantages and disadvantages have to be determined.

1.3. Bioresources as Building Foundation for Bioeconomy

Bioresources is building foundation of bioeconomy, bioeconomy basic purpose is to use bioresources to their fullest extent, to not only decrease the use of fossil resources, but also to gain innovative approach based methods hot to increase bioresource value. Here several options have been researched in scientific literature and applied in real life bioeconomy – biorefinery, industrial symbiosis, cascading principles. In thesis emphasis is made on two cases for bioresource value promotion – existing, but underused bioresource use creating new value chains, and searching for new bioresources that could be substitution to existing or new value chains.

1.3.1. Existing Bioresources Towards New Value Chains

To ensure radical innovations there is a necessity to use existing bioresources with higher added value. To ensure food security, the first emphasis on use of bioresources is on non-food raw materials, for materials and energy purposes. As well the residues are still undervalued and underused, that could make a serious raw material base. For example:

Forest residues and pulpwood

The bioeconomy is experiencing worldwide growth and is playing an increasingly important role in the European Union [60][61] . The existing fossil-based economy is being increasingly challenged by population numbers, climate change and a shortage of resources [62]. The bioeconomy counts on the availability and reliability of supply of renewable resources for the production of high value-added products. Moreover, new bio-products are created in biorefineries, which results in both cleaner production and implements the cascade principle.

The cascade principle incorporates both the production of high value-added products and the use of residues to make those value-added products, thereby achieving little or no waste and reducing the impact on the climate [62]. Bio-based products and bioenergy can have new and innovative functionality along with the potential to enter both new and existing markets [63].

Forests are an integral part of both the landscape and the overall economy. However, the economic benefits from timber production have been decreasing dramatically across Europe even though timber production creates major volumes of by-product or residue that can be used by the pulp industry and for energy production[64].

Forested lands cover about 52 % of Latvia's total area [65]. Wood products are estimated to have excellent potential in Latvia if sustainability in the forestry sector can just be maintained; even more if sustainability can be enhanced The problem is that most forestry biomass is combusted, that is, burned to produce energy, even though manufacturing forest products with greater added value is a strategic goal for the forest product industry [66].

The bioeconomy principles support the intention to create higher added value products from forest residue. But such products cannot be produced if they do not have proven economic viability. Effective feasibility studies are needed before attempting to create products from renewable resources on a commercial scale.

Agro-industrial residues

Agro-industrial residues mostly are untreated and underutilized and without appropriate disposal can cause environmental pollution and negative impact on human and animal health. These wastes can be used for bioenergy production, however they contain various potentially valuable compounds like proteins, sugars and minerals. Agro-industrial residues mostly are untreated and underutilized and without appropriate disposal can cause environmental pollution and negative impact on human and animal health. Agricultural industries produce huge amount of residues every year [67]. These wastes can be used for bioenergy production, however they contain various compounds like proteins, sugars and minerals. According to high nutrition value, these residues can be used as raw materials for other product formation and development [67]. There are many reports about liquid and gaseous biofuel acquisition from agro-industrial waste [68]–[74], however there is a potential to derive valuable compounds (e.g. chemicals) [75]–[77]. There should be a comparative analysis between existing production sectors which use agro-industrial residues and alternative products with respect to environmental, economic and engineering aspects.

1.3.2. New Bioresources as Substitution to Existing Value Chain or Towards New Value Chains

To continue underused biomass value opportunities, there are one residue form, that requires investments on country level, European level, region level and land owners. There is policy implementation, research and projects done on invasive species importance on biodiversity, impact on land, monitoring the species and use. However, some species that are in control and eradication stages, provides country with biomass residues, that could be utilised accordingly.

Invasive alien plant species

One of significant undervalued bioresources in Latvia is the invasive alien plants. Invasive alien species are major driver of biodiversity loss, but should be considered and researched in the context of climate change and adaptation [78] as well as in bioeconomy context.

Globalization has integrated widely dispersed human communities into a worldwide economy. This process provides many benefits through the movement of people and goods, but also leads to the intentional and unintentional transfer of organisms among ecosystems that were previously separate [79]. Since the creation of the EU Biodiversity Strategy, an increased attention has been drawn to the spread of invasive non-native species, their impact on biodiversity, and the caused economic losses which in EU sum up to around EUR 12.5 billion per year [80]. Since the implementation of the strategy, policy measures have been continuously improving i.e., legislative instruments for limiting the introduction and adaptation of such species and their eradication have been implemented. Regulation No 1143/2014 of the European Parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species prescribes that „*in the event that eradication is not feasible or the costs of eradication outweigh the environmental, social and economic benefits in the long term, containment and control measures should be applied*" [81].

Previous studies have shown that the spread of invasive species and their management is a topical issue all around the world. So far the EU co-funded projects regarding invasive plants have focused on monitoring – by development of databases and networks [82]. A growing trend in the scientific literature is to focus studies on the use of certain invasive plants for the production of various products, in particular high value-added products for the pharmaceutical and cosmetics industries [83]–[90]. On the other hand, the planning documents and regulatory enactments referring to invasive plants follow a tactic of elimination of the consequences, i.e., restrictions, sanctions and control or eradication of invasive plants [91]. Therefore, invasive plants are considered as a problem that requires financial resources to solve it, but the potential benefits of invasive plants are only recognized by scientists at a theoretical level and are rarely implemented practically. All invasive plants are basically bioresources that can be used in all sectors of the economy similarly as any other bioresource, and can provide economic, social, environmental and climate benefits when used sustainably. While also emphasizing the fact that deliberate cultivation of invasive plants is not permissible. The sustainable use of bioresources for production of products, including products with high added value, is described by bioeconomy concept, the implementation of which has become particularly topical in the last 7 years since the introduction of the EU Bioeconomy Strategy [92].

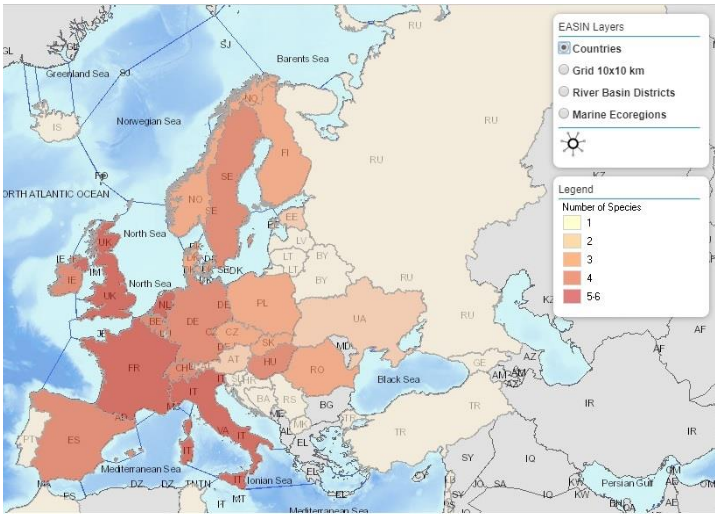


Fig. 1.14. Number of EU worst invasive alien plant species registered per country [93] [94]

If we look at European worst invasive species (figure 1.14.), then France, Italy, United Kingdom and Netherlands are in most concern, and Latvia seems not to have this priority, as there is only one registered species that is on the European 'worst invasive species' list. However, it does not mean, there should not be a national level importance on other invasive species.

For the pan-European region, 121 species are now listed as 'worst invasive' species [95]. If we look at number of species per $1000 km^2$, then the situation differs, but here are all the invasive species (occurring in terrestrial and freshwater ecosystems), see figure 1.15.

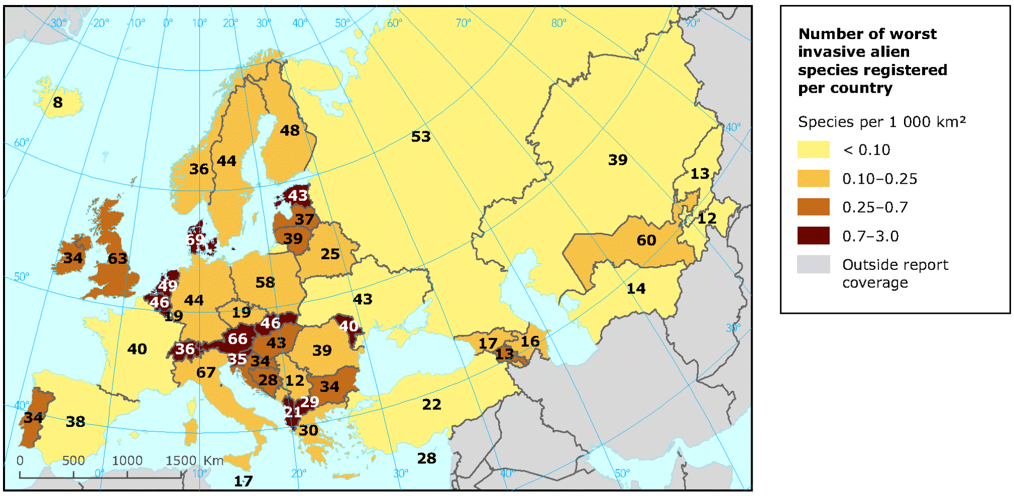


Fig.1.15.Number of worst invasive alien species (IAS) registered per country on area ($1000 km^2$) [95]

The EU identifies certain plant species that pose risk in the EU, but these species differ for each Member State. Therefore, the EU defined species are of priority, but countries should conduct research on the species present at national level on their prevalence, environmental impact and toxicology. The main direction is the integration of scientific research and the process of managing invasive plant species, thus creating the opportunity to use this biomass for the production of high added value products. This will not only enable the research on methods for eradication and destruction of invasive species, but also promote research on their use and simultaneous recovery of the funds invested in the containment measures.

After assessing the possibilities of using invasive plant biomass in the national economy for the production of different products and the environmental impact of such process, the dual nature of the subject under investigation has been revealed:

- In order to preserve biodiversity, the spread of invasive plant species must be restricted;
- To consider the use of invasive plant biomass as raw material for production, the stakeholders (entrepreneurs) are mainly interested in the economic justification of the obtained product, long-term availability of the raw materials and its market potential.

The first reflects primarily the interests of nature conservation and regulatory authorities, while the latter - entrepreneur interests. In order to provide a sustainable solution, a compromise is needed between these two sides, and only then it will be possible to ensure that the population of invasive plants does not rise, and the biodiversity is not reduced, meanwhile the biomass from invasive plant management measures will be used to produce products, thus gaining economic, social, environmental and climate benefits. Consequently, a major international level problem arises: *how should invasive plants be managed in order not only to meet environmental requirements, but also – derive economic and social benefits?*

Invasive alien species are major driver of biodiversity loss, but should be considered and researched in the context of climate change and adaptation [78].

2. METHODOLOGY

Methodology consists of three level analysis (Fig.2.1.) macro- level analysis method, using top-down approach bioeconomy assessment on international scale has been implemented; meso-level assessment, where transdisciplinary approach is applied as various stakeholder interests are taken into account; and micro-level assessment, where particular underused bioresource potential has been assessed and new invasive species management system presented.

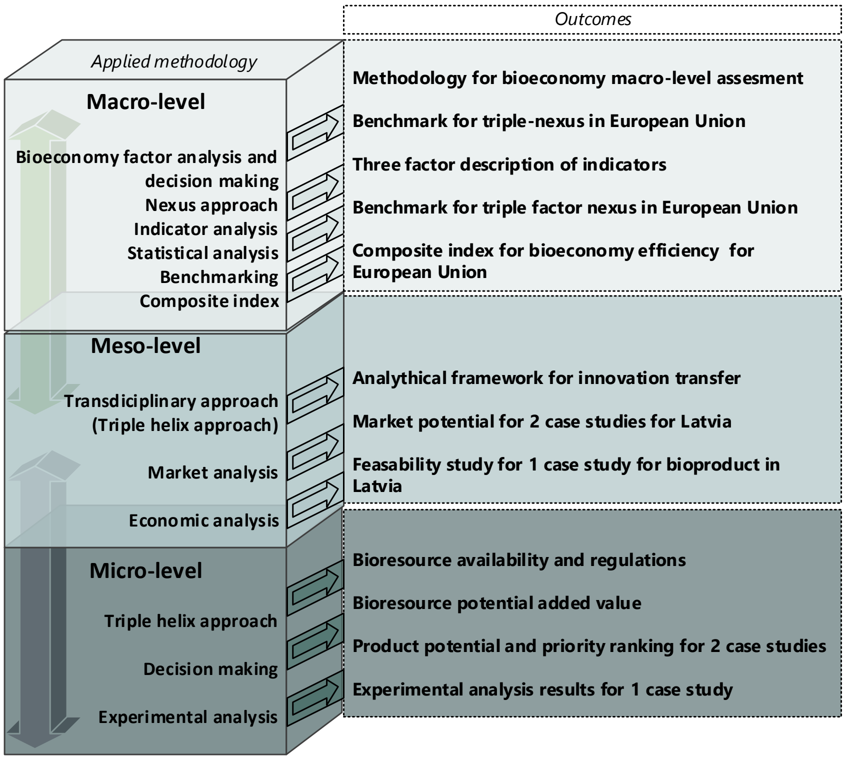


Fig.2.1. Overall applied methodology of the Thesis and the outcomes (created by the author)

Main outcomes of the applied methodology of the Thesis (see Fig. 2.1) are the following: methodology for macro-level assessment; main factors identified and triple factor nexus presented for European Union; benchmark is expressed as a mathematical regression model; and a composite index has been created. For innovation transfer, analytical framework is created, market potential assessment for several cases performed, and feasibility study for early stage innovation presented. New invasive species management system has been created and validated by bioresource potential added value and experimental analysis. Another case of agri-industrial residue product potential and priority ranking is presented.

2.1. Macro-Level Assessment Research Methodology

Macro-level assessment methodology is based on top-down approach, as bioeconomy is stated to be bottom-up approach, there should be a concise assessment how to show bioeconomy efficiency, to measure bioeconomy in macro scale. Therefore, top-down analysis is performed, to find bottlenecks that should be overcome in order to measure bioeconomy with one index – bioeconomy effectiveness index.

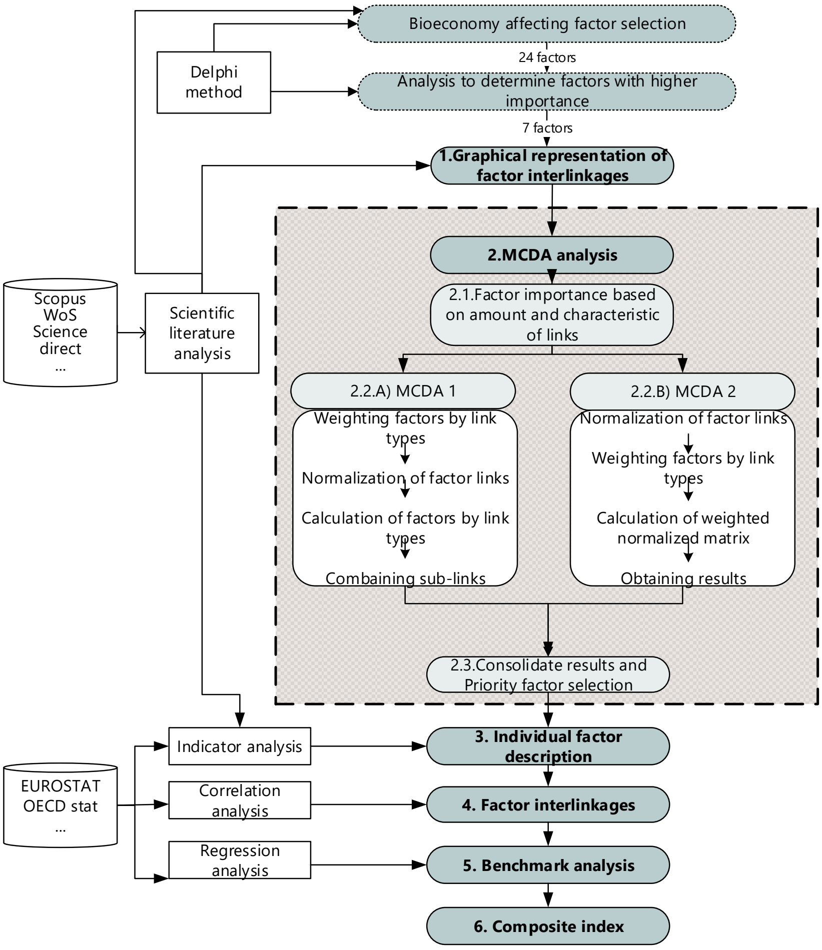


Fig. 2.2. Macro-level methodology (created by the author)

Macro-level assessment methodology consists of five steps and is based on top-down approach, see Fig. 1.2.

Step 1: Based on scientific literature analysis and by the use of Delphi method, seven primary factors were selected from a set of 24 bioeconomy affecting factors, and a graphical representation of factor interlinkages was built by determining whether the link is direct (represented with a straight line) or indirect (represented with a broken line) and whether it is an influencing or dependent link (represented with the direction of an arrow). Indirect links mean that more than two factors are involved in the linkage, therefore, the derivative has been reached through another factor or with more than two factors together.

Step 2: Multi criteria decision making analysis is applied as quantitative approach for determination of factors with the highest impact on bioeconomy development. This is a preliminary assessment and does not mean that other factors should be excluded from assessment; to the contrary, this assessment will only give an overall notion on which factors have the strongest impact on bioeconomy. As it is well known, different MCDA approaches give very different results [16], therefore, to get a better perspective, it is advised to use at least two MCDA methods for the same decision. The consolidated result for decision making is proposed. In this research two MCDA approaches are used: the technique for order of preference by similarity to ideal solution (TOPSIS) and analytical hierarchy process (AHP), which are two of the most commonly used MCDA analysis methods in the context of sustainable development [96].

MCDA analysis is conducted based on four criteria: direct influencing links, direct dependent links, indirect influencing links, and indirect dependent links. Values for seven factors (alternatives) are based on the number of linkages described. Link weights are based on assumptions, i.e., for both methods the weight of link strength is assumed to be 2 : 1, where direct links (both influencing and dependent) are two times more significant than indirect links (both influencing and dependent). As multi criteria decision analysis methods vary and often give slightly different results, a novel approach is used by creating a consolidated result between the two methods. If this methodology is used in other studies, more than two MCDA analysis methods can also be applied if necessary, as well as, different approaches can be used according to the specifics of the problem that needs to be solved.

Step 3: Individual factor analysis. To get an in-depth characterization of factors, each selected factor is analysed separately in the context of bioeconomy. Each of the factors is described through indicator analysis and grouped as environmental, economic, social or technological aspect indicator.

Step 4: The application of nexus approach with the aim to find a way to measure the link strength, e.g., by overlapping indicators that are related to bioeconomy influencing factors that could provide an insight and correlation between each two or more factors.

Step 5: Finding benchmarks that best characterise the linkage between two factors. Benchmark is expressed as mathematical regression models that characterize the link and its strength.

Step 6: Final step is the creation of composite index for bioeconomy efficiency.

2.1.1. Nexus approach for bioeconomy factor analysis

To obtain most important factors for bioeconomy Delphi method were performed from previously selected 24 factors within panel of environmental experts. Delphi method, that is a structured communication technique, were performed to select most important factors. Delphi method implies steps where experts share their opinion on given problem and questions in round one, after analysis of results, second round is generated, where experts can get acquainted with the results of other experts and through discussion come to an agreement of consensus. After factor selection a nexus approach are used for graphical representation and further case of nexus with indicator approach is applied.

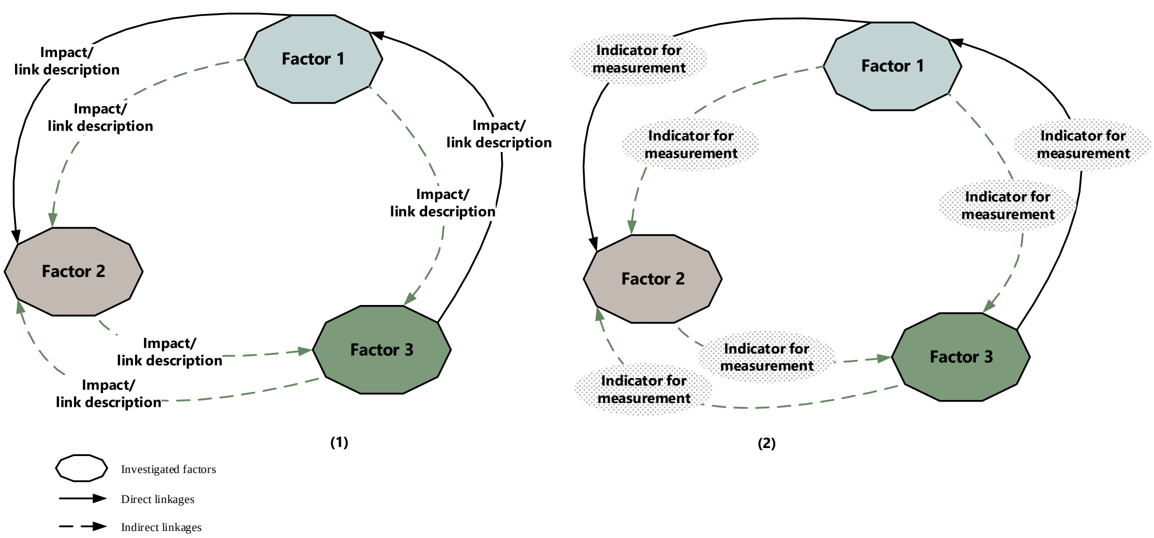


Fig. 2.3. 1) General scheme of nexus approach 2) Nexus with indicator approach (created by the author)

2.1.2. Decision analysis

Decision analysis can be applied to all level assessments.

Decision making is important step in all level assessments, therefore used in macro- level for factor link analysis and micro level for levelling the biomass, and for product selection according to priorities. In Thesis two of the most popular decision analysis methods are used TOPSIS and Analytical hierarchy process (AHP).

Analythical Hierachy Process (AHP)

In macro level, AHP is applied separately for each link type (Fig. 2.4.) to get more consistent results.

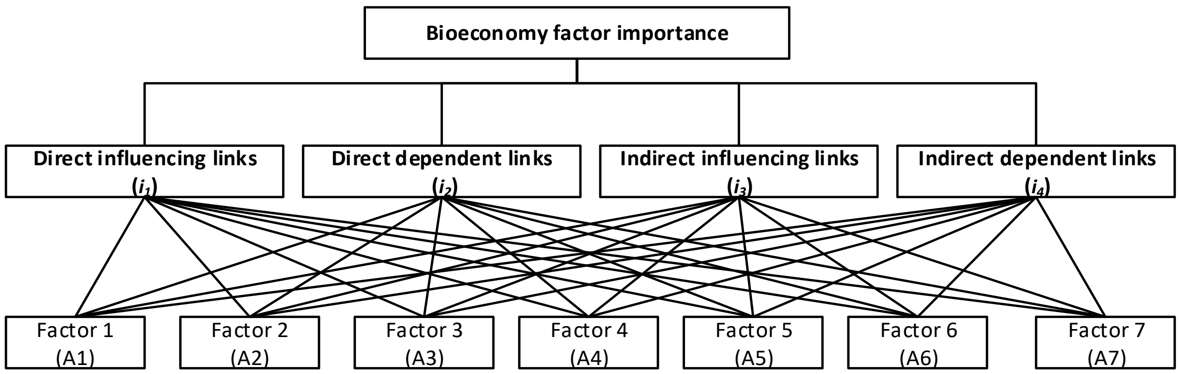


Fig.2.4. Generic hierarchy scheme for calculation of factor importance. AHP analysis method (created by the author)

For each sub-link type results are normalised and priority vector is obtained. Afterwards, the results of each alternative are summarized to acquire final results. AHP values are obtained by the division between link amounts to determine which factor is more important than others. That is the main difference made in AHP calculations, where the typically used importance, e.g., based on fundamental scales from 1-9, is not applied, but exact values are calculated in between criteria pairs instead.

Pairwise comparison is done for each sub-link type individually, where one weighted alternative value is divided with another weighted alternative value, gaining importance value for AHP matrix.

$$A_{im} = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{2n} \\ \dots & \dots & \dots & \dots \\ A_{n1} & A_{n2} & \dots & A_{nn} \end{bmatrix}, \quad (2.1)$$

where

matrix A represents judgments (relative importance) of alternatives, where n is the number of alternatives being evaluated. Matrix A is built for each criterion separately, where $i = 1, \dots, m$ (in this case $i = 1, \dots, 4$).

After pairwise comparison, a normalization of values has been performed:

$$X_{ij} = \frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}}, \quad (2.2)$$

where

X_{ij} – normalized value, $i = 1, \dots, m$, $j = 1, \dots, n$;

A_{ij} – pairwise matrix elements (alternatives), $i = 1, \dots, m$, $j = 1, \dots, n$.

Calculation of priority vector

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n}, \quad (2.3)$$

where

W_{ij} – priority vector, $i = 1, \dots, m$, $j = 1, \dots, n$;

n – number of alternatives [97].

Technique of Order Preference by Similarity to the Ideal Solution (TOPSIS)

TOPSIS analysis method [98], which is based on Euclidean distance evaluation, gives result as closeness to the ideal solution. TOPSIS calculations can be found in author's previous work [99]. The preferable outcome (ideal solution) for all criteria is the maximum and anti-ideal for all criteria is the minimum amount. As stated previously, weights are identical for both methods.

Normalization of values were carried out by standardized form:

$$1. \quad n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (2.4)$$

where n_{ij} – normalized value; $i = 1, \dots, m$; $j = 1, \dots, n$.

Weighted normalized decision matrix is calculated as

$$v_{ij} = w_j n_{ij}, \quad (2.5)$$

where v_{ij} is weighted normalized value, $i = 1, \dots, m$; $j = 1, \dots, n$; and w_j is the weight of the j-th criterion, $\sum_{j=1}^{n} w_j = 1$.

Separation measures calculate the distance from the positive ideal and negative ideal solution:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, i = 1, 2, \ldots, m, \quad (2.6)$$

where d_i^+ is distance to ideal solution.

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, i = 1, 2, \ldots, m, \quad (2.7)$$

where d_i^- is distance to negative solution.

In the final step of the calculation of relative closeness to the positive ideal solution is performed as follows:

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}, \quad (2.8)$$

where $0 \leq R_i \leq 1$, $i = 1, 2, \ldots, m$.

Preference Ranking Organization Method for the Enrichment of Evaluations (PROMETHEE)

For PROMETHEE analysis were used Visual PROMETHEE - Gaia (Graphical Analysis for Interactive Aid) multicriteria decision software, using linear preference functions.

2.1.3. Construction of composite sustainability index

For a couple of decades' various sustainable development assessment tools and indexes have been proposed to evaluate the long-term triple bottom line effects of our production systems, the products themselves, as well as, regional sustainability. Composite indexes have been applied for evaluation of various complex phenomena, e.g. sustainable development, company sustainability [24], biorefinery complexity [100], rural sustainable development [101], [102]. Santos de Freita et al. [103] developed a composite index that they call the Sustainable Tension Index and which accounts for all three pillars of sustainability as descriptor variables. They validate the index on a case of Brazilian municipalities. Variable weights are calculated by principal component analysis. They also apply result classification into five particular groups. Krajnc and Glavič [24] developed a composite sustainable development index to assess a company's economic, environmental and social performance. They note that integrated company level sustainability assessment would aid decision-making.

Another composite index that is related to environmental dimension is the eco-innovation index that is used to describe the eco-innovation progress in EU member countries. Eco-innovation index is composed of 16 indicators that are grouped into five major groups: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes. As well, the eco-innovation progress is describing by the eco-innovation scoreboard [104]. However, to our knowledge, there are no research exclusively regarding composite index for bioeconomy.

The advantages of composite index include describing the multi-dimensional nature of the investigated phenomenon with a one-dimensional proxy that can be easily interpreted. In addition, composite indexes are easier to interpret then scoreboards of indicators; they can be used to follow the development of the phenomenon in time, they can include more information when there are limitations of size. The drawbacks, however, include potential misuse due to erroneous interpretation, subjectiveness due weighting methods used, or the potential to be tailored to the user's desired outcome [105], [106].

Development of a composite index depends on choice of theoretical framework, data availability, and selection of representative indicators, their normalization, comparison and aggregation. Composite index creation procedure consists of:

1. definition of the investigated phenomenon, selection of sub-groups and criteria for indicator inclusion;
2. indicator selection accordingly to their relevance, analytical soundness, timeliness, accessibility, quality, type of data (hard/soft data);
3. indicator normalization to make them comparable (introduce dimensionless numbers;
4. normalized indicator aggregation [105], [106].

The content and the amount of dimensions depends on the specifics of the research topic, however, there is no limit to the number of dimensions and indicators that could be included in the composite index. The basic hierarchy for construction of the CSI from the all the sub-dimensions is illustrated in the Figure 2.5.

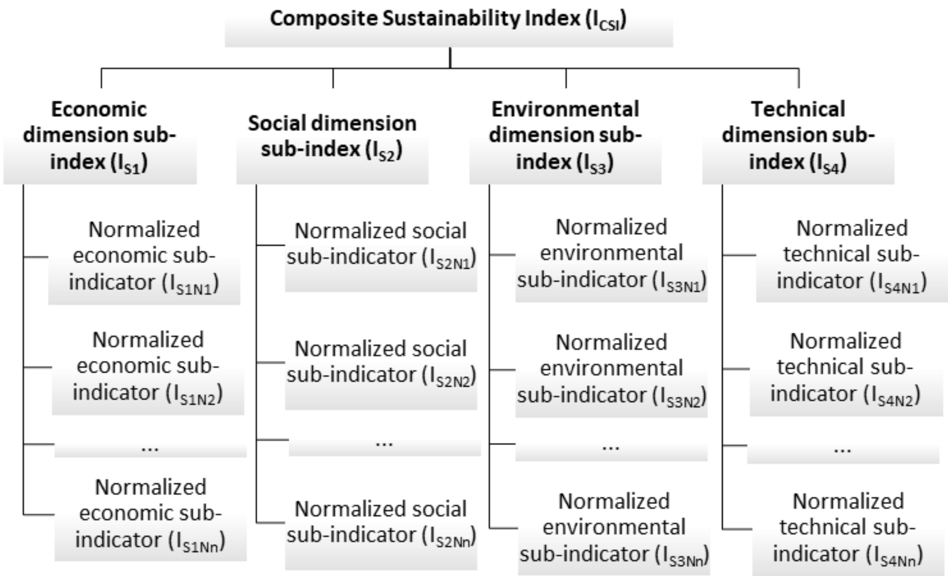


Fig. 2.5. Basic hierarchy for construction of the CSI [24].

After the identification of the key inicators and development of the CSI sub-dimensions, it is necessary to consider the potential impact of the sub-indicators on the CSI. In addition, in min-max data normalization technique, it should be recorded whether each indicator has a positive or negative impact on the composite index [103] positive impact (I^+) and negative impact (I^-) on the sustainability development. The categorization according to the impact is important since it will determine the calculation methodology for data normalization in the further steps of CSI construction.

Table 2.1.

Grouping Indicators According to Their Impact on CSI [24]

Dimenssion	Sub-dimension notation, j	Sub-indicator's positive impact	Sub-indicator's negative impact
Economic	1	$I^{+}_{act,1i}$ i=1,…,n	$I^{-}_{act,1i}$ i=1,…,n
Social	2	$I^{+}_{act,2i}$ i=1,…,n	$I^{-}_{act,2i}$ i=1,…,n
Environmental	3	$I^{+}_{act,3i}$ i=1,…,n	$I^{-}_{act,3i}$ i=1,…,n
Technical	4	$I^{+}_{act,4i}$ i=1,…,n	$I^{-}_{act,4i}$ i=1,…,n
…	j_n	$I^{+}_{act,ni}$ i=1,…,n	$I^{-}_{act,ni}$ i=1,…,n

Normalization is done to ensure that variables of different magnitude and different measurement units can be compared [103]. Potential normalisation methods to be applied include ranking, standardization (z-scores), min-max normalisation, distance to a reference, categorical scale, transformation of above/below mean indicators, etc. [106].

I_{act} is the actual value of an indicator (raw data), I_{min} is the minimim value from the data set of the specific indicator, I_{min} is the maximum value from the specific indicator's data set. Notation *j* represents the particular sub-dimension (j=1 is economic dimension; j=2 is social dimension, j=3 is environmental dimension; j=4 is technical dimension). Notation *i* represents the name of the specific sub-indicator of the particular sub-dimension.

$$I^{+}_{\mathrm{N},ji} = \frac{I^{+}_{\mathrm{act},ji} - I^{+}_{\mathrm{min},i}}{I^{+}_{\mathrm{max},i} - I^{+}_{\mathrm{min},i}}, \tag{2.9}$$

$$I^{-}_{\mathrm{N},ji} = 1 - \frac{I^{-}_{\mathrm{act},ji} - I^{-}_{\mathrm{min},i}}{I^{-}_{\mathrm{max},i} - I^{-}_{\mathrm{min},i}}, \tag{2.10}$$

where $I^{\pm}_{\mathrm{N},ji}$ is the normalised value (positive +, or negative –) of individual indicator *i* for dimension *j*.

After that the weighting is performed by one of several potential methods, see table 2.2., – equal weighting, multivariate analysis (e.g. principal component analysis, factor analysis, data envelopment analysis), analytical hierarchy process (AHP) or even by participatory methods as involving various stakeholders for weight assignment (i.e. experts, society, politicians) [106].

Table 2.2.

Weighting methods for CSI construction [107], [108]

Method	Composite indicators
Equal Weighting	Composite leading indicators
	Environment sustainability index
	Human Sustainable Development Index
	Sustainable society index
Expert Weighting	FEEM Sustainability Index
Analytic hierarchy process (AHP)	Composite sustainable development index
	EU new economy policy indicators
Principal component analysis/factor analysis	Mega Index of sustainable development
	Sustainable development index

When weights have been assigned to each sub-indicator the following step is the aggregation of all the sub-indicators in each dimension. The calculation is performed using the Eq. 1.11, where W represents the determined weight of the indicator and I_N is the obtained normalized value of the indicator.

$$I_{S,j} = \sum_{i}^{n} W_{ji} \times I_{N,ji}^{+} + \sum_{i}^{n} W_{ji} \times I_{N,i}^{-}, \qquad (2.11)$$

where

$I_{S,j}$ – weighted sub-indicator, in dimension j;

W – weight of variable i in dimension j.

Then the final composite sustainability index is determined by the accumulated sum for each dimension with its corresponding weight. The calculation is done according to Eq. 2.12.

$$I_{CSI} = \sum_{j}^{n} W_j \times I_{S,j} \qquad (2.12)$$

where I_{CSI} is complex index of alternative I.

The obtained sum of all the dimensions is the final CSI index that can be used for further comparisons in the research study.

2.2. Meso-level assessment research methodology

The successful transition towards sustainable bioeconomy comes about through radical innovations that are promoted mostly by academics of universities and research institutions.

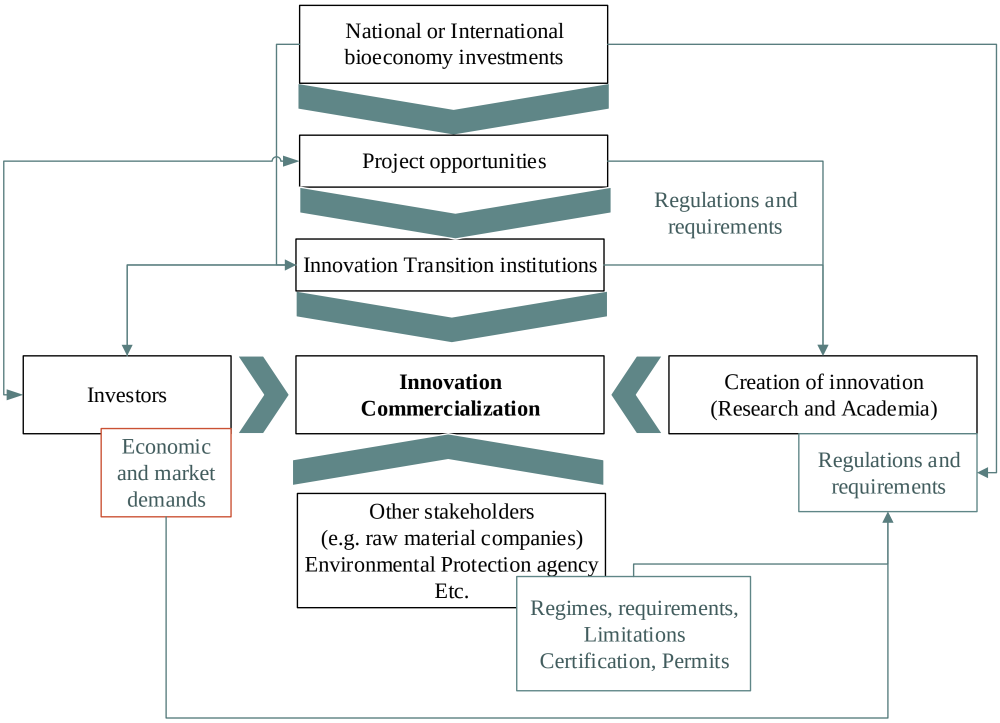


Fig. 2.6. General meso-level algorithm through transdisciplinary lens (created by author)

In fig. 2.6. general meso-level algorithm shows the importance on transdiciplinarity, where several stakeholders'(institutions') views, regulations and requirements should be taken into account for radical innovation transition to successful commercialization, for example the main interest of investors are economic justification and market opportunities, that are the base for successful product or technology commercialization. Innovation commercialization now is promoted by innovation transfer institutions that work as a bridge between investors (business thinking) and academia (science thinking) through projects that are funded by national or international stakeholders. From one point of view it is very useful for innovation commercialization and bringing together two differently thinking parties, but it comes with some requirements and challenges and trust from both sides. For example, if the requirement is to commercialize the technology or product with licence costs not less than 300 000 Eur, for academics it could be a challenge to adapt this product or technology so that the revenue from it is not less than investments made.

Meso-level assessment methodology is shown in Fig. 2.7. For transdisciplinary analysis it should include scientific point of view and stakeholders' interests of meso-level assessment.

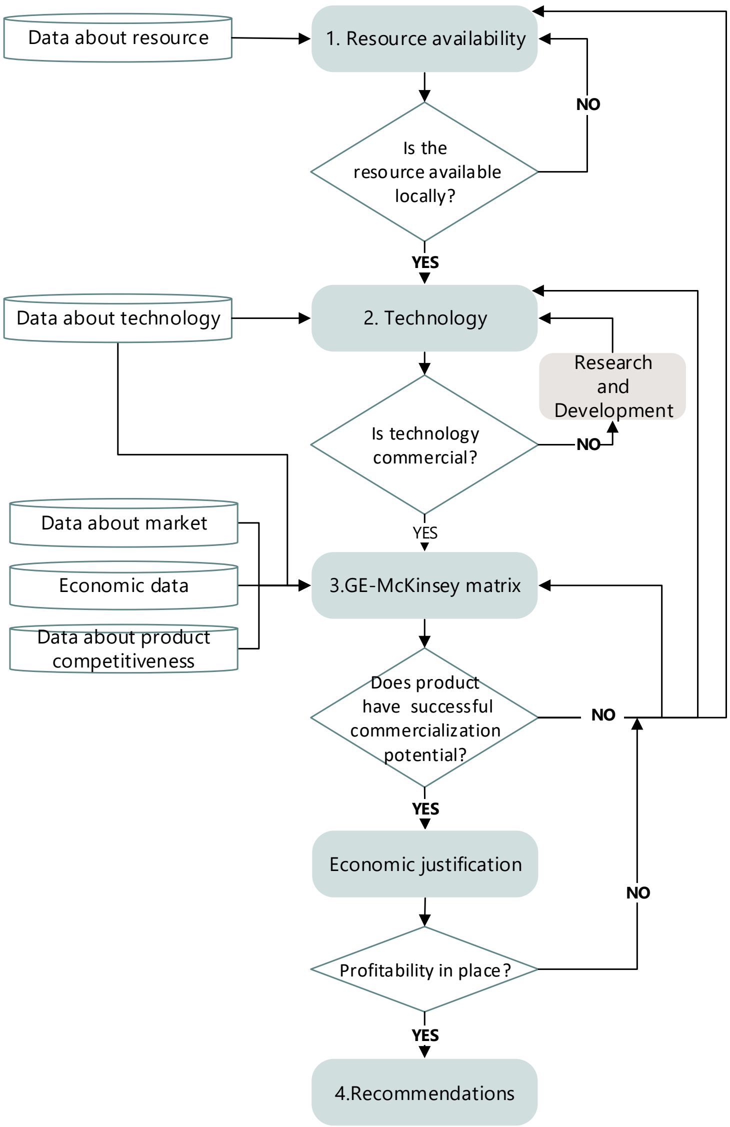


Fig. 2.7. Meso-level assessment algorithm (created by the author)

Step 1: Resource availability is the first step to promote bioeconomy. Resources should be local and not dependent on import.

Step 2: Technology should be available on commercial scale even if it is innovative technology. If innovative technology is not yet in commercial stage it goes back to research and development (R&D) stage.

Step 3: Decision making matrix in this case is GE–McKinsey matrix that has been used for market assessments. Economic data and data about technology have been collected for calculations, as well as data about product competitiveness and data about the market. After obtaining the results, these data are placed in the matrix for decision making. A positive result from calculation does not always show the actual situation; use of the matrix visualization is typically necessary. Information sources for the matrix consist of scientific publications, existing plant data, and annual reports. Expert opinion, not including consumer surveys, can also be considered. Data analysis is carried out based on the collected data from information sources and shown in two dimensions (market attractiveness and product competitive advantage) on the GE–McKinsey matrix. The main data are collected from information sources such as scientific research papers or the subject company's data sources (excluding consumer surveys).

Step 4 is matrix result visualization and recommendations on further assessment on new product production in current location or country where local resources are available.

2.2.2. Market potential analysis GE McKinsey Matrix

The methodology employed here (GE–McKinsey Matrix) uses nine modules or boxes to denote aspects of the market for potential new bioproducts. The methodology, see Fig.2.7, has been developed and proven on three existing products.

The methodology for the GE–McKinsey matrix has been modified to include considerations and constraints, such as environmental protection, required in the manufacturing process and product sustainability. 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 an insight into market opportunities for the product.

A similar analysis can be made using the Boston Consulting Group matrix, which may be the best known planning framework. However, the GE–McKinsey matrix is newer and provides a more highly developed analysis with a broader range of factors. Basically, the GE–McKinsey matrix has been developed from the Boston Consulting Group matrix, as the latter was found not to be sufficiently flexible and had complexity issues as well [109]. The GE - McKinsey Matrix is widely used for product portfolio management and in the analysis of competitive scenarios [110].

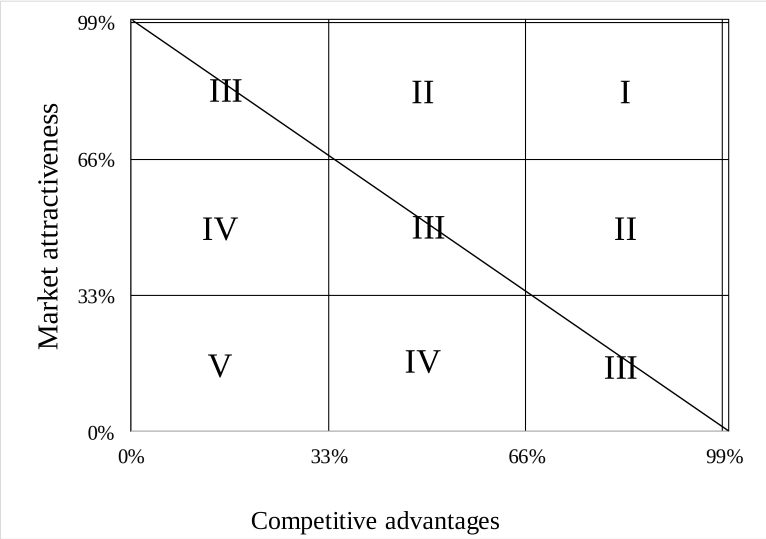


Fig.2.8. “Market attractiveness – competitive advantages” matrix, or the GE-McKinsey Matrix [109][110]

Figure 2.8. shows that products that are above the diagonal line are high performers with commercialization potential; these are the products that a company needs to focus on. Products that fall below the line need to be further analysed and improved until they appear at least above that line. Otherwise they should be discounted or in some cases discarded. Products can be also evaluated based on the quadrant in which they are located. A product in Quadrant I is worth investing with no further calculation or assessment and may be marked as a product leader. Products in Quadrant II have potential for growth and it may be advisable for the company to invest in them if improvements can be found and implemented. Products in quadrant III are in passably attractive markets but before proceeding need to be evaluated further to see if there are opportunities for biorefining. Quadrant IV represents weak markets; it is not advisable to invest in those products. Quadrant V products should be discarded [109][111].

The advantage of this matrix is that it takes into account a wider range of factors than the Boston Group matrix and is visually easier to understand. GE–McKinsey matrix has wider dimensions because it has nine fields, three *x* three grids. For comparison, the Boston Group matrix has only two *x* two grids [109][112].

Market attractiveness

Market attractiveness replaces market growth as the measurement of industry attractiveness. An analysis of market attractiveness includes market size, market growth rate, market profitability, demand seasonality and cyclicality, price sensibility, differentiation of product, presence of equivalent competitors and their level of specialization, investment capacity and access to raw materials.

Market attractiveness may be calculated as follows:

$$M_a = (z \times k)/100, \quad (2.13)$$

where

M_a – market attractiveness total score;

Z – estimated rating score.

$$k = \frac{100}{f \cdot B_{\max}}, \quad (2.14)$$

where

k – coefficient;

f – number of factors;

B_{max} – max rating score.

Competitive advantage

An analysis of competitive advantage includes demand, market share, availability of resources, market price, product quality and environmental friendliness of the manufacturing process, for example, cleaner production, circular economy principles or greenhouse gas decrease in process and in resource consumption.

The evaluation of competitive strength is conducted using a five-point scale where 1 (one) represents a lower competitive advantage and 5 (five) a greater one. Each of the factors selected are weighted by importance and relevance.

Each factor is evaluated differently: higher demand for the product is weighted as five and lower demand is weighted as one. Market share is evaluated as follows: one represents 1-20%, two represents 20 – 40%, three represents 40-60%, four represents 60 -80% and five represents 80 – 100%. For the availability of resources, five represents easily available and one indicates the resources is available but with difficulty. Pricing is from a manufacturer's perspective where one represents the lower price and five the higher price. For quality, five represents the highest quality and one the lowest acceptable quality. If little or no positive environmental impact results from the manufacturing process a one is assigned; whereas a five is assigned if the environmental impact is very positive. A circular economy, closed loop process, technologies and/or resources that result in decreased greenhouse gas emissions, ecological footprint etc. would be considered high positive impact and therefore would be given a five.

Competitive advantages or strengths can be evaluated for either a business unit or a product. In this case, the evaluation is done for a product and as competitors are selected, similar products based on resemblance in consumption and global market share will also be evaluated.

Market segmentation can be adapted to this assessment. If required, a particular product evaluated in one segment can be assessed in several segments to determine the resulting variations. The results of the evaluation in different segments are unlikely to be the same for any one particular product.

Different products from one particular resource, in this case woody biomass, cannot be compared, because the evaluation applies solely to the product evaluated. The means, for example, that a score of five for one product is not the same as a five for a second product.

The relative competitive advantage indicator is calculated by comparing a product with its strongest competitor and is expressed by the equation:

The relative competitive advantage indicator is calculated by comparing a product with its strongest competitor and is expressed by equation

$$R = \left(\frac{B}{B_{\text{comp}}} - 1\right) 100, \%, \quad (2.15)$$

where

R – relative indicator of product competitive advantages;

B – new product score estimation;

B_{comp} – score estimation of strongest competitor.

However, the disadvantage of the GE-McKinsey Matrix is that compilation of the factor indicators can be difficult and the assessment and weight given to their importance are based on the opinion of a person or persons, albeit someone with demonstrated expertise in the subject field.

2.2.2. Market segmentation and Economic analysis

For every stage of technology readiness, it is necessary to analyse the situation on whether the research idea is viable. The most important factors for viability include economic and market analysis and consumer profile, information on whether the new product is going to meet its potential consumer. In early stages such as TRL3–TRL5, it is important to understand the value of the potential product by analysing potential outlet market segments, their size and growth rate.

To assess market demand and consumption, the consumer profile should be developed, segmentation and market trend (by compound annual growth rate and market size) should be assessed. Political instruments can facilitate eco-innovations entering the market, and thus the assessment of relevant existing political instruments, such as directives, national regulations and standards, should be acknowledged. Demand pull instruments are important for successful commercialization, therefore economic justification is needed. Economic justification is based on the evaluation of industrial manufacturing calculations with emphasis on product price which should be the same or lower than fossil-based products. Eco-innovations cannot enter the market if they are not cost effective and if their price is significantly higher than fossil-based products. This is one of the challenges that should be overcome in the product development stage.

$$0 = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{(1+IRR)^3} + \cdots + \frac{CF_n}{(1+IRR)^n} \qquad (2.16)$$

where

CF_0 - initial investments

$CF_{1,2,\ldots n}$ – cash flows

N – period

NPV – net present value

IRR – internal rate of return

$$NPV = \sum_{t=1}^{n} \frac{Rt}{(1+i)^t} \qquad (2.17)$$

where

R_t = Net cash flow during single period

i – discount rate

t- time period

2.3. Micro-level assessment research methodology

Micro-level assessment methodology algorithm is described and showed in Fig. 2.9.

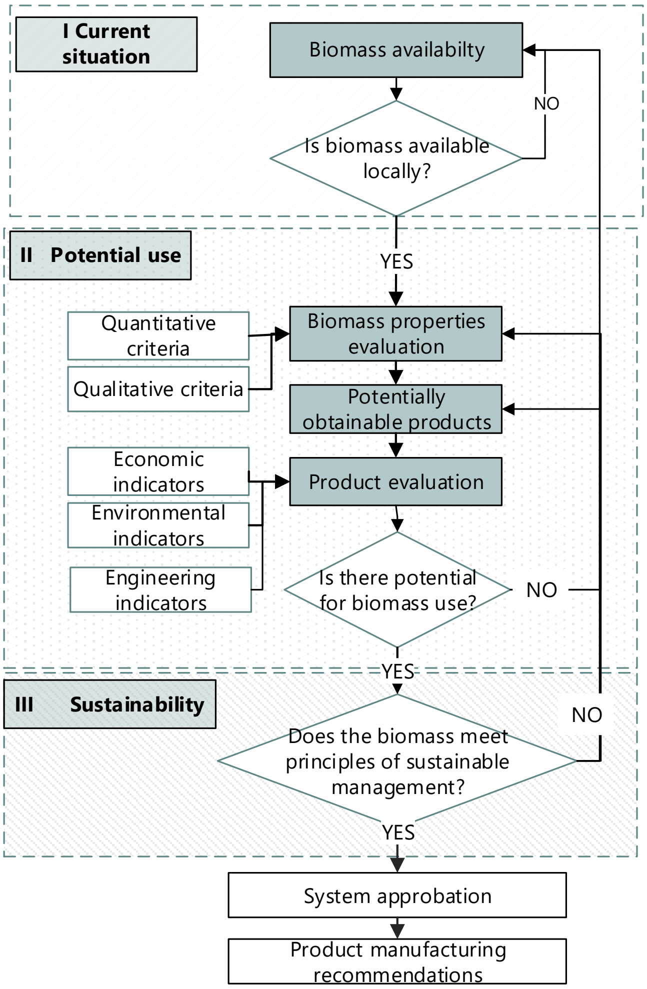


Fig. 2.9. Micro-level assessment algorithm (created by the author)

Micro level assessment is based on bioresource availability locally, potential value assessment and priority selection as decision analysis. Experimental analysis done for solid biofuel potential.

MCDA method Technique of Order Preference by Similarity to the Ideal Solution (TOPSIS) was used to prioritize underused bioresources occurring in Latvia accordingly to their valorisation aspect. In this case the ideal solution' is the species that show priority for further assessment of impact on ecosystem services, to biodiversity, social and economic impact (high, moderate of low). The alternatives are the invasive or potentially invasive alien plant species detected within a country.

2.3.1. Experimental analysis for solid biofuel potential assessment

Methodology is focused on the selection of raw materials that can be used as a solid biofuel and are not used in forestry, agriculture, aquaculture, and food industries. Sustainability criteria are determined to select appropriate materials and binders, as well as to find low cost and preferably residue/waste bioresource. At first, samples were prepared with and without binders. Binders were used in the same proportion for each sample. Determination of main solid biofuel parameters (ash and moisture content, calorific value) allows to evaluate the quality of raw material, binder and mixed pellet. Materials with higher calorific value, lower ash and moisture content were selected for further testing. In further sample preparation different binder proportions (10 wt. %, 30 wt. % and 50 wt. %) are used. Tested parameters are the same as previously. If calorific value increases, ash content remains the same or decreases and moisture content is lower than 10 wt. %, then solid biofuel and binder classifies as justified. If the changes are significant and without clear tendency, more samples need to be tested in different proportions to find the optimal proportion and results.

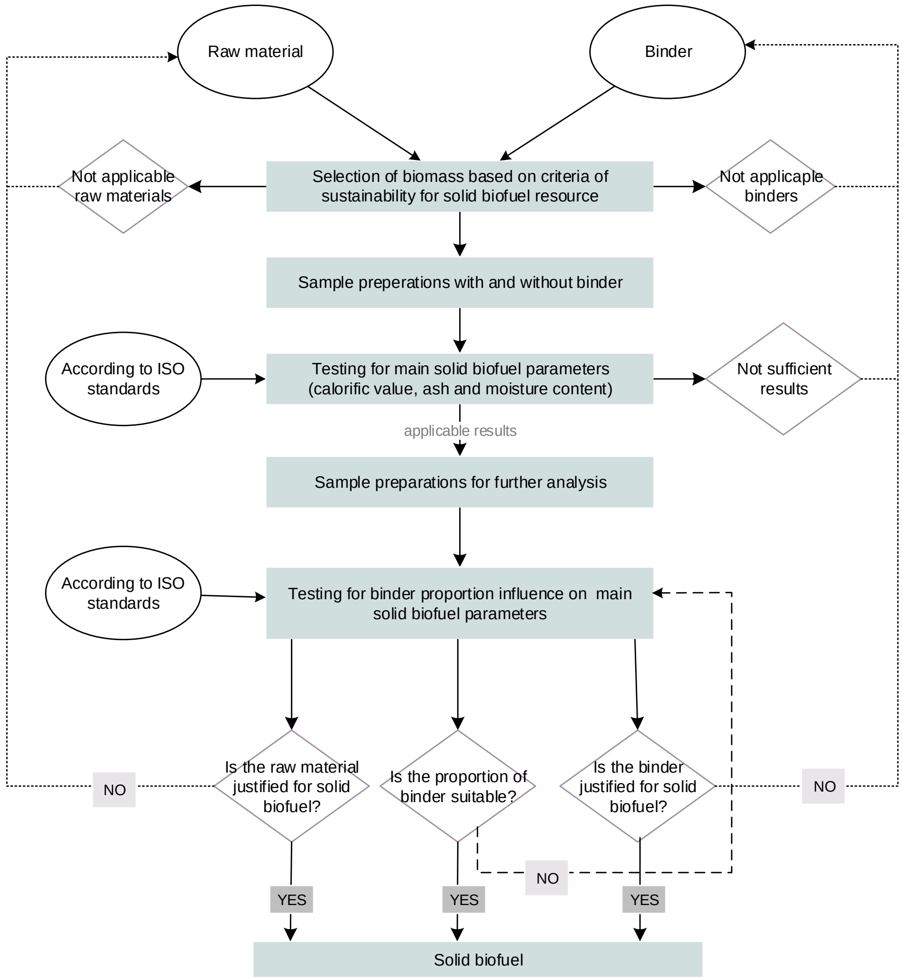


Fig. 2.10. Algorithm for new source solid biofuel validation (created by the author)

Fig. 2.10. shows the methodology algorithm for resource validation as solid biofuel. The steps and criteria selected restrict the selection of biomass and biofuel. The methodology case study is conducted on invasive species.

After selecting raw materials and binders by criteria of sustainability, two raw materials and two binders have been selected for sample preparation and further analysis.

Criteria of sustainability for raw material and binder selection for solid biofuel are as follows:

- non-woody resource;
- non-agricultural resource;
- resource that is not used in aquaculture;
- no fertilizer or additional water needed;
- resource that is not used in food industry;
- bioresource (not fossil fuel);
- residue/waste unused elsewhere;
- available/local resource (corresponds to geographical location and climate zone)
- low cost resource;

- resource is not used in the production of high added value product in the specific location (country);
- resource has positive impact on environment and climate.

The main biofuel characteristics was tested according to ISO standards on biofuel testing: ash content, moisture content and calorific value.

Ash content

Ash content analysis has been done according to ISO 18122. Nominal top size of particle was less than 1 mm. Ash content has been calculated by taking into account initial mass of test portion and mass of ash that remained after sample had been heated up to temperature of (550ºC ± 10)ºC and held for 2 hours. To prevent absorption of moisture from the atmosphere dishes with ash were kept in a desiccator.

Ash content was calculated according to equation (1):

$$A_{\mathrm{d}} = \frac{(m_3 - m_1)}{(m_2 - m_1)} \cdot 100 \cdot \frac{100}{100 - M_{\mathrm{ad}}}, \qquad (2.18)$$

where

m_1 – mass of empty dish, g;

m_2 – mass of dish plus the test portion, g;

m_3 – mass of dish plus ash, g;

M_{ad} – moisture content of the test portion used for determination of ash content, wt. %.

The result is calculated to two decimal places and the mean value is rounded to the nearest 0.1 % for reporting [113].

Maximum acceptable relative difference between results of ash content larger than 1% is 10%.

Moisture content

The sample was kept in air-tight plastic bags (according to EN 14778) and nominal top size was reduced below 1 mm [114]. The moisture content of general analysis sample has been determined according to ISO 18134-3. The sample was dried in a drying oven at 105 °C. Dishes were from non-corrodible and heat-resistant material covered with a well fitted lid [114].

It was assumed that the sample does not lose moisture during preparation of the test portion. The mass of test portion was in range 0.8–1.1 g.

After sample preparation, an empty and clean weighing dish with its lid was dried at (105 ± 2) °C and then cooled to room temperature in a desiccator. Then the test portion was put in dried dishes and dried without its lid at (105 ± 2) °C for 1 hour. One heating period lasted for 60 min. Each test portion was dried three times and each sample was tested in triplicate.

$$M_{\mathrm{ad}} = \frac{(m_2 - m_3)}{(m_2 - m_1)} \cdot 100, \qquad (2.19)$$

$$M_{\mathrm{ad}} = \frac{(m_2 - m_3)}{(m_2 - m_1)} \cdot 100, \qquad (2.17)$$

where

m_1 – mass of the empty dish plus lid, g;

m_2 – mass of the dish, lid, and test portion before drying, g;

m_3 – mass of the dish, lid, and test portion after drying, g.

For repeatability the result of triplicate determinations did not differ more than 0.2 % absolute [114].

Calorific value

Calorific value analysis was performed according to ISO 18125 standard. Experiment was done at isoperibolic condition, reference temperature was 30ºC [115].

Calculation of gross calorific value for dry mass (at constant volume):

$$Q_a^d = H_0 - \frac{Q_{N,S+} Q_S}{m} \tag{2.20}$$

where

$Q_{\mathrm{a}}^{\mathrm{d}}$ – gross calorific value at constant volume, J/g;

m – mass of sample, g;

$Q_{\mathrm{N,S}}$ – correction of heat, considering formation of nitric acid, J;

Q_{S} – correction of heat, considering formation of sulphuric acid, J;

H_0 – gross calorific value of the analysed fuel, J/g.

Repeatability limit for non-wood solid biofuels is 140 J/g[115].

$$Q_S = 57 S^{\mathrm{d}} m_{\mathrm{s}}, \tag{2.21}$$

where

S^{d} - sulphur content in the analysed sample (on dry basis), %.

$$Q_{V,\mathrm{dr,d}} = Q_{V,\mathrm{gr}} \frac{100}{100 - M_{\mathrm{ad}}}, \tag{2.22}$$

$Q_{V,\mathrm{gr,d}}$ – gross calorific value of dry mass at constant volume, J/g;

M_{ad} – moisture content of general analysis sample, wt. %.

$$Q_{p,\mathrm{net,d}} = Q_{V,\mathrm{gr,d}} - 212.2 H^{\mathrm{d}} - 0.8\left(O^{\mathrm{d}} + N^{\mathrm{d}}\right), \tag{2..23}$$

where

$Q_{p,\mathrm{net,d}}$ – net calorific value of dry mass at constant pressure, J/g;

H^{d} – hydrogen content in the analysed sample (on dry basis), wt. %;

O^{d} – oxygen content in the analysed sample (on dry basis), wt. %;

N^{d} – nitrogen content in the analysed sample (on dry basis), wt. %.

$$q_{p,\mathrm{net,ar}} = q_{p,\mathrm{net,d}} \left(1 + 0.01 M_{\mathrm{ar}}\right) - 24.42 M_{\mathrm{ar}}, \tag{2.24}$$

where

$q_{p,\mathrm{net,ar}}$ – net calorific value for sample as received at constant pressure, J/g;

M_{ar} – total moisture content, wt. %.

Testing for binder influence.

Validation on whether the resource and binder is justified as a solid biofuel is based on results or calorific value, ash content and moisture content. For resources the justification is based on calorific value – closest to wood calorific value, lower ash content and lower moisture content. Binder justification is based on increasing calorific value or it can remain the same if it does not change other parameters, i.e. if binder added decreases calorific value it is not justified. Binder is also justified in terms of decreasing ash content, if adding binder to the main resource it increases ash content, then binder is not justified and have to select a different binder. By adding the binder, the moisture level will increase, but it is important to determine the optimal amount of binder added, so the moisture level is optional.

3. RESULTS

3.1. Results of Bioeconomy Macro-Level Analysis

The transition to sustainable bioeconomy with a customized approach would speed up its development and make it more targeted. There is still no common international method for determining, measuring and comparing the extent of sustainability. The aim of this task is to develop a methodology for the assessment of bioeconomy influencing factor interlinkages, and creation of benchmarks through a top-down approach. The main output is the assessment of factor interlinkages that could be further used for composite sustainability index creation. A case of triple factor nexus is presented: policy, research and innovations and technology nexus for European Union countries. As a result, the empirical model presents the mathematical description of policy, research & innovation and technology link benchmark.

Altogether 24 bioeconomy affecting factors had been obtained in previous research. After expert evaluations and application of Delphi method, seven primary bioeconomy affecting factors and their linkages were identified (Fig.3.1.). Linkages were also based on scientific literature and discussed. Linkages are described as direct or indirect based on how they are affecting factors. In future research it is advised to use triple or quadruple factor link assessment to gain more insight into linkage characteristics based the factors that the link is connecting.

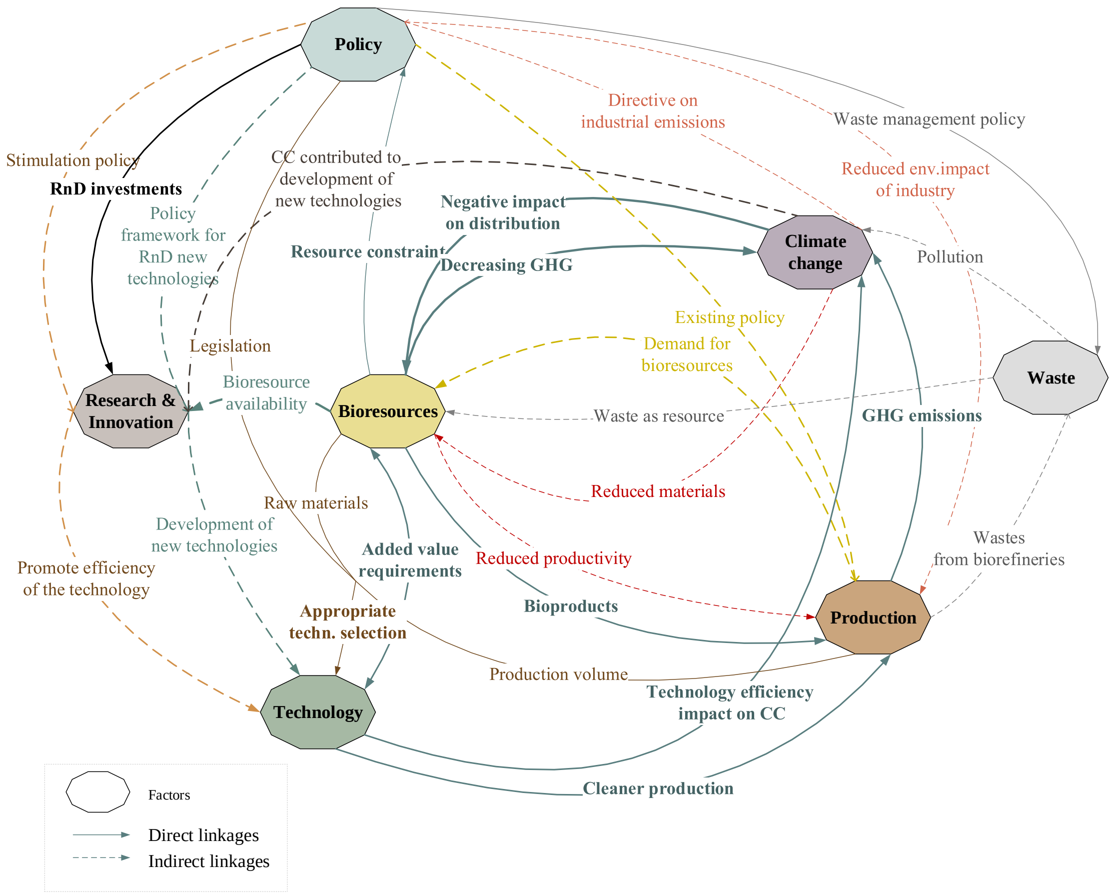


Fig. 3.1. Graphical representation of seven bioeconomy factors interlinkages (created by the author)

Modern technologies have impact on environment; energy efficiency has one of the more noticeable effects [116]. The industry has come a long way from burning coal with efficiency as low as 0.5% [117] to around 90% efficiency in the last decades [118]. In addition, technologies play an immense role in industry by allowing to produce bioproducts from raw materials, thus creating strong link between bioresources, technologies and bioproducts [34]. Preference for specific technology is impacted by production volume and raw materials used, as well as regional legislation [119].

Policy has a strong role in technological development as strategic incentives to research and development leads to the improved production efficiency of technologies. Adopting these technologies in new and existing production plants could lead to growing demand for biomass feedstock [120]. Due to existing legislation it is to be expected that demand for biomass feedstock for production will indeed grow in local, EU, and even at the level [121] reducing the negative impact of production on climate [122]. Nevertheless, biorefinery causes pollution in form of gas, liquid waste and solids [123].

One of many negative aspects of the climate change is altered temperatures and water cycles [124] leading to change of bioresource distribution in region [36]. Popular example of this negative effect on industry is predicted decrease in coffee bean productivity [125].

Despite the fact that climate change negatively impacts industry, specific policies aimed at reduction of industry’s negative impact on climate need to be implemented [126]. These policies are made to endorse innovations that prevent industrial emissions, including pollution [127].

Fossil fuel burning releases the carbon sequestered millions of years ago back into the atmosphere, hence increasing the amount of carbon in the active carbon cycle [117]. To slow down the climate change, fossil resources would need to be completely replaced by bioresources [128]. This would be an immense commitment from industry’s part, as demand is dictating the supply. Demand not only dictates the amount of available bioresources but stimulates the development of new greener technologies [129]. Unlike fossil resources, bioresources vary in composition, requiring more variable technologies demanding a more flexible approach form industry [121]. In addition, various biomass leads to different products with varying value per ton of raw material [120].

Recognizing the crucial role of research and development in innovative technology development [120], the EU allocates considerable amount of resources to promote research and development of biotechnologies [121].

Main nexus identified from graphical representation linkages (Fig.3.1) are: policy–research and innovations–technology; production–waste–climate change; production–waste–bioresources; policy–production–bioresources; technology–production–climate change; climate change–policy–production; policy–technology–production–bioresources; climate change–bioresources–production.

MCDA for all seven selected bioeconomy factors is performed with AHP and TOPSIS methods. AHP and TOPSIS methods are two of the most used MCDA methods [130]. TOPSIS matrix with initial values is seen in Table 3.1., it is then normalized using the vector normalization method and weighted accordingly. Distances till positive and negative solutions by Euclidean distance helps to rank the alternatives [131].

Table 3.1.

TOPSIS matrix for factor evaluation based on link type and amount

Alternatives, $A_{n,\ n=1\ldots7}$	A_1	A_2	A_3	A_4	A_5	A_6	A_7	∑
Criteria, $i_{m,\ m=1..4}$	*Research and Innovations*	*Technology*	*Production*	*Waste*	*Policy*	*Bioresources*	*Climate change*	Total number of links
Direct influencing link, i_1	1	2	2	1	1	3	2	12
Direct dependent link, i_2	0	3	1	1	3	4	1	13
Indirect influencing link, i_3	4	2	3	1	1	2	1	14
Indirect dependent link, i_4	2	0	2	1	4	2	3	14
Total number of links ∑	7	7	8	4	9	11	7	

Assumptions made on the link type strength are included in both analysis methods (AHP and TOPSIS). Both direct links (direct influencing and direct dependent) are assumed to be twice as important than indirect links (indirect influencing and indirect dependent). Therefore, weights are 1/3 (or 0.33) for direct links and 1/6 (or 0.17) for indirect links.

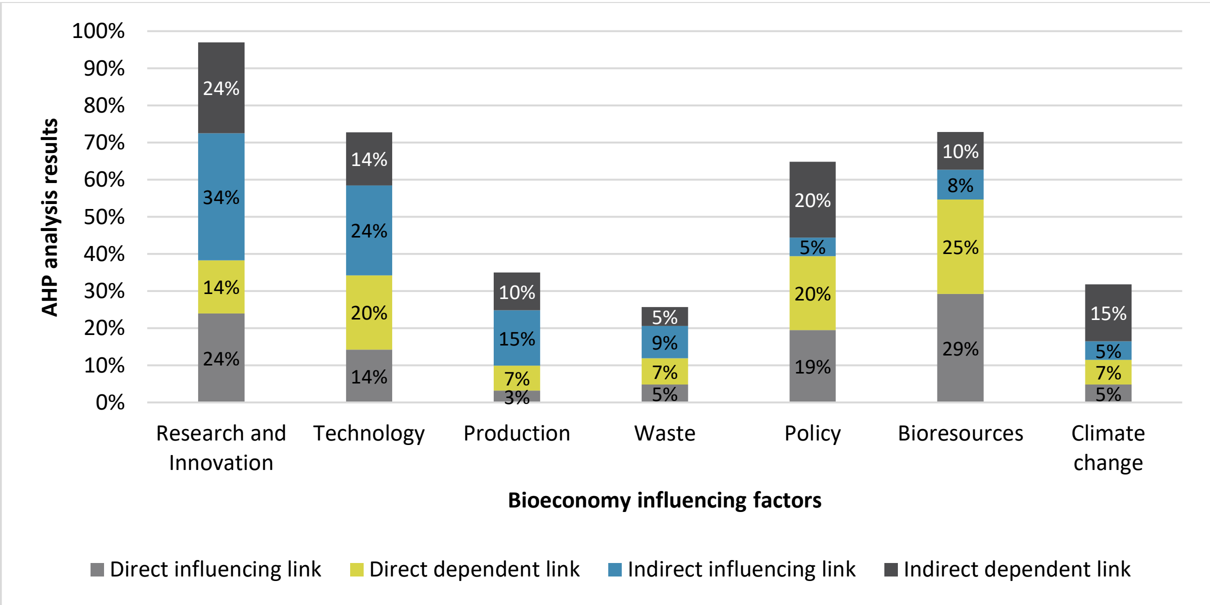


Fig. 3.2. AHP scores for factors based on link type (author analysis)

From evaluation in Table 3.1., it is seen that there are more indirect links than there are direct linkages between factors. For example, for research and innovation the largest share of the AHP analysis result is due to indirectly influencing links (see Fig.3.2.), so it can be understood as this factor is more of an instrument (driver) for bioeconomy development and works in close connection with other factors. The highest share of direct links, is for bioresources, which is a factor that bioeconomy is based on. Policy and technology factors in AHP analysis also show great impact.

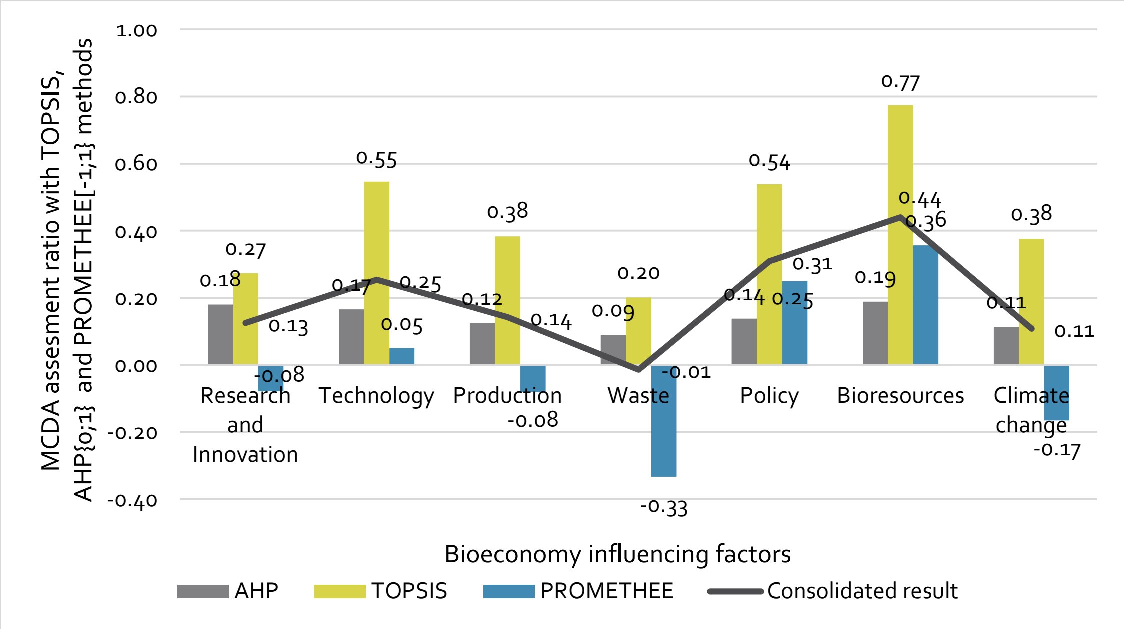


Fig.3.3. MCDA analysis results for seven bioeconomy influencing factor importance based on their interlinkages (author analysis)

Fig. 3.3. shows the final results three methods that differ based on approach used. After a pairwise comparison (AHP) it was determined that the highest impact is for research and innovation, bioresources and technology, that can be confirmed by bioeconomy's definition as knowledge based and bio-based economy [132] and that in 2012, biotechnology was set as priority driver for bioeconomy development [9]. PROMETHEE analysis shows the greatest impact on Bioresources, Policy and Technology. Although according to the TOPSIS analysis, bioresources have the highest score, technology and policy factors are also important. Bioresources play an important role in bioeconomy, as they are based on biomass and its sustainable use. Technology factor has high results in both methods, as it ensures sustainable use of resources, as well as provides a more effective use and development of new technologies and bioproducts. In TOPSIS analysis, policy factor has stronger results (second highest score between the alternatives) than research and innovations (6th highest score), and vice versa in AHP analysis method. Still, if we look back on interlinkages between these factors (Fig.3.1.), policy has indirect linkages through research and innovation that lead to technology factor. Therefore, it is proposed to take into account consolidated results, when selecting priorities for further assessment on factor analysis and linkage selection.

Interval scales for TOPSIS analysis results varies from 0.2 (waste) to 0.77 (bioresources), and AHP analysis results vary from 0.09(waste) to 0.18(research and innovation), PROMETHEE varies from -0,33 (waste) to 0,36 (bioresources).

3.1.1. Triple factor Nexus in European Union Bioeconomy Through Indicator Analysis

To better understand proposed methodology, a case study has been performed for European Union countries. Triple factor nexus has been assessed between the factors: policy, research & innovation and technology, see Fig.3.4. that is extracted from graphical representation(Fig.3.1.) and will be assessed in depth.

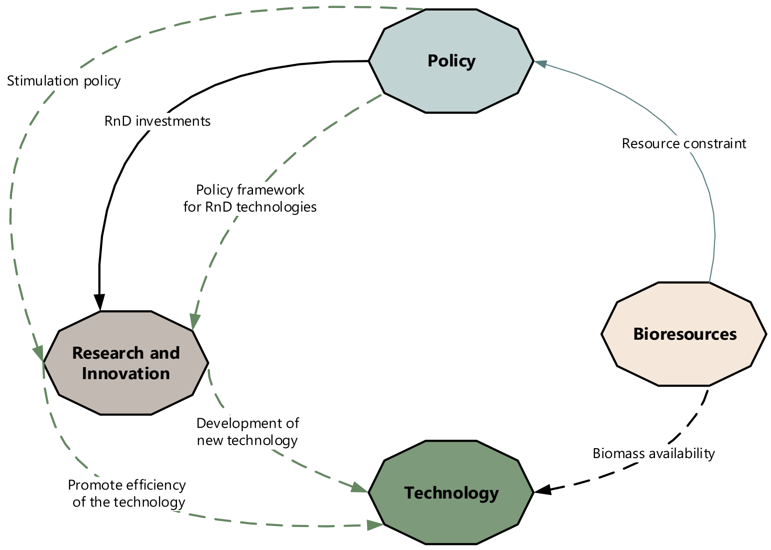


Fig. 3.4. Quadruple factor nexus: policy, research and innovation, technology and bioresources (created by the author)

Each factor has been described through indicator analysis. Main overlapping factor indicators were used to characterize linkage. Based on statistical data and correlation analysis, benchmark was determined.

Individual factor analysis

In order to build quadruple nexus evaluation, each factor is first analysed through indicator analysis.

Bioresource availability is one of the cornerstones of forest biomass and technology based bioeconomy [133]. The bioeconomy development-related increase in biomass demand can lead to biomass availability constraints that in turn manifest as a feedback loop where biomass scarcity hinders bioeconomy implementation [134].

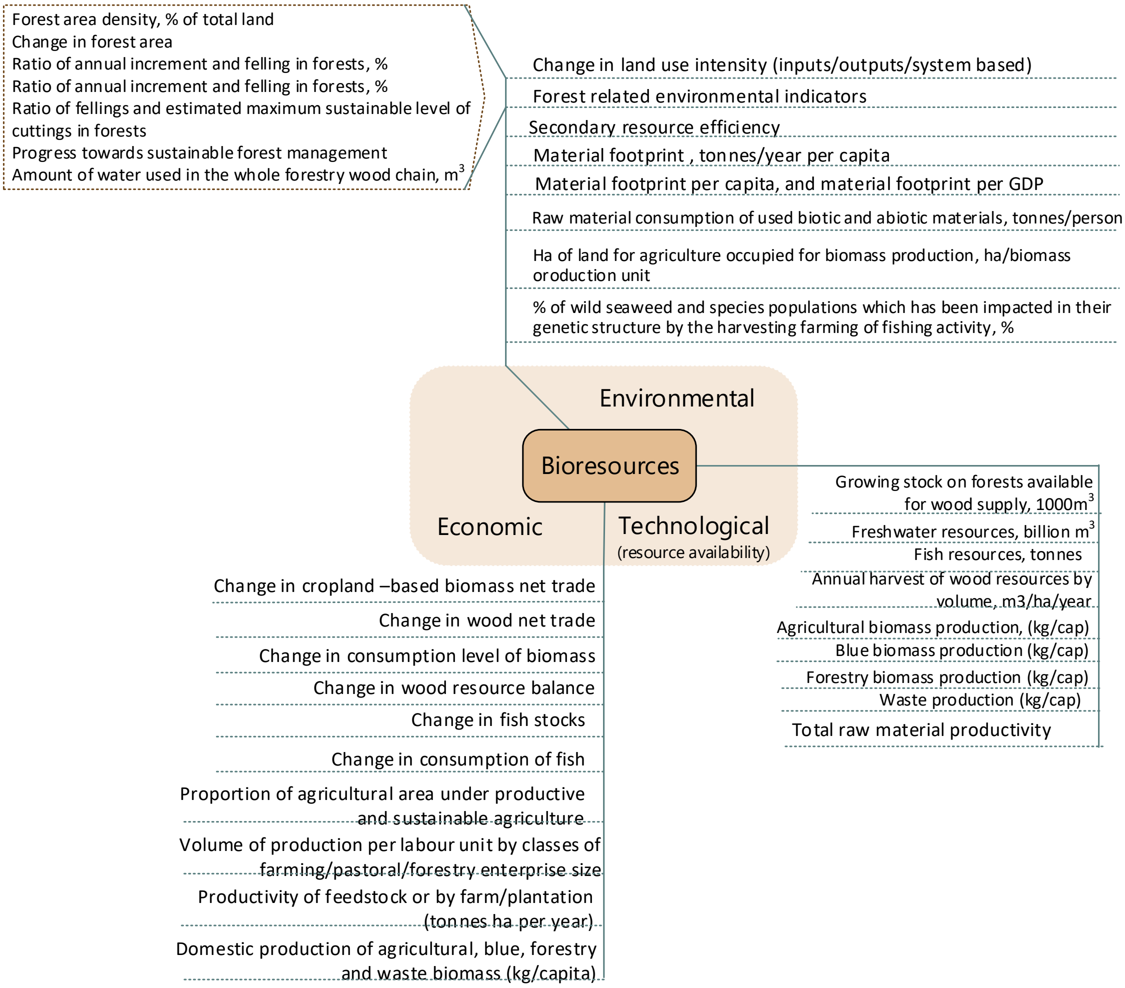


Fig. 3.5. Indicators that characterize bioresources factor in bioeconomy context (created by the author)

One source of bioresource characterizing indicators can be the national material flow accounts, where indicators as biomass domestic extraction amounts, imports, exports, as well as domestic material consumption (DMC) and direct material input (DMI) indicators are available. DMC describes “the total amount of materials directly used by an economy”. Other indicators have been proposed in literature, however, for now, these are more applicable at company or sector level, not country level.

Research and innovation factor characteristics

Technology transfer organisations is the way how to bridge the gap between industry and academics[135]. But countries and regions that rely on transnational science and technology transfer organisations to advance the development of new bioproducts [36], should also consider governmental support.

There are two stages for transition to bioeconomy innovation: incremental and gradual innovations (through new products and processes) and implementation of diverse, radically new and disruptive innovations [39], [132].

For an effective transition to sustainable bioeconomy there is a need for second type innovations. This means that it will take radical innovations to make a global change towards desirable goals. This includes redesigned business models, reconfigured supply chains, setup of new value chains, such as development of new sustainable products and technology’s needs, knowledge and skills outside their fields of expertise. Universities and research institutions are especially conceived as cornerstone to accomplish these radical innovations [39], [132].

Innovations can be described by type of innovation [136], stage of innovation development, technological readiness level (TRL) of innovation, extent to which innovations are disruptive or radically new [132], [137], level of complexity in the knowledge base for the innovation development [132], degree of cooperation between different actors in innovation development [39], level of complexity in the policy framework (European Commission Bioeconomy strategy 2012) and level of nonlinearity in the innovation development. “HORIZON 2020” has been one of the main instruments for promoting innovations in bioeconomy [132], and now it can be seen how efficiently that has worked.

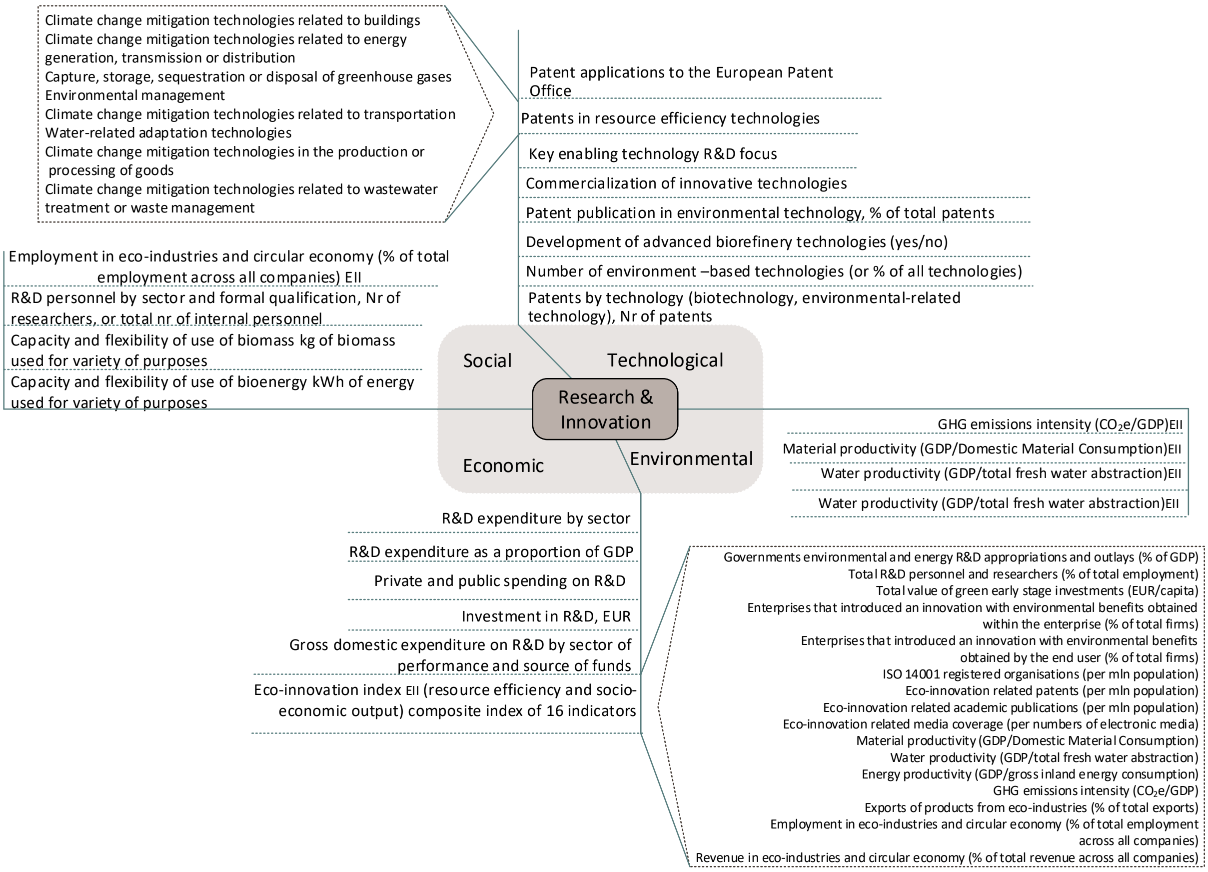


Fig.3.6. Indicators that characterize research & innovation factor in bioeconomy context (created by the author)

Fig.3.6. shows main indicators of research and innovation factor, where two of the indicators have been explained in more detailed by sub-indicators: Patents in resource efficiency technologies and Eco-innovation index (EII). For indicator references see Annex A.

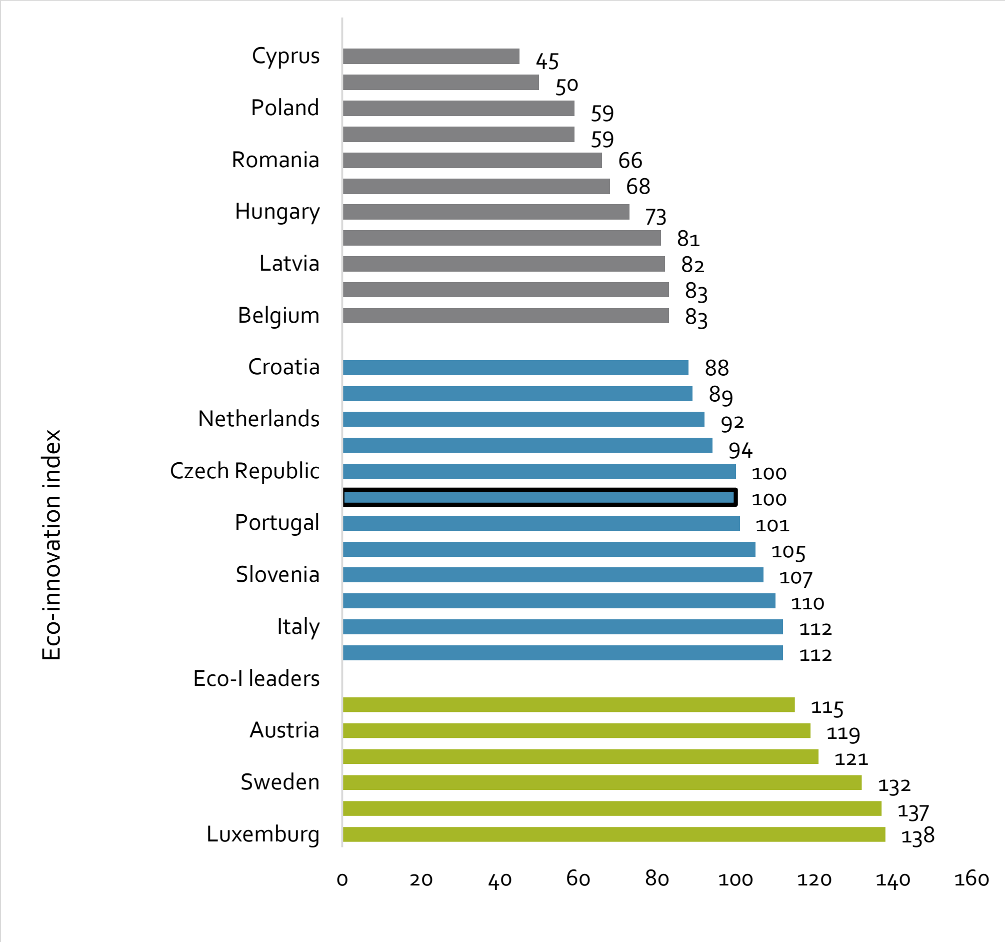


Fig. 3.7. Eco- innovation performence groups between countries (Data: 2018) [104]

Composite index, see Fig.3.7., that is related to environmental dimension is the eco-innovation index that is used to describe the eco-innovation progress in EU member countries. Eco-innovation index is composed of 16 indicators that are grouped into five major groups: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes. As well, the eco-innovation progress is described by the eco-innovation scoreboard. The leader in eco-innovations is Luxemburg.

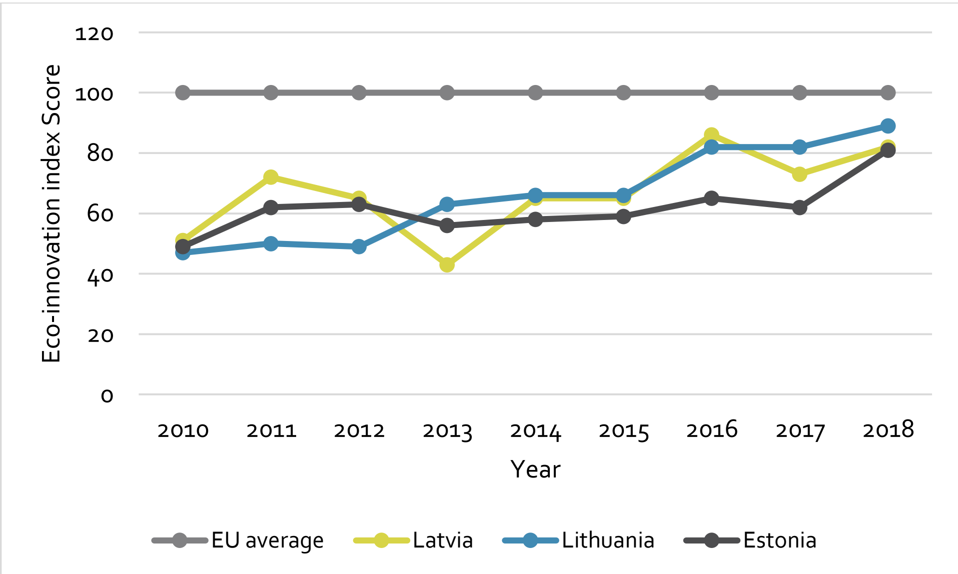


Fig.3.8. Eco-innovation index for Baltic states from 2010-2018 (EU=100)[104]

Baltic states are improving their eco-innovation index, if we look at dynamics of the results, although all Baltic states are still under the benchmark that is EU average, see fig.3.8.

The number of patents is the best quantitative indicator that characterizes Research and Innovation factor, especially, patents for biotechnologies and patents of resource efficiency technologies. Number of patents on resource efficiency technologies are divided into several sub-indicators [138] that include:

- Climate change mitigation technologies related to buildings
- Climate change mitigation technologies related to energy generation, transmission or distribution
- Capture, storage, sequestration or disposal of greenhouse gases
- Environmental management
- Climate change mitigation technologies related to transportation
- Water-related adaptation technologies
- Climate change mitigation technologies in the production or processing of goods
- Climate change mitigation technologies related to wastewater treatment or waste management

All of these sub-indicators mainly focus on climate change and GHG mitigation technologies. Therefore, they do not cover all of the technologies whose development impacts bioeconomy.

Patent data are available and easily collected for analysis, however patent data do not capture all innovations [139].

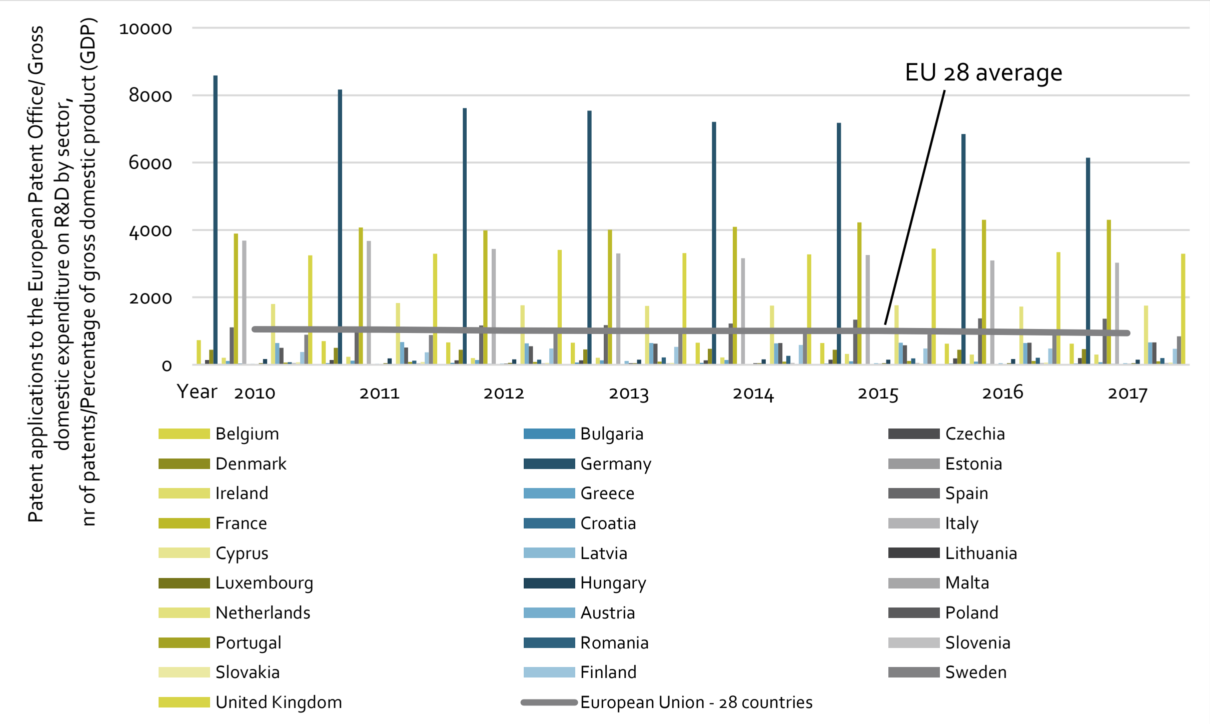


Fig.3.9. Patent applications to the European Patent Office/ Gross domestic expenditure on R&D by sector, *nr of patents/Percentage of gross domestic product (GDP*) (author analysis)

Patent applications are the main research and innovation output that can determine efficiency of Innovations. Fig. 3.9. shows the results for the indicator Patent applications to the European Patent Office according to gross domestic expenditure on Research and Development by sector from 2010 till 2016 (available data from EUROSTAT database). The EU 28 average is taken as benchmark and countries over the benchmark are selected as top countries for Research and Innovation factor benchmarking. Top countries are Germany (explicitly higher), France, Italy, United Kingdom, Netherlands and Spain.

Policy factor characteristics

Policy is defined as a general set of actions and measures that are planned and set at the highest level of management and which include approved attitudes and regulations that must be followed when managing the operations of an organization [140]. Another policy understanding states that "a policy is a statement of intent to change behaviour in a positive way, while an [policy] instrument is the means or a specific measure to translate that intent into action" [141] [142].

Policy is one of the strongest and most significant factors that influences the implementation of sustainable bioeconomy. Bioeconomy development in a country depends on its political system and preferred policy instruments [143]. The EU Bioeconomy strategy (2012) and its updated version (2018) [27] both emphasize the significance of policy for the development of bioeconomy.

The general types of policy instruments are: constraining and control measures, innovation promotion, product pricing mechanisms, information measures, enabling actors, supporting investment [142].

Policy interventions may enable transition to sustainability and bioeconomy, but no single policy can ensure full systemic implementation of such transition. [126] A combination of various policy instruments is required to ensure the development of bioeconomy [120]. The policy instruments that are intended to promote the development of bioeconomy can generally be classified into four groups:

- legal, i.e. necessary changes in regulations and/or quality standards to allow and advance the sale of bioproducts;
- support for voluntary initiatives and requirements for public sector regarding implementation of biological waste collection;
- providing financial incentives for private investments in biorefineries (e.g. green certificates or feed-inn tariffs);
- public financial support for research and development [120].

Referring to the latter two groups of instruments, policy is related to the production and research and innovation, as the subsidies prescribed by a bioeconomy enhancing policy are commonly directed towards industry or research and innovation.

By providing performance measurement, reporting and communicating to stakeholders, policy indicators help ensuring consistent and transparent consideration of sustainability within public policy [144]. Indicators that can be used for assessment of bioeconomy policy are those that characterize bioeconomy development (for references, see annex B.). Figure 3.10. provides a graphical summary of indicators related to policy factor. Better indicator performance as a result of the implemented policy would prove the effectiveness of the policy, while no change or even decrease of indicator performance indicates inefficiency of applied policy.

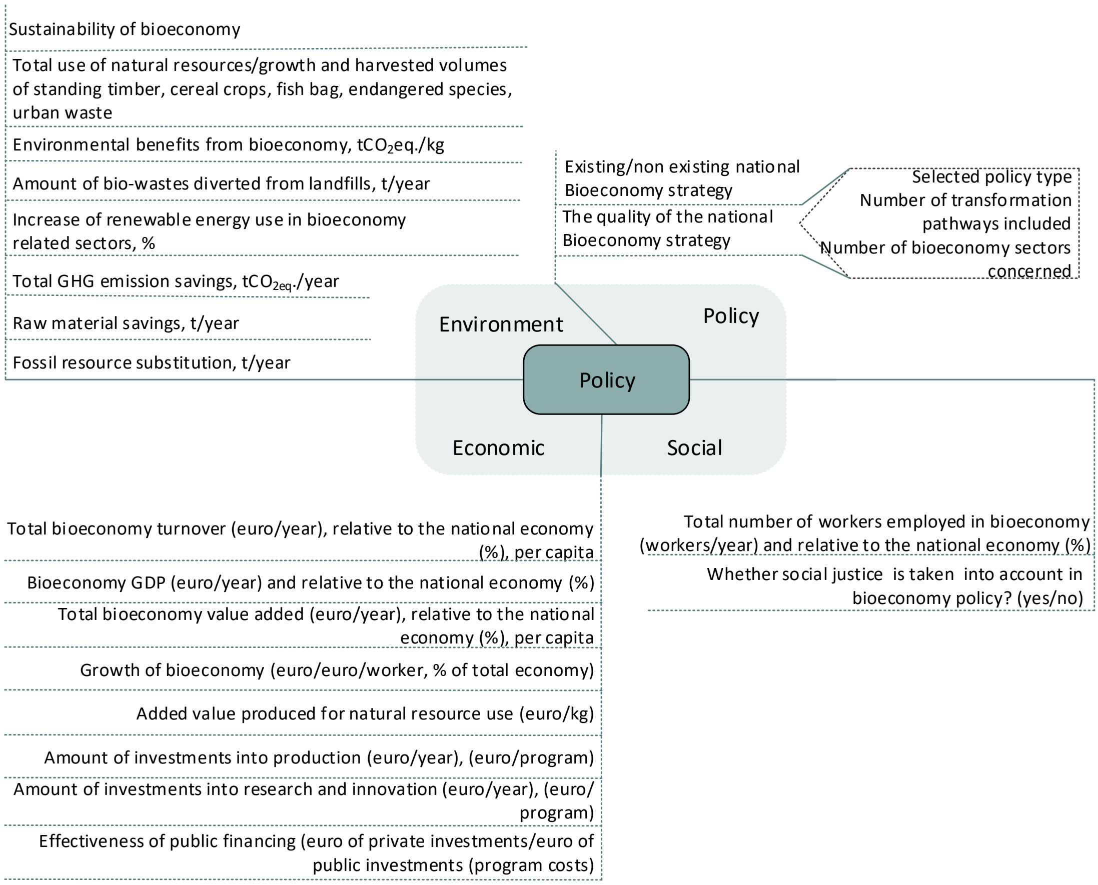


Fig.3.10. Indicators that characterize policy factor in bioeconomy context (created by the author)

Regarding policy instrument assessment, another aspect to consider is that various countries may have preference to different policy measures. Nevertheless, policy effectiveness should be assessed in respect to the chosen indicator, not based on what type of instruments are used [142] also longevity of certain policies [10], for instance, change of a left-wing government to a right-wing one might affect the policies.

Technology factor characteristics

Technologies are one of the main pillars of bioeconomy. Technologies bridge the gap from innovations to production and from unused or underused biomass to bioresources. Technologies include environment-related technologies, that allow to mitigate climate-change, biotechnologies and existing technology improvements that either solve the possibility to use biomass that otherwise could not be collected, or help advancing efficiency of resource use

One of the greatest emphasis of the technology factor in the context of bioeconomy is for biotechnologies. By collecting a list of biotechnology definitions OECD has made one single statistical biotechnology definition: “The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.” [145] Biotechnology has an important potential not only for economic development, but also for bioeconomy development [146]. Biotechnology cannot be advanced without knowledge, therefore there is strong link to education and research institutions. As the main result from development of technologies are patent applications, there should be a correlation between promotion of patent production at a local level as well as at international level to succeed in technology commercialization [146].

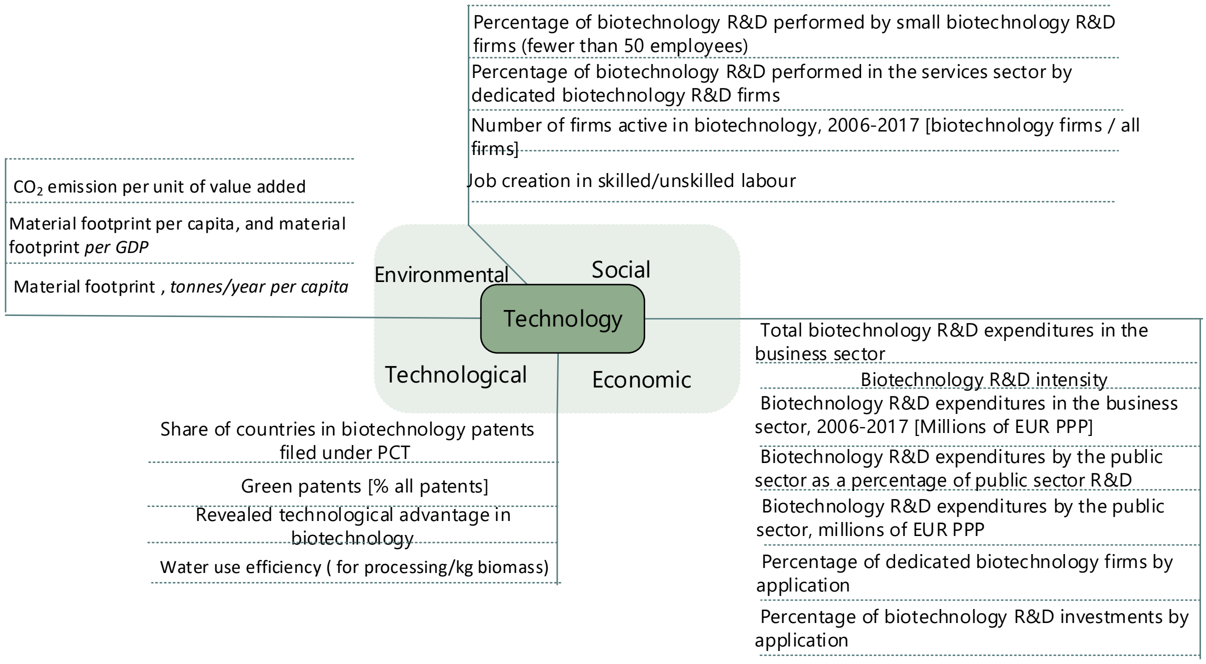


Fig. 3.11. Indicators that characterize technology factor in bioeconomy context [147], [148] (author representation)

Technology indicators showed in fig.3.11. are derived from OECD statistics as key indicators for technology (biotechnology). The number of active biotechnology firms in Latvia (including medical biotechnology, environmental biotechnology, industrial biotechnology and agricultural biotechnology) according to the data that are available in OECD database for the last 2 years (2016 and 2017) is 9 and 12 accordingly [147]. That is the smallest amount in respect to the other countries for which data has been provided. However, in order to see actual situation, normalization should be applied.

3.1.2. Benchmark for Triple Factor Nexus: Policy, Research and Innovations and Technology

Effective policy framework is imperative in order to ensure innovation and the development of new technologies and production methods. In [120] and [126] it is stated that R&D investments are crucial for the development of innovative technologies. In [120] it is also stated that technology and machinery knowledge and organisation of biomass logistics are required for the development of bio-based solutions.

Maes and Van Passel [120] explain the dynamic relationship between policy, innovation, technology, production and bioresource factors. A stimulation policy that provides incentives to research and development, would promote improved production efficiency of the technology, which would in turn result in installation of those technologies in existing and new production plants. Sequentially, the requirements of the biomass feedstock would grow. Resource constraints are actually one of the main concerns in [120].

One indicator that is clearly overlapping between policy and research and innovation factors is investments in research and development. Countries are committed to significantly increase public and private R&D expenditures and number of researchers by 2030 as the part of

Sustainable Development Goals [149]. In more detail, the dynamic loops of R&D expenditure and dynamics of innovation diffusion and technology adaption are described in [150]. Environmental policy has an effect on technological innovations. It can be manifested through tax measures or quota obligations with an impact on patent activity [151]. Patent data helps to examine eco-innovations across and suggestions for future policy. Resource (input) indicators are R&D expenditures and personnel (in terms of knowledge acquisition), R&D intensive goods or expenditure for licenses. The output indicators for R&D results are patents. Patent data are more commonly used as output indicator and key measure of innovations [151]. Policy framework should search for optimal solution on innovation rate and direction. Market-based instruments may affect technological trajectory of the economy. The use of subsidies in support of environmental R&D could be in form of grants or tax credits.[152].

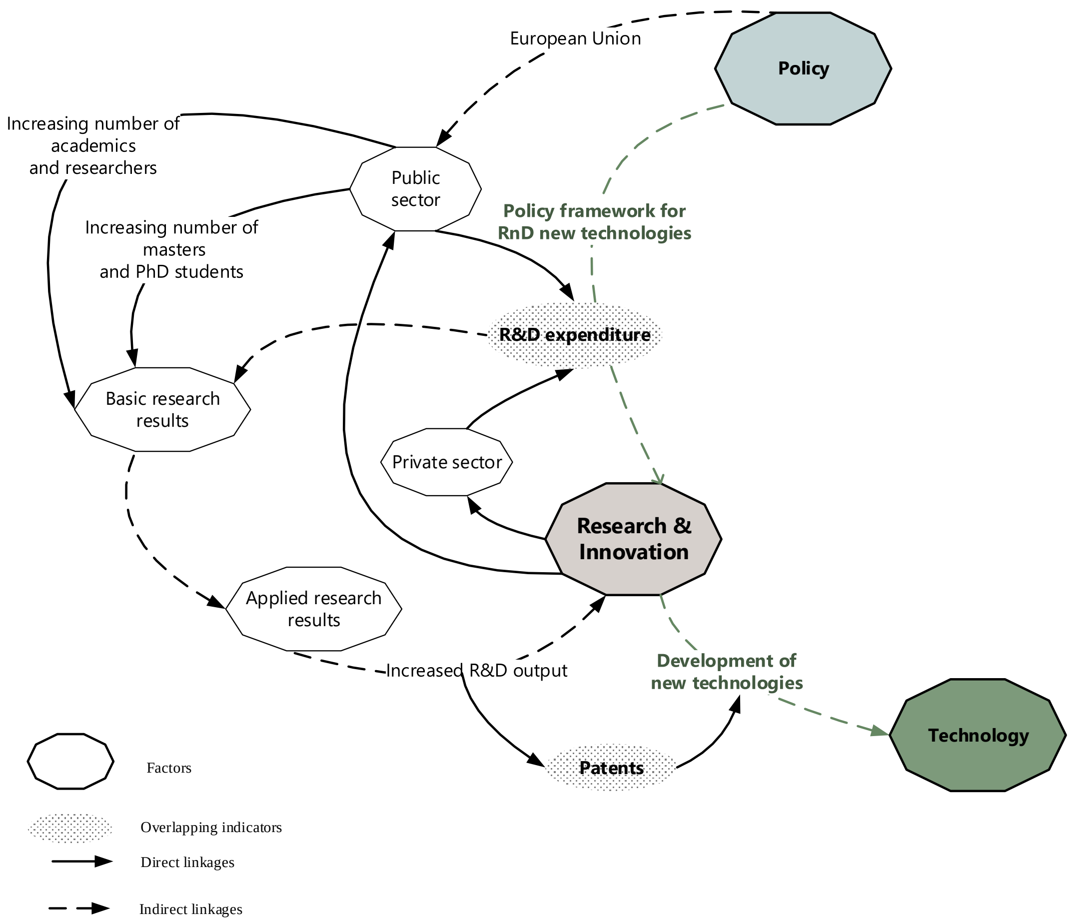


Fig.3.12. Triple factor nexus: policy, research and innovation and technology (author representation)

Looking at graphical representation in Fig. 3.1., the connection between policy and research & innovation goes through policy framework for new technologies can be measured as R&D expenditure (public sector (government) see Fig.3.11.), further connects research & innovation to technology as the development of new technologies (that can be measured with patent applications). Assessing the nexus in-depth, there are more additional factors, that ensure the existence of these linkages as presented in Fig.3.12.

The indicator of this link coincides with Sustainable Development Goal 9 (SDG9) [153], therefore is considered as a strong link towards bioeconomy sustainable development.

Benchmark analysis is one of the effective analysis methods for description of bioeconomy performance at a country level. In this case, the existing performance in each European Union country is analysed and compared with the practice in leading EU countries to adapt or improve the existing policy, moving towards sustainable bioeconomy development. In triple factor nexus, two indicators that have been selected for the assessment of one of the possible link benchmarks are R&D expenditures (that characterize the link between policy and R&D) and the number of patent applications (that characterize the link between R&D and Technology).

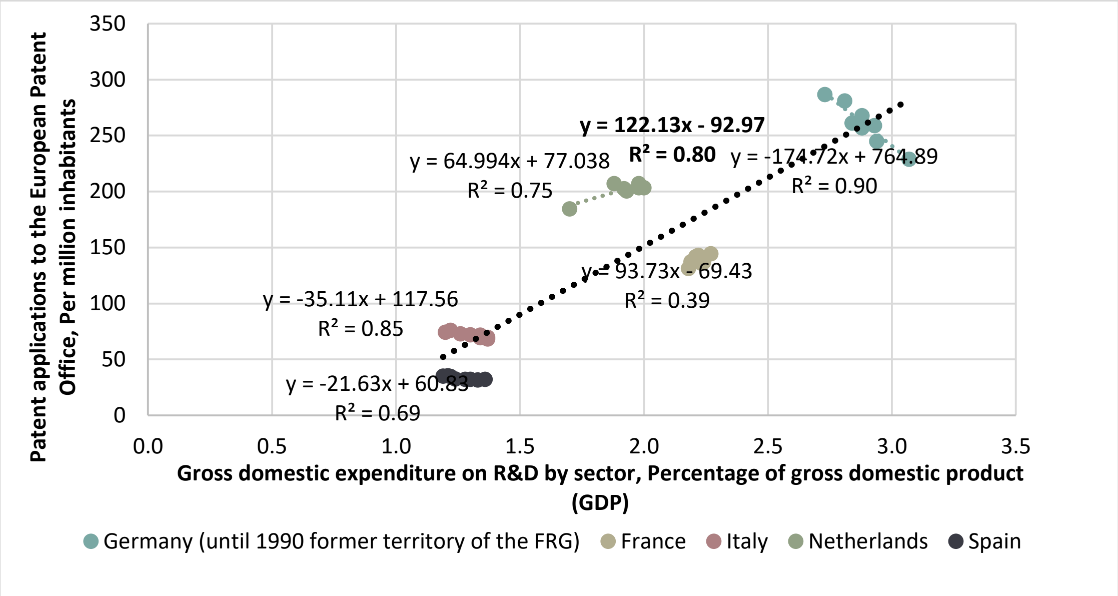


Fig.3.13. Benchmark for Policy, Research & Innovation and Technology link (author analysis) (Data: Eurostat)

Top countries[1] over the benchmark (which is set as European Union 28 country average (see Fig.3.9.) in Patent applications to the European Patent Office (SDG_9_40;Eurostat) attributed to the Gross domestic expenditure on R&D by sector (SDG_09_10; Eurostat) are selected for link indicator benchmark analysis. For these top countries (Germany, France, Italy, the Netherlands and Spain) data correlation is good at intra country level, as well as at inter country level (see Fig.3.13.), providing European Union with the best practice benchmark, with strong correlation (R=0.8).

The empirical model (3.1.) presents the mathematical description of policy, research & innovation and technology link benchmark.

$$P = 122.13c - 92.97, \quad (3.1)$$

where P – patent indicator: applications to the European Patent Office per million inhabitants;

c – gross domestic expenditure on R&D by sector.

With the use of this empirical model, each country can calculate their situation, based on the benchmark.

Some countries that are not in the top list, prove that there is an imbalance between these two indicative parameters, at intra country level. Therefore, more detailed assessment at a country level is needed to address appropriate policy measures or strategy that could accelerate

[1] United Kingdom is excluded from analysis due to Brexit and to provide reliable future benchmark.

patent applications as a result of expenditure for Research & Development. Policies in different countries may affect these trends, for instance, different, country specific incentives for researchers in academic institutions to apply for patents.

MCDA analysis can be integrated during system dynamic model development to quantify indirect and direct link parameters. In the current analysis, bioresources, technology and research & innovation factors acquired the highest scores from all seven factors considering the consolidated result. This quantitative analysis could help setting priorities and determine which of the factors are more linked with other factors.

The methodology for bioeconomy factor nexus approach presented in this research is a way how to move towards measuring of sustainable bioeconomy development. Once the collection of each factor-related indicators is performed, it is easier to find continuous linkages between factors and their indicators and therefore to establish benchmarks. Several benchmarks could be addressed for each linkage characteristics. Assessments of additional nexus in future research would provide a more comprehensive view. Limitations of using a top-down approach could be reached when statistical data are not available or have not yet been created (for example, for biorefineries or biowaste), for such situation bottom-up approach could be applied, e.g. companies' cases could provide a notion of which data are needed in order to develop the appropriate indicators and build a complete bioeconomy factor nexus. Such research could give important recommendations for statistical data necessity. The created methodology can be used as a starting point for holistic bioeconomy assessment, and it can be further expanded in system dynamic modelling or Complex index distribution.

3.1.3. Bioeconomy efficiency index

This index includes indicators that are related to the primary bioeconomy influencing factors and their interlinkages that were identified. The seven selected bioeconomy related indicators include biotechnology patent share, bioeconomy labour productivity, the added value of bioeconomy sectors attributed to its turnover, bioeconomy employment location quotient, development of environment related technologies, government support to research and development in agriculture sector, and biomass use location quotient, see table 3.2. These indicators were selected as they characterize the identified primary bioeconomy influencing factors, e.g. research and innovation, production, policy, technology, bioresources. However, the addition of indicators that characterize the factors climate change and waste at this moment was not possible, as the national statistics for the metrics that characterize these factors are only available in the context of the economy as a whole, but not separately for bioeconomy related sectors.

Table 3.2.

Selected dimensions and indicators for bioeconomy efficiency index

DIMENSION	INDICATORS
BIOECONOMY INPUTS	Government support to agricultural research and development (euro per inhabitant) Bioeconomy labour productivity per person employed (Turnover/Number of people employed) Location Quotient (people employed/people employed EU)
TECHNOLOGY	Development of environment-related technologies, % all technologies Biotechnology patent share (Number of biotechnology patents/ total number of patents)
BIOECONOMY RESOURCE PRODUCTIVITY AND AVAILABILITY	*Bioeconomy resource productivity (added value/biomass DMC) (million euros/1000tonne) (insufficient data)* Biomass DMC quotient (Biomass DMC/ biomass DMC EU) (tonnes/tonnes)
ECONOMIC VALUE	Bioeconomy value added/ bioeconomy turnover (million euros/million euros)
ENVIRONMENTAL IMPACTS	*GHG emissions due to production (insufficient data)* *Waste data from production (insufficient data*

The data limitations regarding bioeconomy assessment are also related to the fact that bioeconomy related metrics for added value, turnover and employment are only available in a particular database [154] which has been compiled by the Joint Research Centre of the EU, but there are no official bioeconomy specific databases in the national and European statistics. However, the most recent data in this database are for 2015, thus there is no possibility to develop the bioeconomy efficiency index for more recent years for which the indicators are available from other databases. For the index presented in Figure 3.13., average indicator values between 2011 and 2015 were applied, as it was identified that annual data for some indicators (especially for biotechnology patents) are very variable.

The results are obtained by developing an MS Excel based calculations model. Equal weights are applied for all seven indicators. The results of the proposed bioeconomy efficiency index for EU28 countries are presented in Figure 3.14.

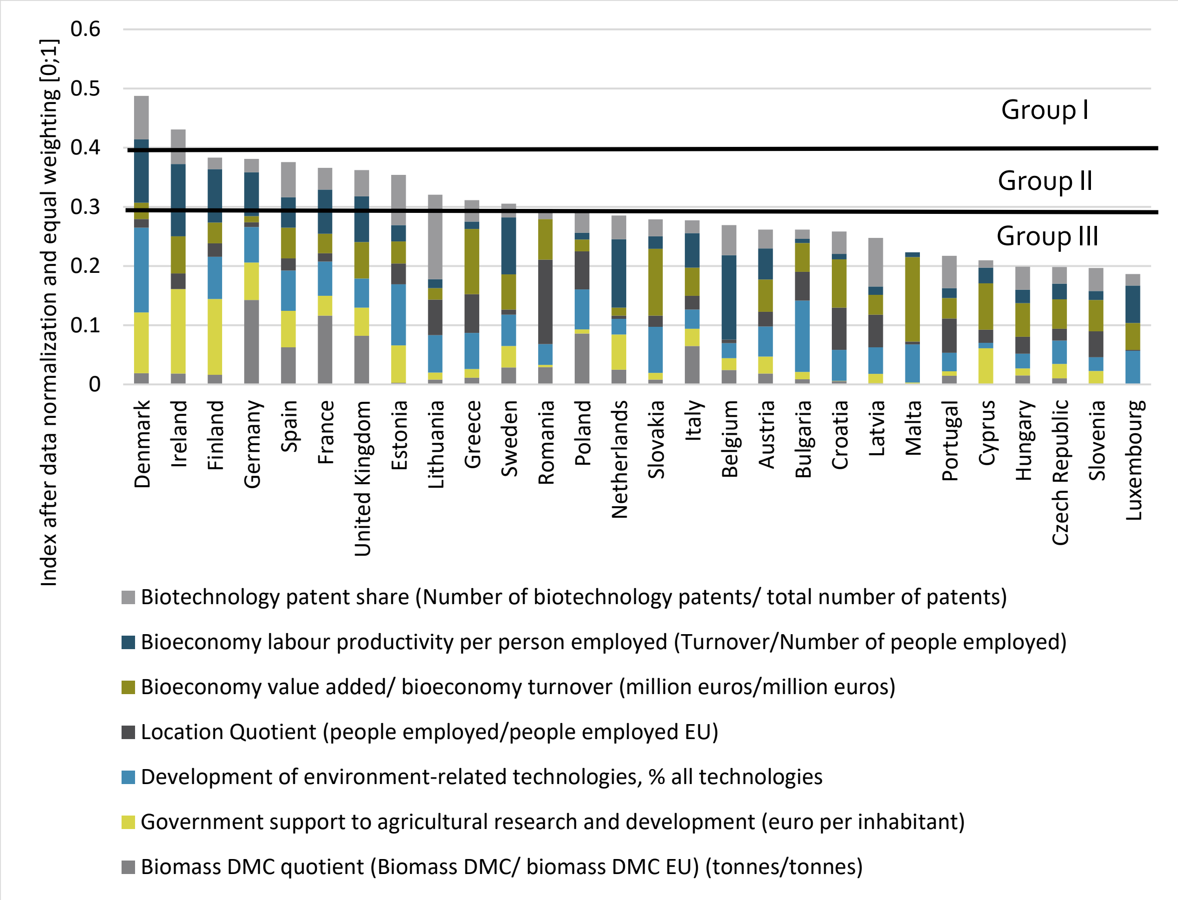


Fig. 3.14. Bioeconomy efficiency index for EU (2011-2015) (author analysis) Databases: DataM, OECD and Eurostat.

Average values from used in timeframe of 2011-2015, see Fig. 3.14. Number of indicators used are seven and data sources were from portal of agro-economics modelling – DataM, OECD and Eurostat.

From all assessed countries Denmark, Ireland and Finland have the highest bioeconomy efficiency index, while Czech Republic, Slovenia and Luxembourg have the lowest index scores. The index scores between the highest (0.49) and lowest ranked (0.19) countries differ by 0.30. We apply three benchmark levels for the bioeconomy efficiency index for the analysed countries with 0.29 and 0.39 as the benchmarks. Only Denmark and Ireland qualify for group I, there are 11 countries in group II and 15 countries in group III.

The index representation in Figure 3.10. also indicates which of the indicators have higher or lower impact on each country's overall bioeconomy efficiency evaluation. For example, for Denmark and Ireland a large share of their evaluation comes from three highest positions – patent share, bioeconomy labour productivity and government investments into R&D in agriculture sector. For Denmark another strong position constitutes environmental technology development. The share of government support for R&D in agriculture sector is the highest only for the top three countries. The highest impact from the indicators bioeconomy labour productivity on the overall score is for Belgium, followed by Ireland and the Netherlands. This might be related to the fact, that each country has selected its specific pathway for bioeconomy development. This does not mean that any one country's strategy is awry, however the bioeconomy efficiency index allows the decision makers to identify the most influencing indicators for each country to focus on strengthening the country's performance and could help in bioeconomy strategy development.

Further refinements of the approach should include consideration of additional indicators for the characterisation of the bioeconomy system in the context of its primary influencing factors. As well, fewer data were found regarding one of the three components of bioresource value – the biorefinery development. The aspects of biorefinery implementation, metrics and indicators that can be used and are available for its characterization will be further assessed and potentially added to the bioeconomy efficiency indicator. The bioeconomy efficiency index can be further used as a measurement tool for assessment of the bioeconomy development prognosis and also for scenario analysis by searching for optimal indicator values in order to promote bioeconomy development.

3.2. Meso-level: Innovation Transfer, Market and Economic Analysis

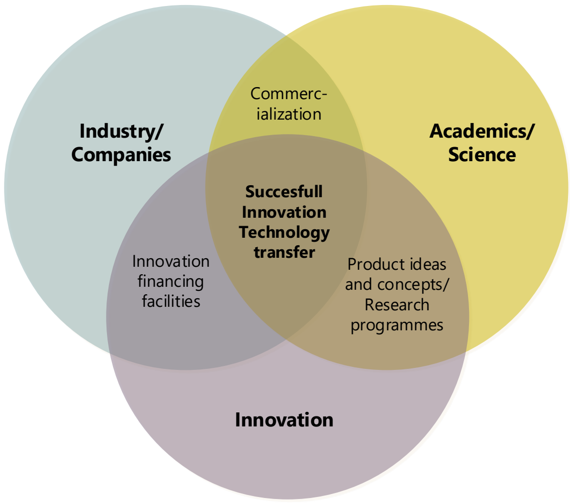


Fig. 3.15. Triple helix of knowledge drivers in bioeconomy through technology transfer (created by the author)

Major commercialization gap is the knowledge gap between academics and industry [155], the challenge is to link the market needs to new research and to industries (fig.3.15.). Energy and product consumption increases because of increasing population and welfare level, leading to unsustainable use of resources, resulting in an increase in the use of fossil resources for product production, which has a negative impact on climate and the environment. Insulation packaging industry is energy intensive production process mainly depends on fossil resources that do not degrade in nature, causing additional load on the environment. Energy consumption and impact on environment can be decreased by implementing bio-based products with new technological solutions. The main issue for new bioproducts and technologies entering the market is inefficient commercialization strategy and high product costs that cannot compete with fossil-based products.

Eco-innovations get more attention in latest years [156], but to enter a market with new eco-product is not enough to have a sustainable production process, biomaterial use and ecological and environmental concerns taken into account. If the product is not proven economically viable, it is challenging to enter the market. Therefore, a feasibility study should be done in early development stages. This research focuses on analytical framework for assessing commercialization potential for innovative products, especially market potential and economic viability.

In order to understand the innovation commercialization in meso level analysis is important to provide a market and economic analysis framework to determine if the new bio-based product will have the potential of entering market successfully and to show the shortcomings on product that should be focused on from market point of view.

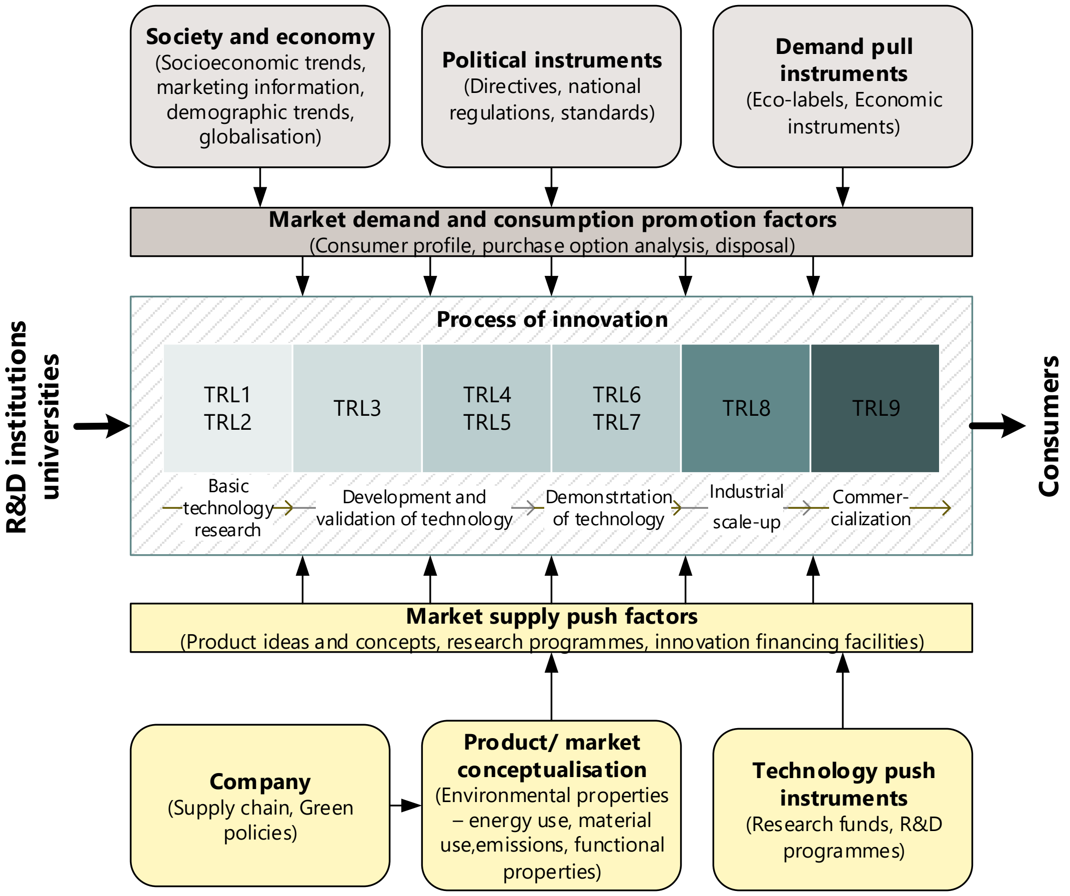


Fig.3.16. Analytical framework for assessing the potential innovation for commercialization

The analytical framework for assessing the potential innovation[157] for commercialization has been modified with a focus on feasibility assessment in the early development stages, although it is needed in all stages of technological readiness levels (TRL), shown in Fig. 3.16. In the early development stage – from TRL3 to TRL5, the first feasibility study on eco-innovation should be conducted. In the basic technology stage (TRL1, TRL2) market analysis can be done, but there will not be sufficient data available for economic analysis at this stage.

Particular case study

The case study of thermal packaging material is based on research of a new, natural material made from coniferous needle greenery (logging residues – needles and fine branches) which is a widely available and underused bioresource in Latvia [3–5]. At present, the technology of natural thermal packaging production is at the TRL2 (technological readiness level) stage and, in order to commercialize it, it must be developed at least up to the TRL6 level. The production of thermal packaging with medium power production technology is analysed and evaluated. The production process consists of seven steps: 1) Preparation of binder; 2) Biomass preparation; 3) Mixing of biomass and binder; 4) Expelling shapes; 5) Drying; 6) Cutting; 7)

Thermal insulating layer treatment (if necessary for primary food packaging). Binders used are potato starch or xanthan, preparation is mixing binder with water. The biomass preparation process is screening and crushing, screening because there should be only needles and small branches (5 mm), no soil, stones or other impurities are acceptable. Crushing is required for granulometric composition and should not exceed 10 mm.

Consumer profile

The consumer profile is based on geographical, demographical, behavioural and psychological segmentation. Geographical is European (second largest market for thermal packaging with fastest growing demand), demographic segmentation is based on age, employment, income level and education. Higher income gives greater chance for a person to choose to buy an eco-product. The level of education is important, because a person with higher education can more critically evaluate priorities and think more sustainably. Behavioural segmentation suggests that they are regular and frequent purchases in the food and pharmaceutical industries, but the cosmetics industry is not so predictable. Psychological segmentation is the most important aspect of segmentation for this product, because it mainly involves the green lifestyle, use of only environmentally-friendly materials, healthy and well-preserved food, thinking about the environment and human health. By analysing the profile of a potential client and taking into account all of these aspects, the potential consumer is identified as located in Europe.

Segmentation is done by potential sector, segment and product type (see Table 3.3.). Primary thermal packaging is in contact with the product and there is an additional layer needed to ensure the packaging does not hinder the product quality and parameters. Secondary packaging is intended in order to transport several products and tertiary packaging includes containers, pellets transportation. Secondary packaging has a wider use in all segments and is most commonly used.

Table.3.3.

Potential market segment and product evaluation matrix

Sector	*Segment*	*Example*	*Primary packaging*	*Secondary packaging*	*Tertiary packaging*
Food	Fast food (deliveries)	Beverages	X	X	
	Supermarkets (product delivery)	Frozen products, beverages, confectionery, fruits, vegetables, meat, fish, milk		X	X
	Banquets	Beverages, fruits, vegetables	X	X	
Medicine / Pharmacy	Hospitals (transportation of sensitive products)	Blood samples, medicine, drugs, organ/ implant transportation		X	
	Outpatient clinics	Blood samples, vaccines, drugs, medicines		X	
	Pharmacy	Medicines		X	X
	Veterinary clinics / veterinary pharmacies	Blood samples, vaccines, drugs		X	
Cosmetics	Laboratories	Raw materials, base compositions		X	
	Shops (product delivery)	Creams, perfumes		X	
Chemical industry	Chemical production factories	Raw materials for other products		X	X
	Universities	Laboratories		X	
	Research centres	Laboratories		X	

The target market and the target product after the segmentation and customer profile is determined as a secondary thermal packaging for the transport of several primary products. The geographic market is Europe with sectors - food, pharmaceuticals and medicine - with segments of fresh, frozen products and beverages in the food sector and drugs, vaccines and blood samples in the pharmaceutical and healthcare) sectors, their market potential is analysed and seen in Fig.3.17. Most promising market sector in Europe is food, healthcare(medicine) and pharmacy. Pharmacy is promising by its growth rate, while healthcare by its market value, although it could be difficult to enter such a saturated market, only if the fossil packaging is replaced. Food sector is almost in the middle and could be a promising sector to start entering the market, because of the growth rate and market value balance.

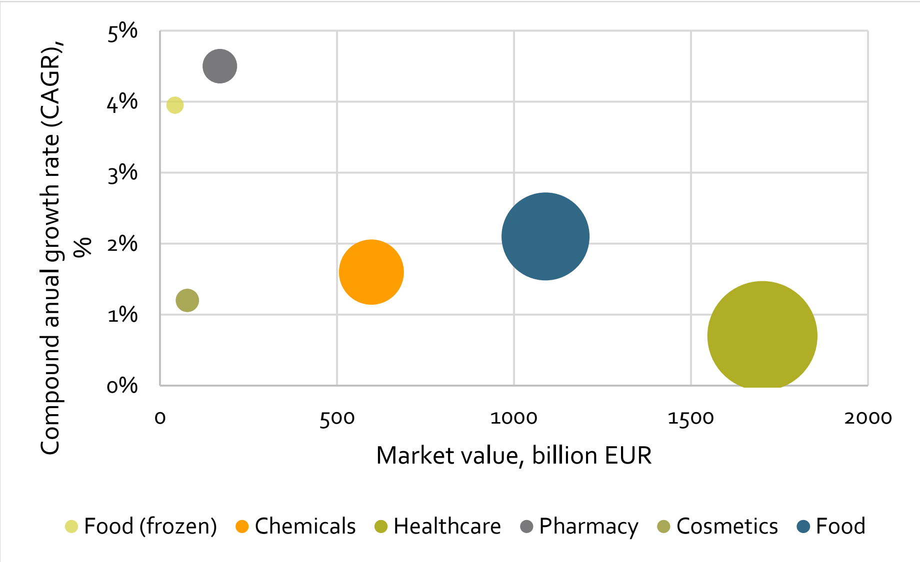


Fig.3.17. Market sector analysis in Europe (author analysis)

Political instruments

Specific requirements and regulations of the European Union are laid down in Directive 94/62 / EC on packaging and packaging waste, covering all types of packaging throughout their life cycle and beyond, regardless of their type of use. The purpose of this Directive is to limit the generation of packaging waste and to promote recycling, reuse or recovery. The essential requirements, which need to achieve, are: to reduce the weight and volume of packaging to a minimum, preserving the quality level, reduce the contents of the hazardous substances and materials in the packaging and its components, and develop a reusable or recoverable product [158].

The environmental objectives of the EU directive and the export market for large pharmaceutical products, as well as the rapid development of the pharmaceutical sector, the packaging, in which these pharmaceuticals are transported and exported, plays an important role and eco-innovations and natural thermal packaging will become increasingly important.

Market pull tools work by increasing the demand for products or services with special features to achieve the goal. The demand for environmentally-friendly products is expected, creating a higher overall level of innovation and responding to changes in demand. The eco-innovation process also involves green public procurement, accounting for 16% of EU GDP, thus bringing eco-friendly products to the market if they are economically viable [159].

Economic justification/Feasibility

The economic justification is based on the creation of a new plant, which processes 3469 tons of needle greenery per year and with a total product output of 2050 tons per year. Fresh greenery contains about 50% moisture, so from 3469 tons of fresh greenery there is 1735 tons that remains in the product. Binder is added in proportion 1:2 where two is for binder. Binder used is xanthan and it is mixed with water in proportion 1:10 where 1part is binder and 10 is water. Binder with water is two times dry greenery is in total 3469 tons from which 1/11 part is dry binder: 315 tons/year.

Assumptions, capital investments, exploitation costs and revenues for economic justification calculations is given in Table 3.4. Capital investments consists of license costs, equipment purchase, provision of land and production facilities, other equipment and unexpected capital costs. 25 employees are included in calculation with average remuneration of 15000 EUR/year. Price per unit is slightly lower than expanded polystyrene price, which is the most used fossil-based material for thermal packaging.

Table 3.4.

Assumptions and data for economic analysis

Assumptions		***Investments, costs and revenue***	
Own investment profit margin in real term	12%	Capital investment	4800000
Part of own capital	30%	***Operating costs***	
Part of borrowed capital	70%	Maintenance of equipment	50000
Cost of borrowed capital% rate	5%	Electricity	25000
Average long-term inflation rate (Latvia)	2.5%	Thermal energy	10000
Profit margin	15%	Purchase of raw materials (needle greenery with binder)	682762
WACC	8%	Remuneration of employees	375000
		State Social Insurance Compulsory Contribution (Latvia)	88463
		Marketing costs	15000
		Other expenses	20000
		Total operating costs per year	1266225
		Revenue	
		Price per unit item (EUR / ton of product)	1020
		Number of sold units (tons / year)	2050
		Total Revenue	2090861

In the calculation is assumed that the capital part is 30%, own investment profit margin in real term is 12% and the share of borrowed capital is 70% with a borrowing interest rate of 4% (according to the data of the Bank of Latvia of macroeconomic report - the interest rates of major loans (over 1 million EUR) fluctuated between 1,5% and 6,5%, therefore 5% was taken in calculations). The average long-term inflation rate is assumed 2,5%, with a fixed profit margin of 15% and with a calculated weighted average cost of capital of 6% (also a discount rate).

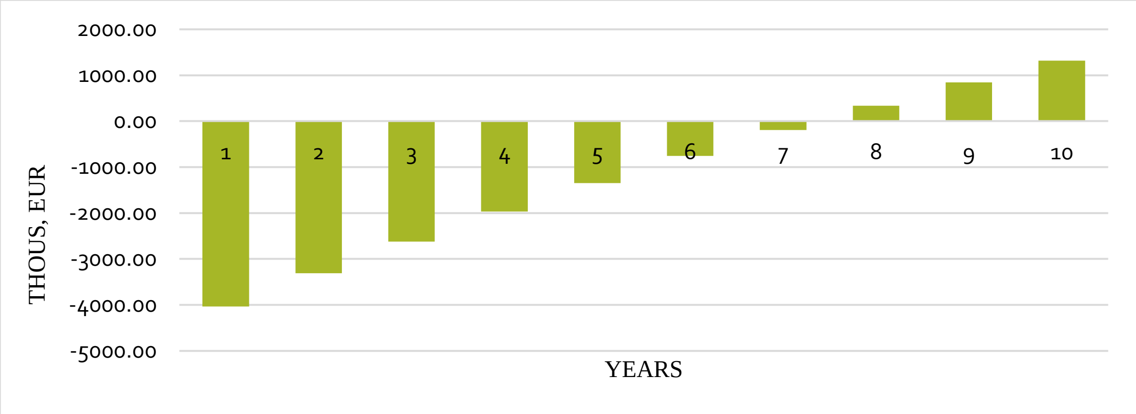


Fig. 3.18. Current net cash flow of thermal packaging (author analysis)

The project was calculated for 10 years with an initial capital investment of EUR 4.8 million. The expected payback time is eight years, see Fig.3.18. Internal rate of return (IRR) is 13%, Net present value (NPV) is 1320756 and Cash flow net present value (CF_{NPV}) value is 330269. Also Profit index (PI) is 1.28, which is important when different alternatives with same NPV values, but different capital investments are compared. These results show that for this stage the product is economically viable ($NPV \geq 0$ and $PI \geq 1$) and is advised to continue research for further development. For detailed calculations see Annex C.

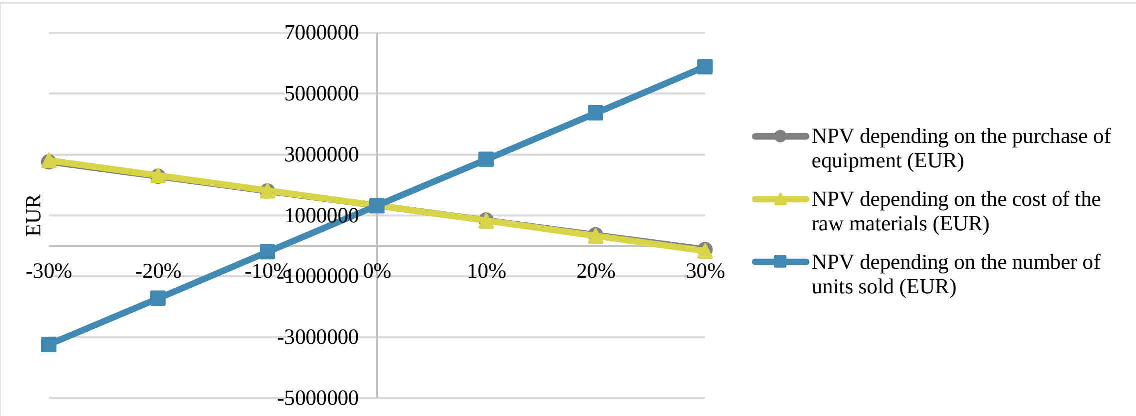


Fig. 3.19. Sensitivity analysis (author analysis)

In Figure 3.19. the sensitivity analysis results show that the economic performance of a product is most influenced by changes in the number of sold units, as it increases, the economic benefit of a project increases. However, it is not recommended to reduce capacity. The other factor which affects the production of a product is the cost of raw materials. During the product further development, the technology should be refined to minimize raw material costs. The third factor with similar impact as raw material costs, on the economic performance of the product is the purchase cost of the equipment (capital investment). Sensitivity analysis show that dependence on number of units sold is very high, therefore concentrating on operating cost minimization or increasing the production capacity. It also may differ when research of the best binder is applied.

3.2.1. Bioeconomy Investments: Market Considerations

The introduction into the forestry sector of bioeconomy has led to the search for new high value-added bio-products that can be produced using the woody biomass residue from timber harvesting. Any introduction of new bio-products must be justifiable from economic, socio-economic, and technological points of view. For successful commercialization, one of the important consideration is the market potential for such products.

Case of basic cellulosic products

The resource is combination of forest residues and short rotation woody crops together with invasive species – hogweed and goldenrod. The technology acknowledged is chemical method with biopulping pre-treatment. The market is set as international and products are chosen the most basic cellulosic products – paper, packaging, wadding, fluff pulp, film, fibre and textile.

Table 3.5.

Results of cellulose product market attractiveness and competitive advantages

Product	Market attractiveness	Competitive advantages
Wadding	43%	33%
Fluff pulp	64%	21%
Textile	66%	55%
Film	59%	18%
Packaging	49%	6%
Paper	50%	4%
Fiber	76%	38%

In table 3.5. results are shown for product types and the range is from 43 – 76% for market attractiveness and from 4 – 55 % for competitive advantages. Market attractiveness does not show considerable disparity and results are more average, however competitive advantages are contrary – significant disparity from average to low results.

For better visual and decision making all results have been put in GE/McKinsey matrix as shown in Figure 3.20.

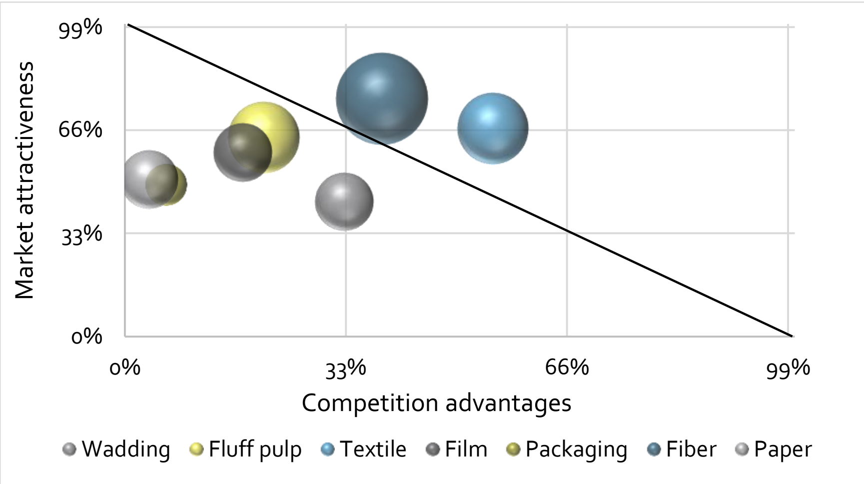


Fig. 3.20. GE/McKinsey matrix results for cellulose products (author analysis)

Results in matrix show that neither product is in leader position nor discarding position. Best results are for fibre and textile, which are relevant – because fibre can be used for different applications one of which is textile therefore market share for textile is smaller. Paper and packaging show major competition and takes the weakest position in market sales, to improve its positions, there should have a major contribution in ability to compete as well as improve the market attractiveness if possible. Fluff pulp takes relatively large market share, it also has good market attractiveness, but the competitive advantages is rather low, if there is a possibility to perform activities to improve this rating, then there could be possibility for commercialization. Film has the similar result as fluff pulp, with smaller market share, but the same possibilities to improve. Wadding has an average market attractiveness and average competition advantages, improving both of these ratios there is a possibility to have a better result. Although the results showed only two products with great potential in international market, there can be different situation in local market or in specific market segments.

Case on three products: lyocell (textile), bio-oil and xylitol.

A case study has been developed for three existing products - lyocell (textile from wood), bio-oil and xylitol (a sweetener). After the results have been obtained, the capability of a product to enter a market as a primary product or as a value-added by-product of a biorefinery or not to enter at all should be determined.

Lyocell is a man-made textile derived from wood cellulose. The leader in lyocell production is the Lenzing Group in Austria. It is widely acknowledged that lyocell has superior qualities to viscose, which is also derived from cellulose, and has price advantages compared to Modal (a similar textile from wood). Lyocell has a greater market share than all the cellulosic fibres produced by Lenzing. The highest demand for lyocell fibres is in the clothing segment, sportswear, after which comes the home textile segment. Lyocell fibre is produced in a closed cycle and is biodegradable [160]. Lyocell can be manufactured using N-methylmorpholine-N-oxide (NMMO) or Ionic liquid [160]. The tree species mostly used in lyocell production is eucalyptus [160].

Starting in 1989 bio-oil was used both in food and as a chemical additive in certain manufacturing processes. Since 2009, it has also been used in the production of electricity. From 2013, it has been used in biodiesel production. Today it replaces fossil fuels (mostly mazut and natural gas) in energy production (electricity and heat) in both the residential and industrial sectors [161]. Mazut has not been used as a resource in cogeneration plants in Latvia since 2014. However, significant amounts of natural gas are being used, according to data from the Central Statistical Bureau of Latvia [162].

As the forestry industry is the main biomass and bioenergy supplier, there is considerable potential for bio-oil production in the European forestry sector [163]. Bio-oil commercialization would not represent a problem if the price of biomass were zero or close to zero. This not being the case, significant market demand is also required for the by-products of bio-oil in order to grow the market for bio-oil itself [164].

Global market demand for textile fibres in 2015 was 62,1%; for synthetic fibres, 25,2 %; for cotton, 6,4 %; for cellulosic fibres, 5,1 %; for all other natural fibres and wool 1,2 % [165]. Latvia's textile market is small and primarily focuses on export. Some 80% of output is redirected to European countries and to the CIS (Commonwealth of Independent States), including Russia[166]. According to forecasts, lyocell fibre in global markets will increase by 7,84 % after CAGR (compound annual growth rate) in the period from 2016 to 2020 [167]. The required investments are 150mn Euro for a lyocell plant [168] and 140mn Euro for a pulp plant [169] with a production capacity of 67 000 t/year. The price of Lyocell is about 2,54 Euro/kg [170]. For profit calculations in the Latvian context [171] see table 3.6.

Table 3.6.

Main data used in analysis

	Global market demand	Investments, MN EUR	Capacity, t/year	Price	Profitability (calculated 2018-2030) on 2030, EUR/m^3 [171]
Lyocell	7,84%	290	67 000	2,54 EUR/kg	65
Bio-oil	3%	30	50 000	9-15 EUR/GJ	7
Xylitol	6%	75	15 000	6 EUR/kg	-20

The main competitors of bio-oil are mazut and natural gas [172]. There are no bio-oil plants in Latvia; however, there are some (bio-oil plants) in the EU including Fortum (Finland) and Empyro BV (Netherlands). Bio-oil is carbon dioxide (CO_2) neutral and does not contain sulphur dioxide (SO_2), therefore is not produced during combustion. Moreover, bio-oil produces only half as much nitrogen oxide (NOx) as do fossil fuels [164].

The capital investment for a bio-oil plant with a capacity of 50 000 t/year is 30mn Euro [29]. The price of bio-oil is about 9-15 Euro/GJ [173]. Profits from bio-oil in Latvia have been calculated to be very low and in some cases close to zero (7 EUR/m^3) [26].

The main xylitol manufacturers are Danisco (DuPont), Futaste Pharmaceutical, Yucheng Luijan and Hangzhou Shouxing [31]. The forecasted growth rate is 6% both in quantity and in value [32]. The investment for xylitol plant with a capacity of 15 000t/year is 75mn Euro [33]. The price of xylitol is strongly dependent on the resources used both as feedstock and in production. The price of wood-derived xylitol is approximately 6 Euro/kg [34] while corn-derived xylitol fetches only 2,5 Euro/kg [26]. Profits from a xylitol plant located in Latvia are calculated to be negative [26].

After a market attractiveness evaluation, all three products showed better results in the international market but inferior results in the Latvian market.

Table 3.7.

Market attractiveness evaluation ratings (L1 –lyocell for export market, L2-lyocell for local market, B1 – bio-oil for export market, B2 bio-oil for local market, X1 – xylitol for export market)

Factor importance scale	Extremal importance	Very unattractive	Unattractive	Neutral	Attractive	Very attractive	Extremal importance	Source
Market factors								
Market size	Little		L2	B1; B2; X1	L1		Great	[164], [167], [174]–[177]
Market growth	Low		B2	B1; L2; X1		L1	High	[165], [176], [178]–[183]
Demand cyclicality	High				B2; X1	L1; L2; B1	Low	[164], [174], [176]
Demand seasonality	High				B1;B2; X1	L1; L2	Low	
Price sensitivity	High	L2; B2		L1; B1; X1			Low	[171]
Market profitability	Low	X1	B1; B2	L2	L1		High	
Differentiation of product	Low					L1; L2; B1; B2; X1	High	[164], [174], [176], [184]
Competitiveness factors								
Presence of equal competitors	Many	X1		L1; B1	L2	B2	Few	[161], [163], [170], [174], [176], [177]
Competitor level of specialization	Low			L2	L1; B2; X1	B1	High	
Entry barriers								
Investment capacity	Great	L1; L2	X1		B1; B2		Little	[166], [168], [169], [185]
Access to raw materials	Difficult					L1; L2; B1; B2; X1	Easy	[162], [186], [187]

In Table 3.7., L stands for Lyocell, B for Bio-oil, and X for Xylitol and number one is for export market and number two is for local market (in this case Latvia is the local market). The evaluation is based on a five-point scale where one is very unattractive and five is very attractive. The external importance is indicated by its position on the scale: for example, low market growth is very unattractive and high market growth is very attractive, high price sensibility is very unattractive and low very attractive.

Table 3.8.

Competitive advantage evaluation weights and ratings

Factors	Demand		Market share		Availability of resources		Price		Quality		Environmental actions in manufacturing processes	
Market	Local	Export	Local	Export	Local	Export	Local	Export	Local	Export	Local	Export
Weight	**0,2**		**0,15**		**0,2**		**0,2**		**0,15**		**0,1**	
Lyocell (all textile segment)	3	5	2	2	5	4	4	4	5	5	5	5
1. Cotton	4	2	3	3	1	3	2	3	4	4	2	2
2. Synthetic (PP)	5	4	5	4	2	3	2	2	3	3	1	1
3. Wool	1	1	1	1	2	3	5	5	4	4	1	2
Lyocell (natural textile segment)	4	5	3	3	5	5	4	4	5	5	5	5
1. Cotton	3	3	4	5	2	2	2	2	3	3	1	1
2. Linen	2	2	2	2	3	3	4	4	3	3	3	3
3. Wool	1	1	1	1	4	3	5	5	4	4	2	2
Bio oil	3	4	3	3	5	5	5	5	3	3	5	5
1.Natural gas	5	5	5	4	1	2	2	2	4	4	2	2
2. Heavy fuel oil	-	1	-	2	-	1	-	1	-	2	-	1
Xylitol	-	5	-	4	-	5	-	3	-	5	-	4
1. Sorbitol	-	3	-	5	-	3	-	5	-	3	-	4
2. Maltitol	-	2	-	3	-	3	-	4	-	4	-	4

In most situations at least 3 competitors have been evaluated. But in the case of bio-oil there are only 1 or 2 as shown in Table 3.8., because the evaluation is based on the direct use of bio-oil excluding the use of products that can be further obtained or derived from bio-oil. Competitors are chosen based on the product not the resource. Sorbitol and maltitol have been selected as competitors for xylitol, where both are low-intensity sweeteners, the same as xylitol.

Table 3.9.

Total weighted scores for competitive advantages

	Total weighted score	
	Local market	Export market
Lyocell (all textile segment)	3,95	4,15
1. Cotton	2,65	2,85
2. Synthetic (PP)	3,1	2,95
3. Wool	2,45	2,75
Lyocell (natural segment)	4,3	4,3
1. Cotton	2,55	2,7
2. Linen	2,85	2,85
3. Wool	2,95	2,75
Bio oil	4	4,2
1.Natural gas	3,15	3,2
2. Heavy fuel oil	-	1,3
Xylitol	-	4,35
1. Sorbitol	-	3,8
2. Maltitol	-	3,25

Table 3.9. shows the total weighted score for products and their competitors. In all textile segments the strongest competitor is considered to be the synthetic. In the natural segment (the segment that includes only natural fibres) wool is the strongest competitor in the local market and linen the strongest in the export market. The strongest competitor for bio-oil is natural gas. For xylitol, it is sorbitol.

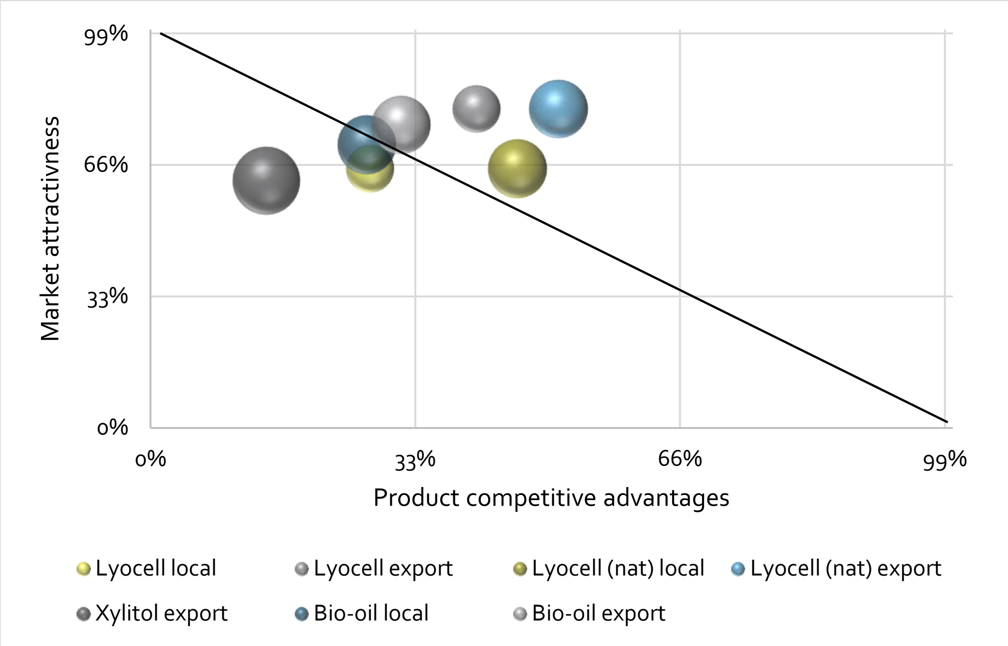


Fig.3.21. Results of GE-McKinsey matrix (author analysis)

Results (see Fig.3.21.) for lyocell are the following – lyocell local market attractiveness is 65%; its competitive advantage 27%; its export market attractiveness is 80% and competitive advantage 41%. Lyocell shows better results than the competition in the natural segment– lyocell local market attractiveness in the natural segment is 65% and 46% for competitive advantage; lyocell natural segment export market attractiveness is 80% and competitive advantage 51%. The results for bio-oil show that its competitive advantage is low: 27 % for the local market and 31% for the international market. In the local market, its attractiveness reaches 71% and in the international market 76%. As for xylitol, the strongest competitor is calculated to be sorbitol. The relative competitive advantages are only 14% in international markets; while among low intensity sweeteners, its market attractiveness is 62%.

The competitive advantage for all products shows low to average results. However, the most promising is lyocell. The GE - McKinsey matrix shows that while lyocell in international market has a good position in both segments, it has a better position only in the natural segment in the local market. It is also very advisable to make supplementary assessments before considering the commercialization of this product.

Bio-oil's market attractiveness helps it to achieve a relatively high result. In this case, its market attractiveness is based on the increasing use of renewable resources and as a replacement for fossil fuels. Together with competitive advantages the product shows average results in both markets and requires further evaluation. It is also necessary to evaluate bio-oil in comparison with other alternative renewable sources and bio products.

Improving competitiveness for product development could be one of the recommended solutions for xylitol. Xylitol results clearly show that this is a by-product that would not bring a positive result as a primary product. It is therefore advisable to consider this as a by-product of a biorefinery [47,48].

These results show that before building a biorefinery or any other new bio-product manufacturing facility, this type of analysis is necessary and could yield insights into overall market outlook. In the case where a cost-benefit analysis shows positive results, a market outlook analysis could be a decisive indicator in whether to invest in the product. It might also indicate the need to change some of the factors that strongly affect the results. It could even show that it is advisable to discard the product. A good feasibility study or product portfolio would help to determine which market or market segment it would be advisable to enter, which products would need further research to increase quality, and whether the technological processes used in production might be implemented in more environmentally sustainable ways.

3.3. Micro-level: New vision on invasive alien plant management system

The scientific literature already indicates the scientific potential for solving this problem, because the application of scientifically-based methods allows not only to find innovative and environmentally friendly technological solutions for the use of invasive plants in production, but also to determine the potential for commercialization and valorisation, the impact on the environment and the climate throughout the product life cycle, the availability of resources and the opportunities for using alternative resources, which is very important in the case of invasive plants as a resource. Therefore, as a first step for the research towards increasing the value of invasive alien plant biomass, MCDA applied to categorize and prioritize various IAP species to further select those species for which an in-depth valorisation assessment should be done. The main concern on using IAS as potential biomass source is the risk of cultivating. There should be political instruments set to exclude this risk, therefore one of very important aspects for product production is to find a non-invasive plant substitute biomass, to ensure sustainable production.

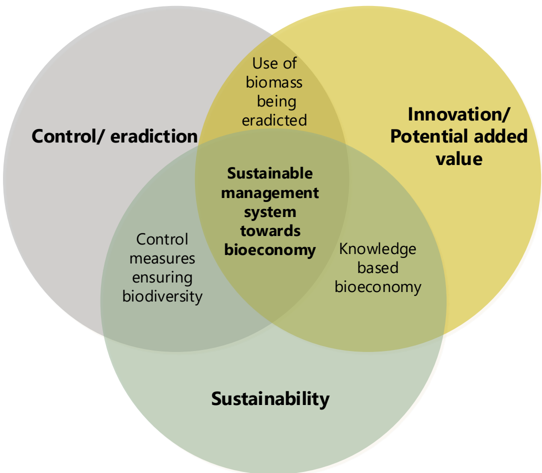


Fig. 3.22. The main pillars of the Invasive Alien Plant (IAP) management system (created by the author)

The main pillars of the invasive alien plant species management system can be seen in Figure 3.22. The use of invasive plants for production of products opens up opportunities not only for bio-economy development and acquiring the benefits related to it, but also creates a new stock of bioresources, without competing with agricultural crops intended for food production. At the same time, the product production should aim to find solutions that can later be applied for the use of other bioresources, thus reducing the risk of deliberate cultivation of invasive plants.

The proposed methodology (see Fig. 3.23.) is based on existing management plan, with an addition on new vision, where after mechanical control, invasive plant species create potential biomass for product production, however, there should be clear assessment on biomass availability that would have economic viability, and there should also be an assessment on sustainability and possible substitution with other non-invasive plant biomass.

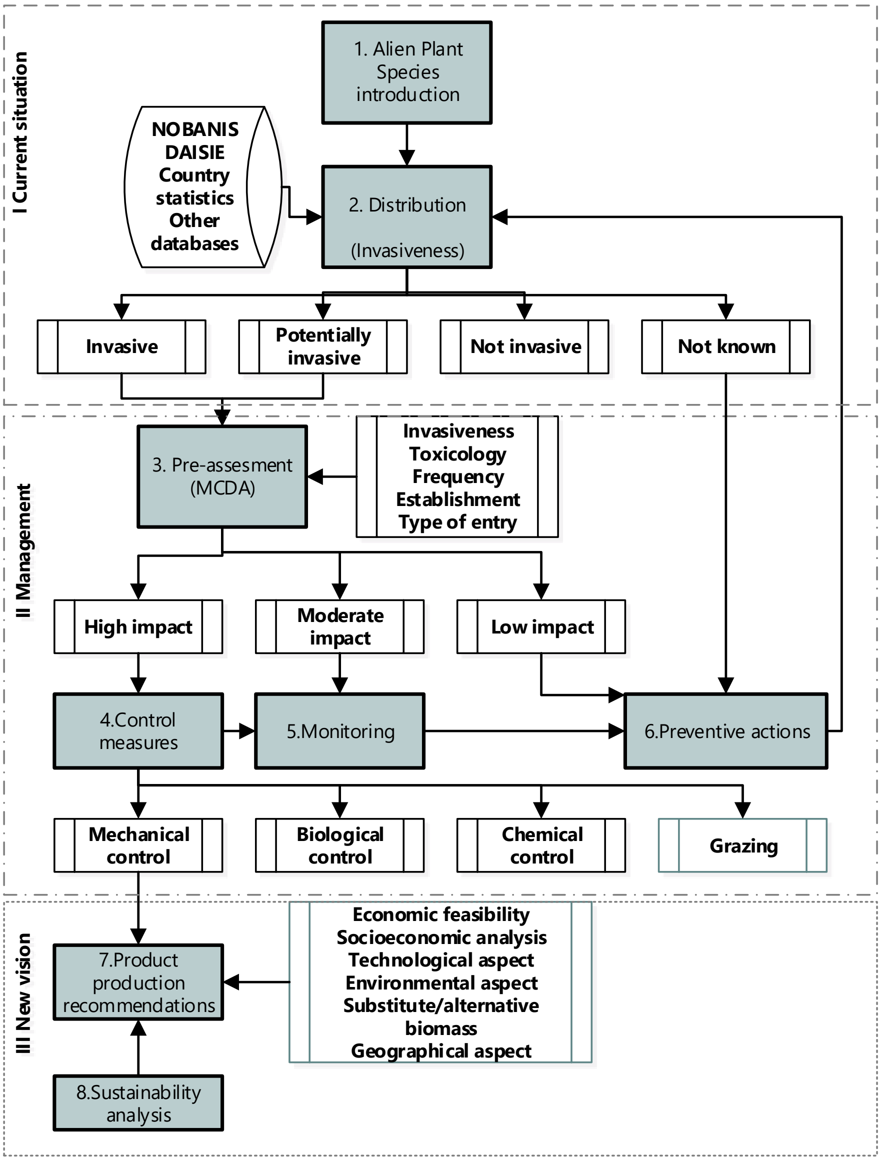


Fig.3.23. New vision on invasive alien plant management system (created by the author)

I Current situation is well researched at international and national level, there are several databases created that can be used on data selection: DAISIE (Delivering Alien Invasive Species Inventories for Europe) [188], NOBANIS (The European Network on Invasive Alien Species) [189], GISD (Global invasive species database) [190], CABI [191], MedPAN (network of Marine Protected Areas in the Mediterranean) [192] and SEBI-2010 [193] all can be found in EASIN species mapper [94] which offers Europe data on environment, impact, species status, taxonomy and pathways. Based on current situation, one of the most important indicators is invasiveness, not all alien species are invasive, but for early detection and eradication the invasive and potentially invasive species must be selected.

II Management System for IAS management differs between countries, and there are national management plans developed in each of the countries, as well as at European level. There could be a potential multi criteria decision analysis (MCDA) in place, to create a common framework on invasive species selection on national level. There are several researches on indicators that should be selected, but a common framework would be an essential and possible way to use for every country as pre-assessment, where priority species can be selected for further analysis. Such criteria selection is still under development in Latvia. Control measures, monitoring and preventing actions are already in place.

MCDA method Technique of Order Preference by Similarity to the Ideal Solution (TOPSIS) was used to prioritize the invasive alien plant species occurring in Latvia accordingly to their valorisation aspect. In this case the ideal solution' is the species that show priority for further assessment of impact on ecosystem services, to biodiversity, social and economic impact (high, moderate of low). The alternatives are the invasive or potentially invasive alien plant species detected within a country.

Table 3.10.

Criteria, valuation score and weight determination

	Criteria, *i*	Valuation score	Weight coefficient
i_1	Toxicology	0/1	0.18
i_2	Type of entry	0/1.5/1	0.07
i_3	Establishment	0/1/2/3	0.18
i_4	Invasiveness	1/2	0.31
i_5	Frequency	1/2/3/4	0.25
		$\sum$	1.00

Evaluation criteria are based on available data on IAP type of entry, establishment, invasiveness, frequency and toxic impact. Eight experts were selected on determination on weights of these criteria, (see Table 3.10.) two biologists, one microbiologist and five environmental scientists. In analysis only criteria weights were selected by experts, valuation of criteria was determined from data about IAP. Valuation ratio was selected as:

- Toxicology of the species values 0 – not toxic, 1 – toxic. Determines species harmful substances as threat to animal or human health
- Type of entry or introduction of IAP can be characterized as intentional – 1, unintentional 2, or both - 1.5. Unintentional type of entry has the higher score, as the control measures is more difficult to implement in this case.
- Establishment or population status: established - 3 were species has formed self-reproducing populations, not established – 1 were species has not formed self- reproducing

populations and escaped – 2 escaped from captivity, gardens, agriculture, other culture, extinct and unknown – 0.

- Invasiveness: Invasive – 2 are alien species whose spread threatens or damages biodiversity and related ecosystem services by occupying new habitats to the detriment of other species [194]. Potentially invasive – 1 that represent a threat to biological diversity, are in neighbouring countries or boreal biogeographical region countries.
- Frequency: Rare – 1 were species observed only in certain places. Local – 2 patchy distributions, with higher abundance in certain localities. Often – 3 or common were are not abundant, but is easy to find throughout country. Very often – 4 Frequently occurring throughout the country in high abundances.

III New Vision The new vision contributes on economic and social levels, assessment already described in previous researches [89], [195]–[197]. IAP as biomass for product production should be under legal permit, to ensure the production is under elimination practices of invasive plant species, and could be as a side stream of production with same qualities provided from another biomass. In terms of bioeconomy there should be a higher added value product, but assessment is required and it could be an multi criteria decision analysis, as presented in previous researches. IAP as biomass source could be transferred from mechanical control, as it provides IAP as waste materials.

Research results are presented by analysing the national level case of Latvia. First the current situation in Latvia regarding invasive plant species is characterized from registered alien plant species to their invasiveness, distribution and establishment. Sankey diagram [198] has been chosen for flow visualization (see Figure 3.5). In Latvia from 636 alien plant species, 210 are not invasive, and for 269 species there is a lack of information on invasive character, however as most of them are rarely distributed, there should not be serious concerns. Invasive and potentially invasive species should be more researched, as most of them have already been established. Criteria have to be selected and both invasive and potentially invasive species should be analysed.

Current situation

First the current situation in Latvia for invasive plant species is characterized from registered alien plant species to their invasiveness, distribution and establishment. Sankey diagram has been chosen for flow visualization.

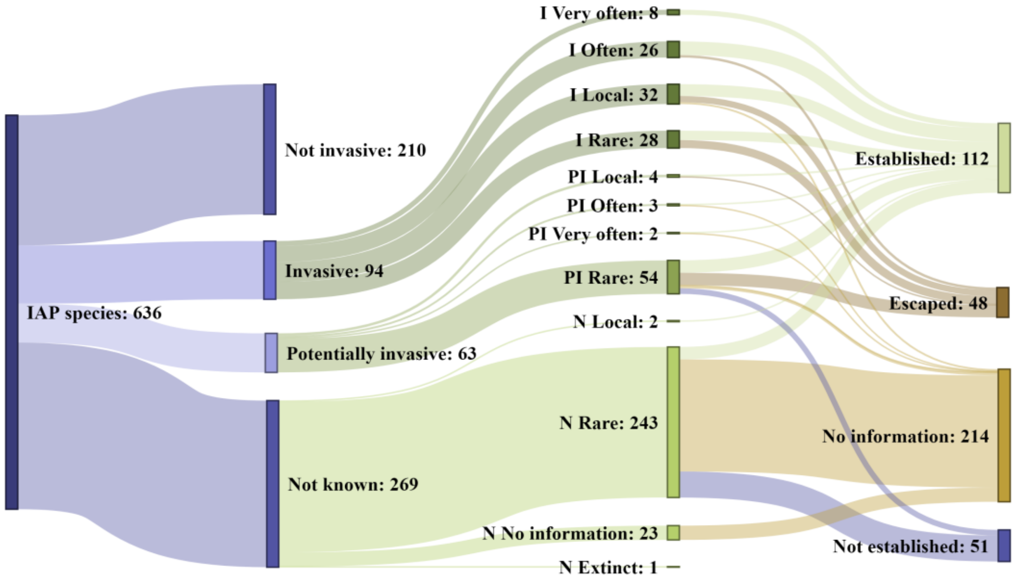


Fig. 3.24. Alien plant species distribution in Latvia (author analysis)

In Latvia from 636 alien plant species, 210 are non-invasive (see figure 3.24.), and for 269 species there are lack of information on invasive character, however as most of them are rarely distributed, there should not be serious concerns. Invasive and potentially invasive species should be more researched, as most of them have already established. Criteria has to be selected and both invasive and potentially invasive species should be analysed.

Invasive plant species that are evaluated as very often in distribution and are established, are:

Bellis perennis, Galinsoga parviflora, Impatiens parviflora, Bunias orientalis, Lupinus polyphyllus, Malus domestica, Sorbaria sorbifolia, Spiraea x billardii(hybrid).

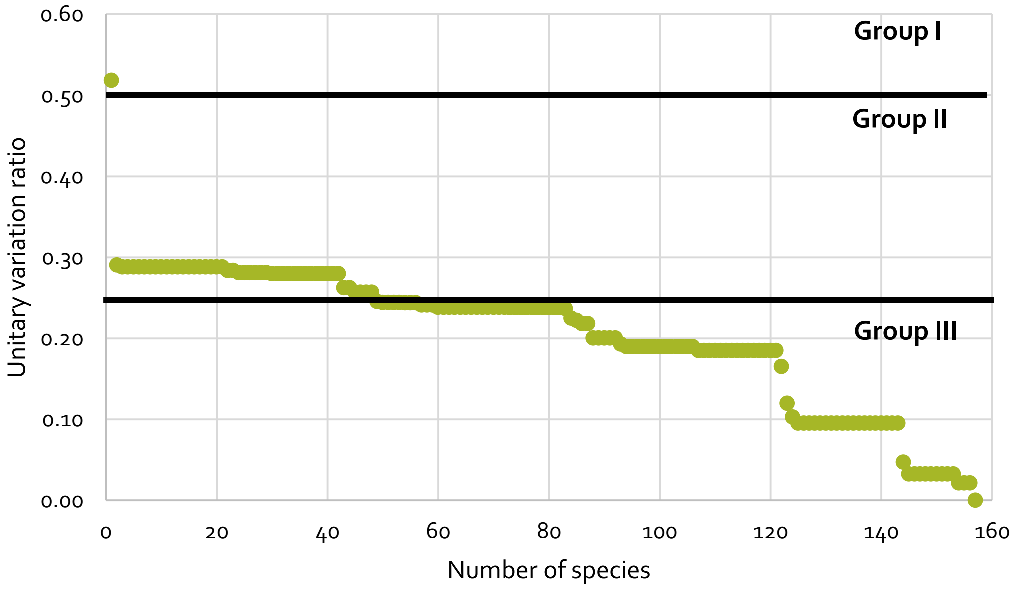
Invasive plant species that are evaluated as often occurred and established are *Acer negundo, Amelanchier spicata, Cerasus vulgaris, Cytisus scoparius, Echinocystis lobate, Galinsoga quadriradiata, Heracleum Sosnowskyi, Hippophae rhamnoides, Impatiens glandulifera, Ligustrum vulgare, Prunus cerasifera var divaricate, Ribes nigrum cv, Ribes rubrum, Rosa rugose, Rumex confertus, Sambucus racemose, Sisymbrium loeselii, Solidago canadensis, Spiraea alba, Swida alba, Symphoricarpos albus var laevigatus, Syringa vulgaris.*

Potentially invasive species that occupation is very often are *Acorus calamus* and *Elodea canadensis.*

Assessment MCDA

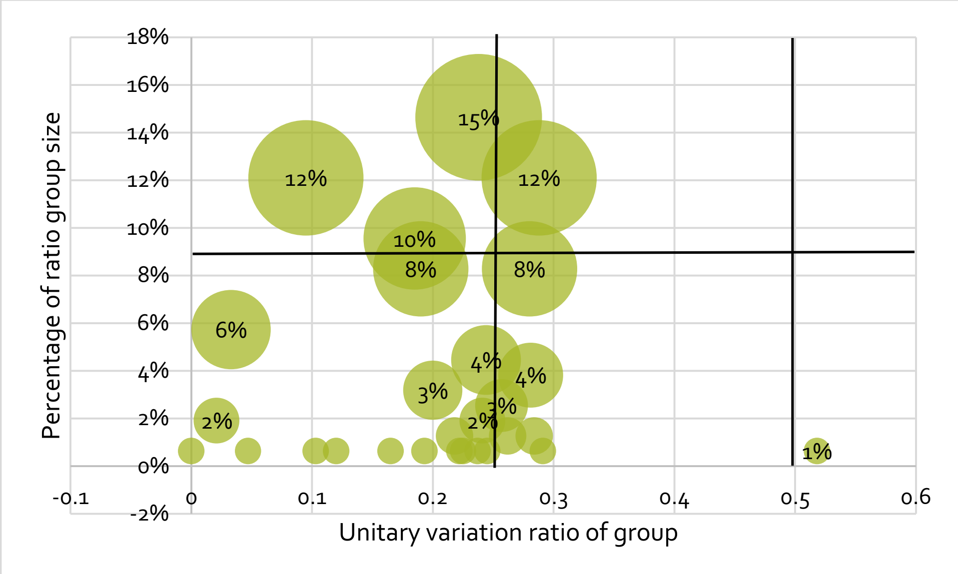
After the preliminary analysis of alien species and their invasiveness, MCDA was made on invasive and potentially invasive species, together 157 species were analysed. The aim of MCDA analysis is to prioritize the invasive alien plant species occurring in Latvia accordingly to their valorisation aspect.

MCDA TOPSIS results in Figure 3.25. show similarity in some ratios, meaning that there can be variation groups of species that share the same ratio.



Fig,3.25. MCDA-TOPSIS unitary variation ratios of analysed IAP (author analysis)

Results are divided in three levels that could determine priority selection for further studies. In the first level, that has the highest score, is IAP species *Heracleum Sosnowskyi* M., in this case the most decisive criterion is toxicology, because the sap of this species is a threat to human health. There are 48 species in group II for which the evaluation score is higher than 0.25 and that could also be analysed for potential monitoring and risk assessment of the impact to biodiversity, and valorisation possibilities. Although most of the analysed species fall into group III, and therefore would not be nominated the highest priority, however, some species in group III are with score that is very close to the benchmark. So it could be advised to further study in detail about 80 species that show higher scores, especially because valuation score on some of the species that have ratio 0.244 was high, as they are established (score 3), invasive (score 2), very often distributed (score 4), and intentional and unintentional type of entry (score 1.5); such species is, for example, *Bellis perennis*. On the other hand, for a species that have a ratio of 0.281, valuation score was slightly lower, as they are established (score 3), invasive (score 2), often distributed (3), and intentional and unintentional type of entry (score 1.5), for example, *Solidago Canadensis*.



Fig, 3.26. MCDA TOPSIS unitary variation ratios on IAP groups (author analysis)

If the results are combined in groups by their variation ratio (Figure 3.26.), the group size can be more clearly determined. If the ratio is high, then all species from that group with that ratio should be evaluated further. These results are obtained by grouping IAP with same result from MCDA TOPSIS analysis. After MCDA ratios, groups of the same ratio have created such as clusters and the size of the cluster is dependent on number of species.

Not all of these species are seen as a threat. Invasive alien species monitoring program in Latvia is still under development, but there are nine criteria in existing system set after which to evaluate species, that should be monitored [199]:

1. Hazardous to natural habitats (criteria that is set as priority)
2. Data on the species are not derived from other existing national monitoring programs
3. The species multiplies in the wild (effective vegetative or generative reproduction occurs)
4. Massive economically invasive species
5. Taxon causes genetic erosion of wild species – actively crosses a wild species
6. Recognized as being invasive in neighbouring countries
7. The species is or has been cultivated
8. Species distribution studies have been carried out (criteria that is set as priority) There is evidence of the occurrence and negative impact of the species on natural habitants
9. The species has not taken its ecological niche and shows signs of further invasion [199]

The methodology they used included yes/no compliance with the criteria and selected species were ones who had correspondence for at least seven criteria, from which two were priority criteria [199]. After which these species were selected for the necessity to monitor. We compared the species accordingly to their priority in the list for monitoring and the obtained MCDA pre-assessment ratio scores to see if MDCA could be used as methodology for recommendations.

Table 3.11.

Invasive alien plant species in international and national concern

International level (EU)	National level (Latvia)		
Species in Union concern [200]	Species in Latvia's concern [201]	Species in Latvia's priority list for monitoring [199]	MCDA pre-assessment (unitary variation ratio)
Alternanthera philoxeroides	*Acer negundo*	*Heracleum sosnowskyi*[3]	0.518
Asclepias syriaca	*Acer pseudoplatanus*	*Acer negundo*	0.280
Baccharis halimifolia	*Amelanchier spicata*	*Amelanchier spicata*	0.281
Cabomba caroliniana[2]	*Aronia prunifolia*	*Aster salingnus*	-
Eichhornia crassipes	*Aster salignus*	*Cotoneaster lucidus*	0.288
Elodea nuttallii[2]	*Bunias orientalis*	*Echinocystis lobata*	0.281
Gunnera tinctoria	*Campylopus introflexus*	*Impatiens glandulifera*[1]	0.281
Heracleum mantegazzianum	*Cotoneaster lucidus*	*Impatiens parviflora*	0.244
Heracleum persicum[2]	*Echinocystis lobata*	*Lupinus polyphyllus*	0.241
Heracleum sosnowskyi[1]	*Elaeagnus argentea*	*Reynoutria japonica*	0.200
Hydrocotyle ranunculoides	*Elodea canadensis*	*Reynoutria sachalinensis*	-
Impatiens glandulifera[1]	*Epilobium adenocaulon*	*Rosa rugosa*	0.281
Lagarosiphon major	*Gypsophila paniculata*	*Sambucus racemosa*	0.280
Ludwigia grandiflora	*Helianthus tuberosus*	*Solidago canadensis*	0.281
Ludwigia peploides	*Hippophaë rhamnoides*	*Solidago gigantea*	0.189
Lysichiton americanus[2]	*Impatiens glandulifera*	*Sorbaria sorbifolia*	0.244
Microstegium vimineum	*Impatiens parviflora*		
Myriophyllum aquaticum	*Lactuca tatarica*		
Myriophyllum heterophyllum	*Ligustrum vulgare*		
Parthenium hysterophorus	*Lupinus polyphyllus*		
Pennisetum setaceum	*Malus domestica*		
Persicaria perfoliata	*Parthenocissus quinquefolia*		
Pueraria lobata	*Petasites hybridus*		
	Reynoutria japonica		
	Reynoutria sachalinensis		
	Robinia pseudoacacia		
	Rosa rugosa		
	Rumex confertus		
	Sambucus nigra		
	Sambucus racemosa		
	Solidago canadensis		
	Solidago gigantea		
	Sorbaria sorbifolia		
	Spiraea chamaedryfolia		
	Swida alba		

1 – species that is on Union concern and is already in list of management in national level or in priority list on monitoring

2 – species that is in boreal biogeographical region countries (Sweden, Finland, Estonia, Lithuania) and pose potential on invading Latvia

3 - Species in regulation in Latvia

Species in Latvia's priority list in Table 3.11., show that nine species of 16 are in level I and II after MCDA ratio, three species are close to level II and two are with score close to 0,2. There should be a detailed assessment on species with lower scores, or the level should be lowered to 0,2 not 0.25. Two of the species without score is species that in this case were not selected for analysis, because they are non-invasive. In information revised for data analysis *Aster salingnus* and *Reynoutria sachalinensis* were stated as non-invasive, established and rare distributed. However, in other sources both species have been stated as invasive. In order to work with decision analysis matrix, data on invasive plant species should be kept up to date. Overall the method is proved to work as pre-assessment.

The new system would suggest not only to use multi criteria decision analysis (MCDA). There should be potential social and economic benefit evaluation, LCA analysis on species that is on controlling measures, especially if chemical controlling method is used. And product production sustainability analysis.

Criteria should be unified as common framework used between EU countries. Criteria mentioned in regulation (EU) No 1143/2014 article 5 risk assessment, should be taken into account [81]:

(a) taxonomic identity, its history, and its natural and potential range

(b) reproduction and spread patterns and dynamics

(c) potential pathways of introduction and spread

(d) risk of introduction, establishment and spread in relevant biogeographical regions in current conditions and in foreseeable climate change conditions

(e) current distribution of the species, including whether the species is already present in the Union or in neighbouring countries, and a projection of its likely future distribution

(f) impact on biodiversity and related ecosystem services, including on native species, protected sites, endangered habitats, as well as on human health, safety, and the economy

(g) potential costs of damage

(h) uses for the species and social and economic benefits deriving from those uses [81]

Management

Management system is controlled by legislation requirements and policy instruments. There should not be registered only species that are under Union concern, but for now, this is the case. Despite the fact that 15 species are already included in the 'unwanted' list for having a significant impact on ecosystems and spread, and more species are intended to be included, only one is officially recognized as invasive (*H.sosnowskyi* Manden) and included in the Cabinet of Ministers Regulation No. 468 [17] on the list of invasive plants. In Estonia, the law includes 13 plant species [18], some of which are species that are included in the 'unwanted species' list in Latvia, for example *Solidago Canadensis* L.

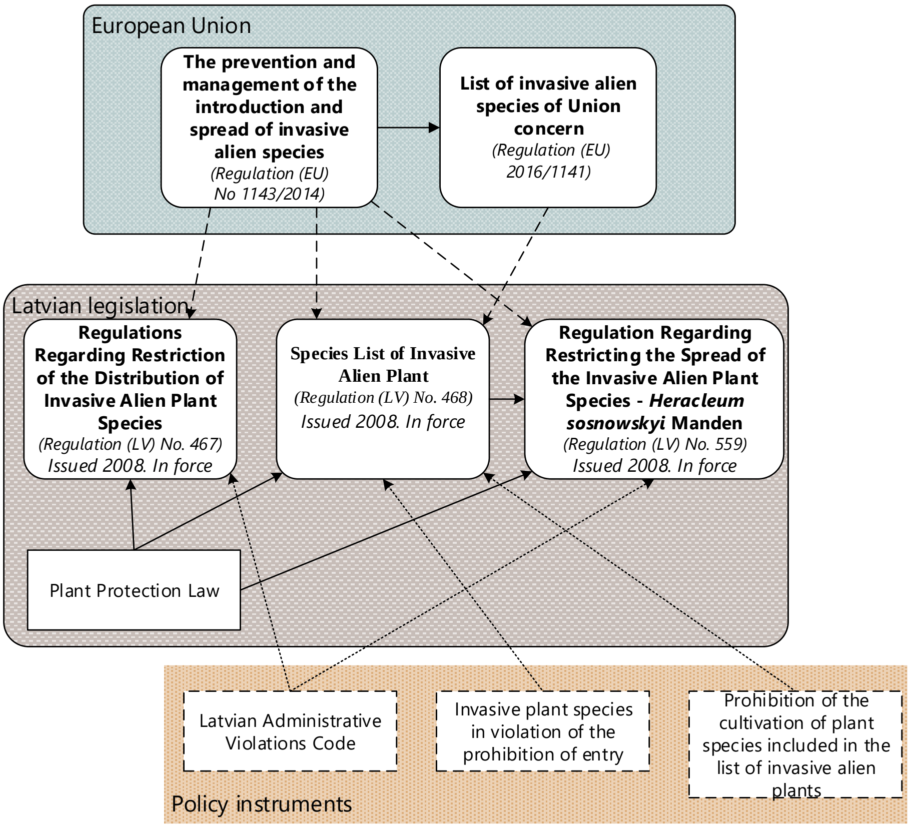


Figure 3.27. Invasive alien species legislation requirements and policy instruments in Latvia (author representation)

Regulations regarding restriction of the distribution of invasive alien plant species, fig.3.27., for now is based on European Union regulations, and the IAS species of European Union concern is already under controlling measures and included in Latvian legislation. There are some policy instruments used to control the spread of invasive alien species – *H.Sosnowskyi* Manden.

There are only sanctions as policy instruments for invasive plant species, that are in the national species list, however there could be an additional policy instruments with positive reinforcement for controlling the spread, so the land owners would be motivated to address the issue, get social interactions and data on invaded land area.

Control measures

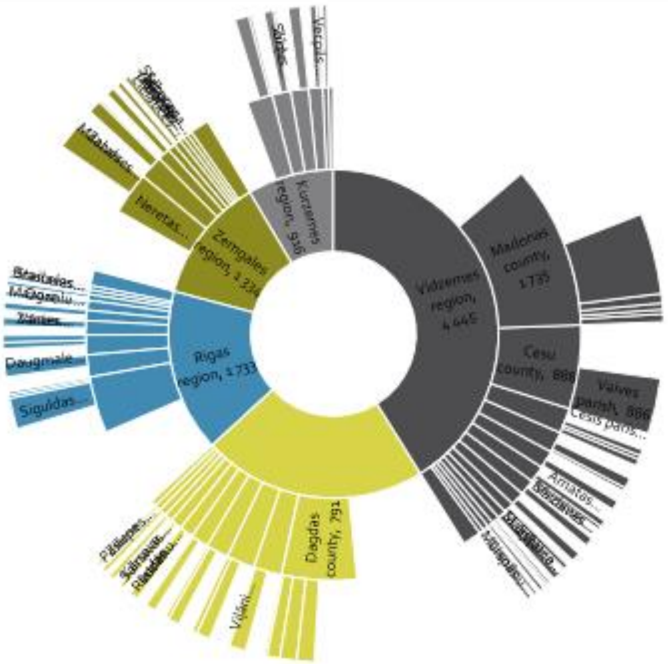
For this species several methods for controlling and eradication are provided within legislation – biological, chemical, mechanical or combined control of species. Biological control used as cattle and sheep grazing has its benefits in terms of use as fodder crop, but there are some drawbacks, that limits the use hogweed as fodder crop, first of all furanocoumarins present in sap can sometimes cause burns in places that are not covered with fur (lips, nostrils, udder, eyes) [202], second hogweed gives anise fragrance in milk or meat. Grazing usually is selected in early spring.

There are several mechanical methods for hogweed limitation, root cutting, mowing, removing umbels, mulching and soil cultivation [203]. Mechanical control is often used, but it still takes at least 3-6 years of continuous treatment (2-3 times during growing period). It means for new vision, biomass supply can be provided more than once a year, as it is for agricultural crops.

Chemical control is based on use of herbicides (glyphosate, triclopyr, imzapyir), most used is glyphosate, that poses risk of toxicity to fish and algae, therefore it is not advisable to use near rivers or other water bodies. Pollution risk remains, as there is no information whether society respects this restriction [203].

Combined control – Mostly combines mechanical and chemical treatment or mechanical and biological treatment.

***Heracleum Sosnowskyi* Manden in Latvia monitoring data**



Fig, 3.28. *H.Sosnowskyi* distribution in Latvia (author analysis)

For assessment on biomass availability for product production, distribution on invasive species and monitoring is very important, however, distribution for *H.sosnowskyi* includes data about area (ha) in region, see figure 3.28. There should be an assessment on biomass availability in Vidzeme region, as it has the most potential in IAP biomass, to help controlling measures at the same time gaining social and economic benefits. Assessment should include the IAP biomass quantity after mechanical control actions. There are many options on product production on *H.sosnowskyi* biomass, as presented in previous researches [89], [196], [197]. After selection of possible product production, sustainability analysis should be next step.

Suitable substitute bio-resources

One of the aspects that has to be considered is suitable substitute bio-resources in order to ensure product production by eliminating the risk of cultivating the invasive alien plants. Invasive alien plants are mostly comparable to lignocellulosic residues, and according to their composition, the corresponding products that can be possible to obtain are selected. Product preference strongly rely on biorefinery platforms, see Fig. 3.29.A.

Biorafinery platforms	
	Cellulose
	Oils
	Lignin
	C6 sugars
	C5&C6 sugars
	Hydrogen
	Proteins
	Pulp
	Fibre
	Biogas
	Electricity
	Pyrolytic liquids

A

Lignocellulosic biomass application	
	Animal feed
	Enzymes
	Biofuels
	Pulp&paper
	Fibre
	Fine chemicals
	Composites

B

Fig. 3.29. A) Biorefinery platforms, B) Lignocellulosic biomass (in this case – agricultural residues) application

Final product production bases on lignocellulosic biomass applications (see Fig.3.29.B), therefore suitable substitute bio-resource, that does not require cultivation, would be lignocellulosic biomass as agricultural residues, such as straw, stover, cobs, stalks, bagasse etc. Lignocellulosic materials are one of the most abundant and naturally available bio-resource [204], continuous research shows the necessity to find best solution for product production based on agricultural residues [205]–[207], that proves that available biomass substitute is freely available and secured and could convince stakeholders about long-term profitability of the technology.

MCDA TOPSIS analysis as pre-assessment should be tested on more than one country statistics, to prove the efficiency. Results of MCDA can be used as pre-assessment at national level, in order to set priority species to monitoring. The results show that new vision on system confirms existing system (the one species that has the highest score is already in regulation) and creates complimentary steps that could improve social, economic and environmental benefits and give contribution to policy makers, invaded land owners and municipalities.

Sensitivity analysis

Sensitivity analysis is done for some of the species, because all 157 species would

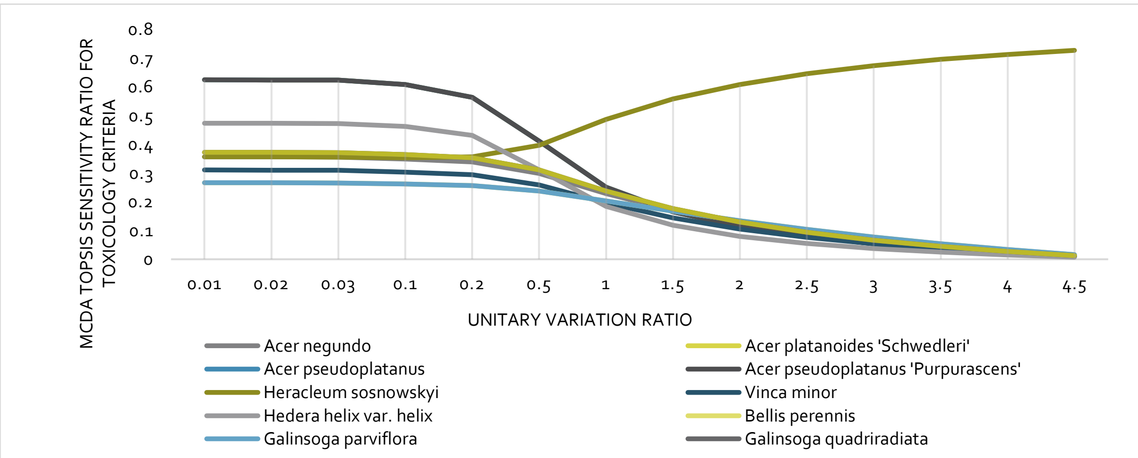


Fig. 3.30. MCDA TOPSIS sensitivity ratio for Toxicology criteria (author analysis)

From selected species toxicology has been selected only for one – *Herecleum Sosnowskyi* Manden, so the sensitivity analysis clearly shows if the importance of the toxicology increases only one species is prioritized for elimination or control.

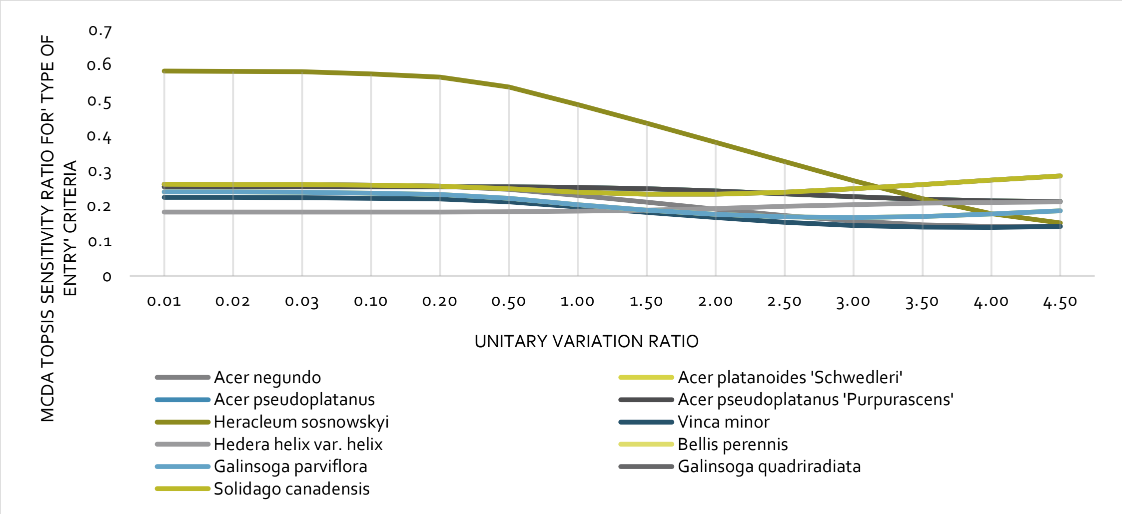


Fig.3.31. MCDA TOPSIS sensitivity ratio for' Type of entry' criteria (author analysis)

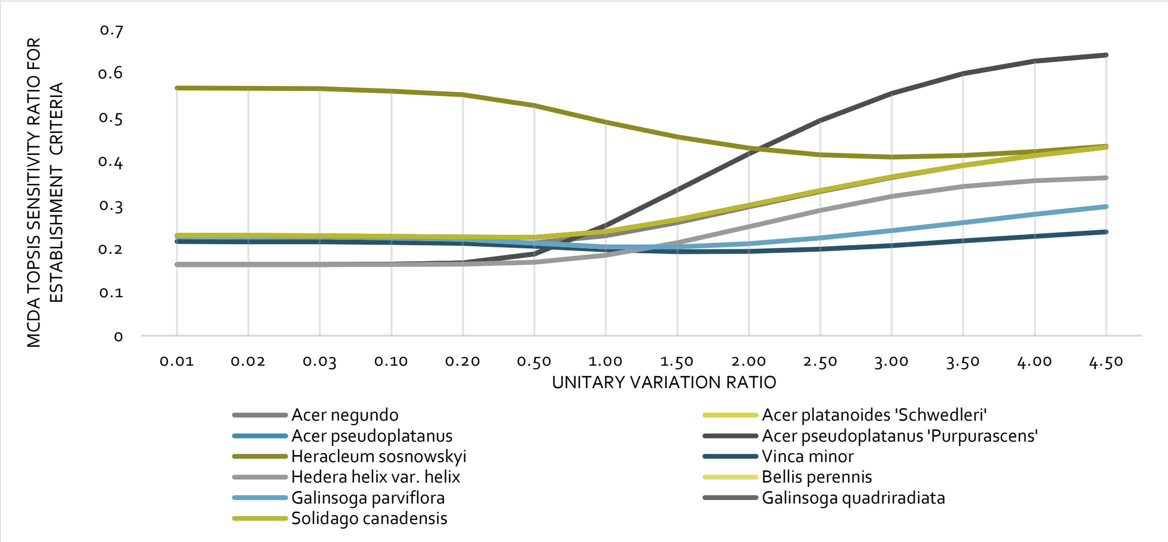


Fig. 3.32. MCDA TOPSIS sensitivity ratio for 'Establishment' criteria (author analysis)

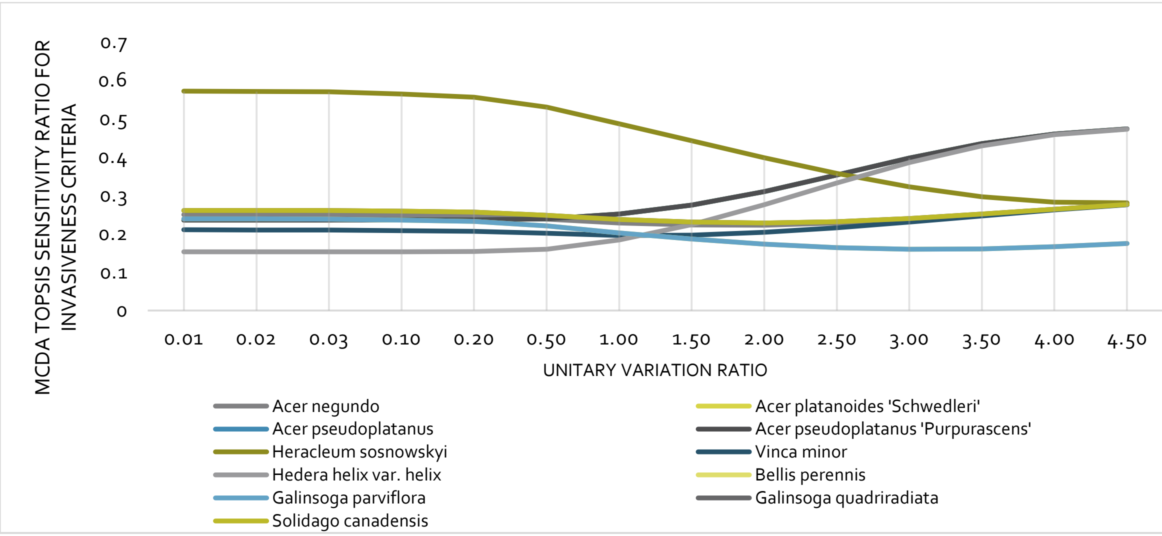


Fig. 3.33. MCDA TOPSIS sensitivity ratio for 'Invasiveness' criteria (author analysis)

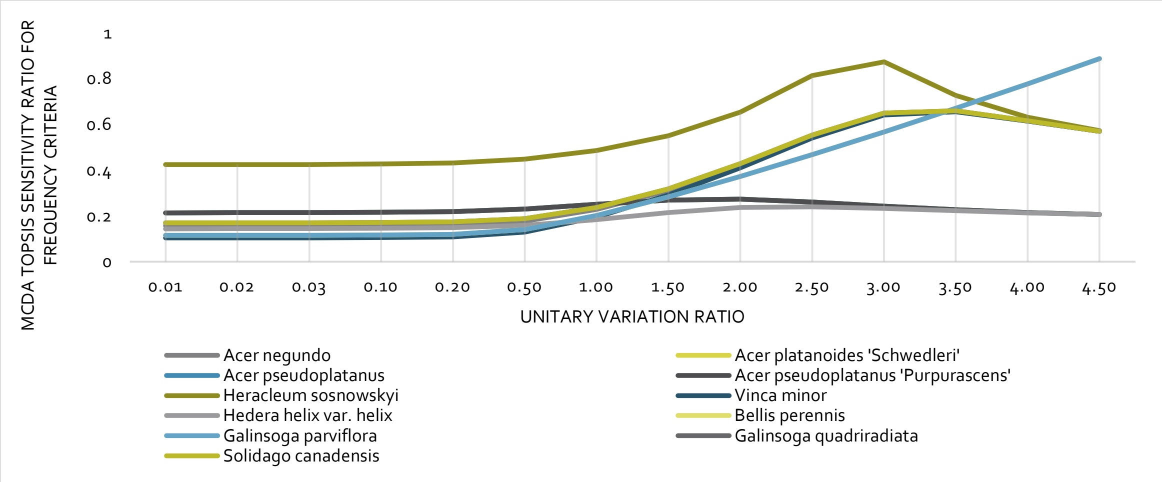


Fig. 3.34. MCDA TOPSIS sensitivity ratio for 'Frequency' criteria (author analysis)

In this task bioresource value analysis by MCDA was analysed at the bioresource level on national level case of Latvia. For current situation visualization Sankey diagram were selected to show flows of alien plant species, based on their invasiveness and establishment. Potentially invasive and invasive species were selected to pre-assessment done by MCDA TOPSIS on five criteria, results were compered to existing priority species set to monitoring, that determined a new level set for MCDA analysis results – if 0.2 ratios is reached, species should be assessed on criteria that determines species of national concern, if higher than 0.5 ratio is reached, species should be monitored and controlling measures should be implemented.

3.3.1. Potential bioresource value

Agro-industrial biomass value

Aquacultures are the fastest growing food-producing sector in the world, therefore new sources for fish oil and fish feed is essential for continuous growth of aquaculture industry. Single-cell oil and single-cell protein produced by microbial fermentation from agro-industrial residues can be an alternative for replacing fishmeal and fish oil in aquacultures [208], [209].

Agro-industrial by-products were classified and screened according to suitability for microbial fermentation. It means only biodegradable industrial residues were selected. Obtainable products were based on scientific database information. For multi-criteria matrix compilation, selection of experts was made according to their expertise in the field. Indicators for multi-criteria analysis are based on environmental, economic and engineering factors: product development stage, potential market size, used amount of agro-industrial resources, technological complexity of the process, waste and residue amount in production process, CO_2 emissions during manufacturing process, effect on environment and human health, necessary investments to start manufacturing process, by-products that can be obtained during manufacturing and product compliance to eco-design based principles.

Multi criteria matrix were based on expert evaluation of products according to these indicators. Experts were selected with expertise in bioeconomy, bioenergy and microbiology. Each expert gave the evaluation without consultation with another to provide a discrete individual evaluation. Weights for criteria were selected by experts in this field and given in Table 3.12. The highest impact is evaluated for economic indicator – product market and start-up costs and engineering indicators – resource consumption amount and complicity of technological process. From environmental indicators, the highest impact is evaluated for specific by-product amount.

Table.3.12.

Indicators and weights used in multi criteria analysis

Criteria	Sub - criteria	Weight
Engineering indicators	Production process readiness level	0.07
	Resource consumption amount	0.10
	Complicity of technological process	0.10
Environmental indicators	Waste and residues from production	0.04
	Specific by-product amount	0.14
	CO_2 emissions in production process	0.03
	Product effects on environment	0.03
	Product effects on human health	0.04
	Product compliance to eco-design principles	0.04
Economic indicators	Start-up costs	0.16
	Product market	0.25
	∑	1.00

Multi criteria analysis, based on TOPSIS, allows to prioritize (rank) chosen products according to the best possible solution. The best results is for the product, with result that is closest to one [210].

Division for agricultural residues is monosaccharide and disaccharide rich sources such as molasses (carbohydrates rich), dairy residues (lactose or protein rich) and fruit processing waste (simple sugar rich). Starch rich sources, like grains, tuber residues, bran (by-product of grain processing) and deproteinized leaf juice (vegetable protein production by-product). Structural polysaccharide rich sources are soy bean hull (by-product from production of soybean meal), starch and sugar processing residues (liquid residues from starch and sugar production), fruit residues (fibre rich, fruit processing residues), poultry residues, spent grains (brewery's spent grains), pawn shell waste (crustacean processing residues). Protein or lipid rich sources are wastewaters (protein rich – stickwater liquid by-product from fish feed production and waste liquor from glutamic acid factory), capscium powder residues (by-product from pigment extraction), slaughterhouse residues (horns, feathers, nails, hair – fibrous protein rich), soy bean meal (by-product from soybean oil extraction – protein rich) and combined agricultural residues [211]. Industrial residues are polymers rich sources, especially lignocellulosic residues, for example waste paper, sulphite waste liquor, also lignin residues and latex rubber sheet wastewater. Carbon compounds are methane, methanol, acetic acid, formic acid, waste gases, glycerol, gas oil and other n-paraffins. Sources for photosynthetic microorganisms are effluents of biogas plants, saline sewage effluents and wastewater effluents [212].

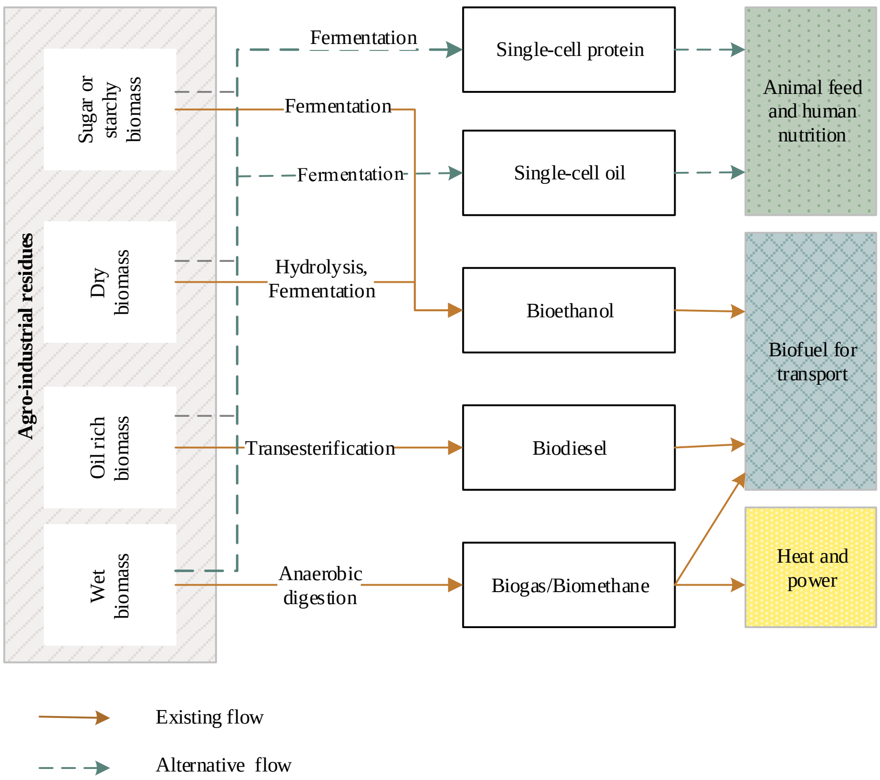


Fig.3.35. Agro-industrial residues existing and alternative flow used in analysis (author analysis)

Agro-industrial biodegradable biomass can be obtained as wet, dry, oil rich and sugar or starchy biomass, the use for biogas is wet biomass by anaerobic digestion, for biodiesel oil-rich biomass by transesterification, and for bioethanol dry, sugar or starchy biomass using hydrolysis and fermentation or just fermentation accordingly. But for single-cell protein and single-cell oil, all types of these biomasses can be used using pre-treatment (if required for particular residue) and fermentation process (Fig.3.35.).

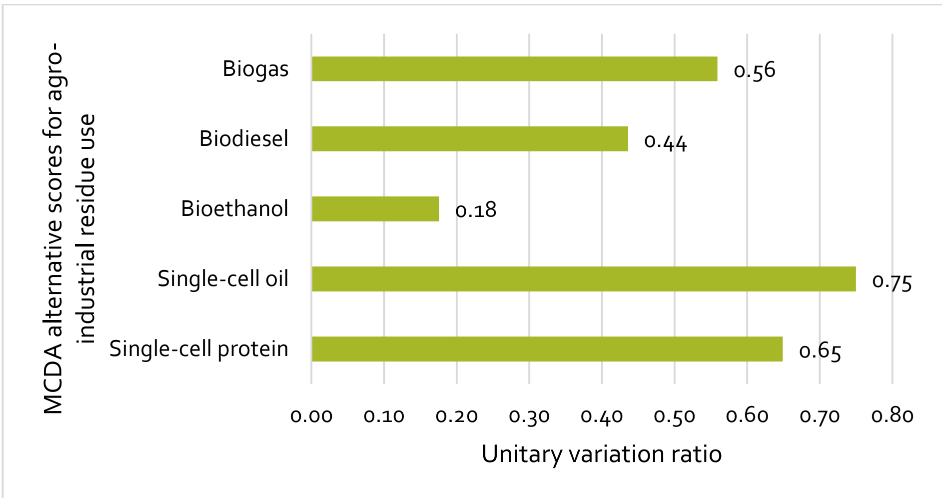


Fig. 3.36. Results of Multi criteria analysis of agro-industrial residue use potential (author analysis)

After multi criteria results (Fig.3.36.) single-cell oil has the highest priority according to the criteria evaluated and bioethanol has the lowest. Single-cell protein shows sufficient results as well. The best of bioenergy is biogas, but in comparison with single-cell oil and single-cell protein, it is only third highest priority in terms of potential of agro-industrial by-products. The key driver in production of given priority products is product market, there is growing demand for animal feed, especially fish feed, due to a growth of global aquaculture production and human nutrition – fish oil, due to an increase in consumption as human nutrition.

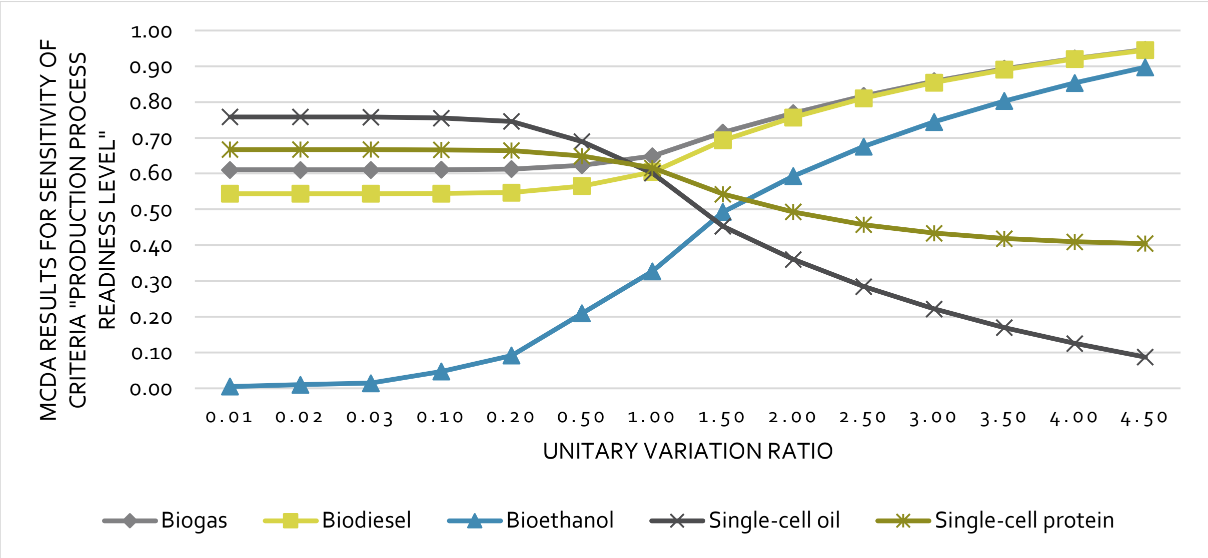


Fig.3.37. Sensitivity analysis for product development stage (author analysis)

The sensitivity analysis (fig.3.37.) shows that if the production development stage weights become more important than other criteria, than products, that is less developed, such as single-cell oil and protein has lower priority than existing products, such as biogas, biodiesel and bioethanol.

Value of invasive species

The introduction of bioeconomy leads to search of new high added value bio products that can be obtained from local natural resources that have not been used or are used with low added value. One of which is invasive species. Tendency is to limit or to eliminate invasive species from environment therefore it can be labelled as waste. One of the bioeconomy principles is to turn waste into valuable products. European Union's primary goal is to use bio resources for production of high value products (European Comission, 2018).

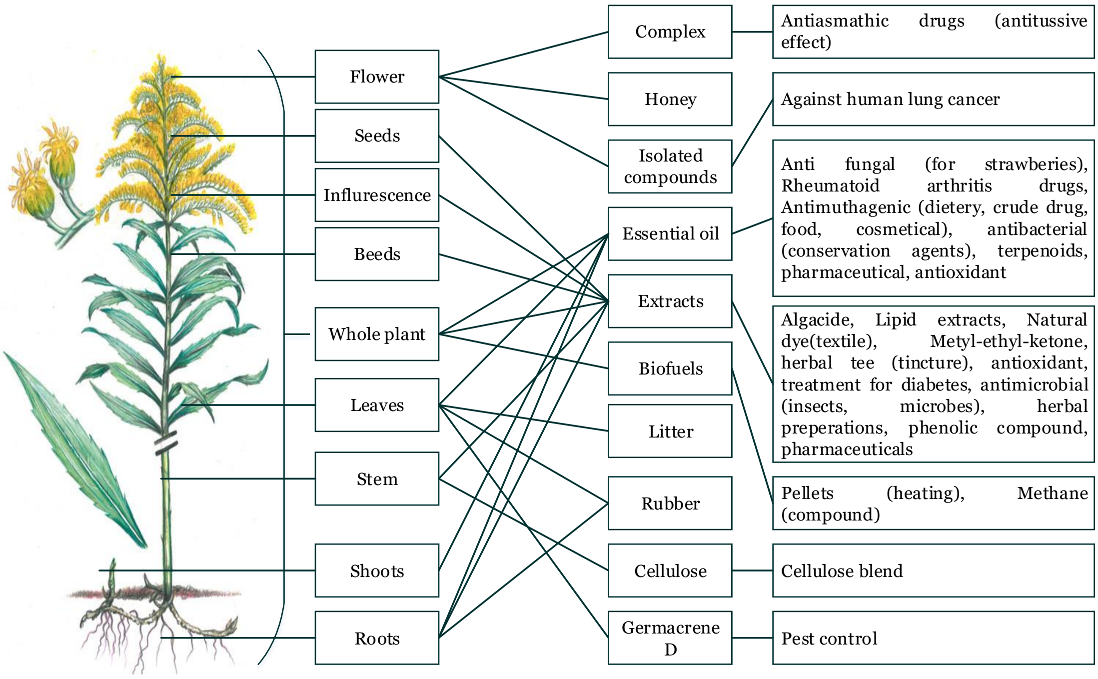


Fig. 3.38. *Solidago canadensis* classifications by parts of resource used in products (author analysis)

Classification in Fig.3.38. shows that all parts of *S. canadensis* can be used for obtaining a product. Significant research is done in field for extracts and essential oil, which can be obtained using leaves, shoots, roots or whole plant for essential oil and seeds, buds, inflorescence, stem, roots or whole plant for extracts. Both have similarities in qualities such as antimicrobial, antioxidant, antibacterial and antifungal. Essential oils can be used in agriculture, medicine, dietary, food, cosmetics, nutraceutical, pharmaceutical purposes [85], [213]–[218]. Extracts can be used in pharmaceuticals, textile, medicine, agriculture and as algaecide in small ponds [86], [213], [227]–[229], [219]–[226]. From flowers it is possible to obtain great quality honey [230] and polyphenolic-polysaccharide-protein complex used as anti-asthmatic drugs [231] and labdane diterpene as isolated compound used as drugs against lung cancer [232]. Biofuels are obtained from whole plant, and there are articles for pellets and methane biofuel [233], [234]. Methane fuel did not prove the great results and has a potential only as component with cattle slurry [234]. Pellets results are more promising [233] only question rises about added value, this plant seems to have more value than burning in households. Leaves can be used for litter that reduces C decomposition and N processes which is important in altering ecosystems [235]. In experiment *S. canadensis* (SCL) trunk were used in cellulose/SCL blend and proven to increase a thermal stability by 75^{o} C than pure cellulose [236]. Roots and leaves were acknowledged as a resource for rubber, although in comparison with different resources it got an average result [237]. Last but not least was pest control from leaves which proves the anti-mutagenic effect [238].

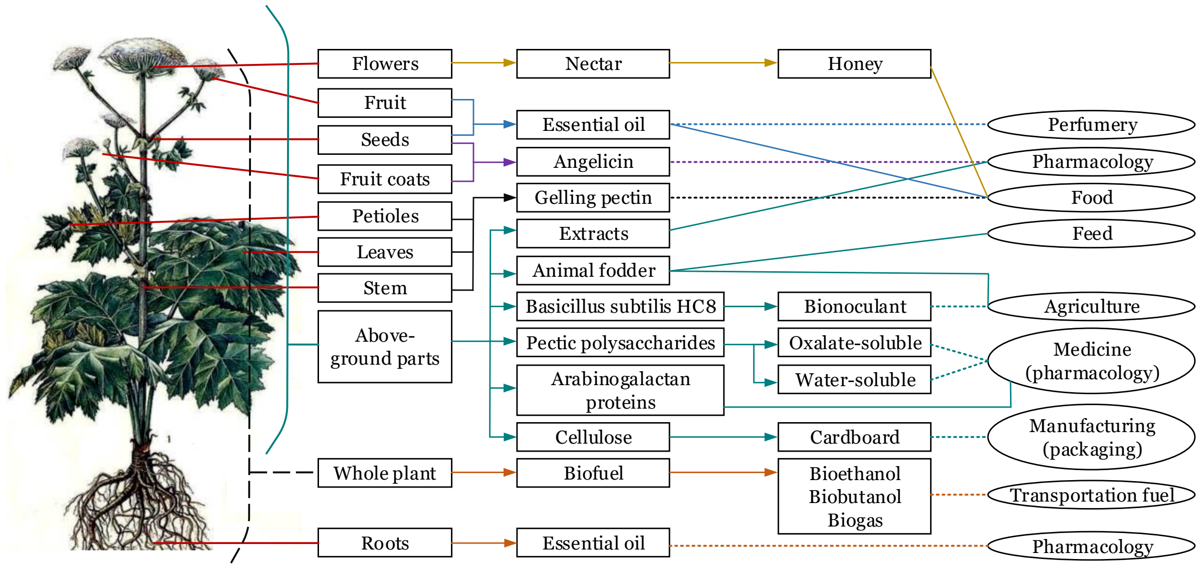


Fig.3.39. Product classification according to the parts of the resource to be used (author analysis)

All parts of *H. sosnowskyi* plant can be used to produce products. As shown in Fig. 3.39., it is possible to obtain honey from the flowers which can be used in food industry [239]. It is possible to extract essential oils from fruits and seeds, which can be used in perfumery, in food and in pharmacy [240], [241]. From seeds and fruit shells it is possible to obtain furanocoumarin - an organic chemical compound derived from plants - angelicin, which can be used in pharmacy [242]. Pectin from the trunk, leaves and stalks can be used as thickener in food, for example, as gelatine [90]. From the surface of the plant can be obtained a variety of extracts which in general, *Heracleum* L. genus has with the characteristics of antimicrobial, antipyretic, immune stimulant, analgesic and vasodilator properties and can be used for enzymes and psoriasis [243]. Silage may be prepared for fodder from the green mass, or be grazed fresh for cattle or sheep [244]. From hogweed it is possible to obtain a bioinoculant which can be used in agriculture as a growth stimulator and biological control agent, for example, against tomato foot and root rot [245]. Studies are available on the production of polysaccharides from hogweed pectins [243], [246] and arabinogalactan proteins [247], that can be used in the food and pharmaceutical industry. The hogweed can be used for the production of cellulose, further for production of cardboard [248]. Biofuels can also be obtained from the whole plant. There are studies available on the production of bioethanol and biobutanol [249], [250], and biogas production [251]. Essential oils used in pharmacy can be obtained from the roots and fruits [252].

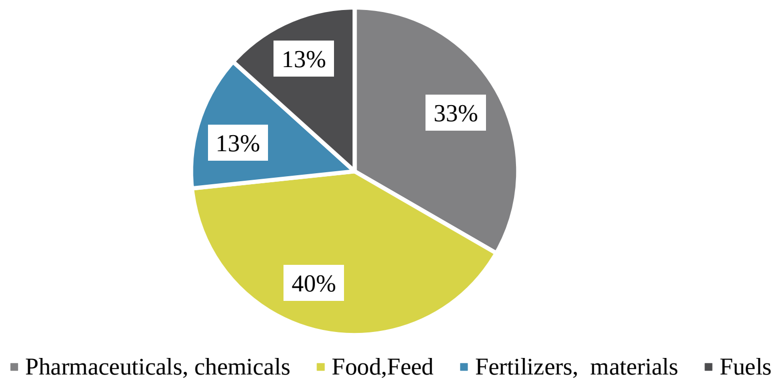


Fig.3.40. Classification of the studied products by added value (author analysis)

So far, the highest emphasis in researches is the second phase of the bioeconomy pyramid - food and feed 40% with high added value, the next is the use in pharmaceuticals with the highest added value (33%), and equal parts divide fertilizers and materials with transport fuels (the lowest added value) 13%, see Figure 3.40. Subsequently, five products – angelicin (pharmaceuticals), bacillus subtilis (fertilizer, biologic control), polysaccharides (food, pharmaceuticals), essential oil (food, pharmaceuticals, perfumery) and cardboard (materials) were raised for multicriteria analysis.

Table 3.13.

Indicators and weight for each indicator determined by experts

Indicators	Weight
Production process readiness level	0.07
Resource consumption amount	0.08
Product market	0.28
Complicity of technological process	0.05
Specific water consumption	0.02
Specific electricity consumption	0.08
Specific thermal energy consumption	0.07
Waste and residues from production	0.04
Specific by-product amount	0.03
Product selling price	0.03
Product effects on environment	0.03
Product effects on human health	0.04
Product compliance to eco-design principles	0.05
Start-up costs	0.14
Total	1

Stated by the experts, the most important indicators are economic indicators. Engineering and environmental and climate indicators takes equal parts, weight for each indicator is shown in Table 3.13.

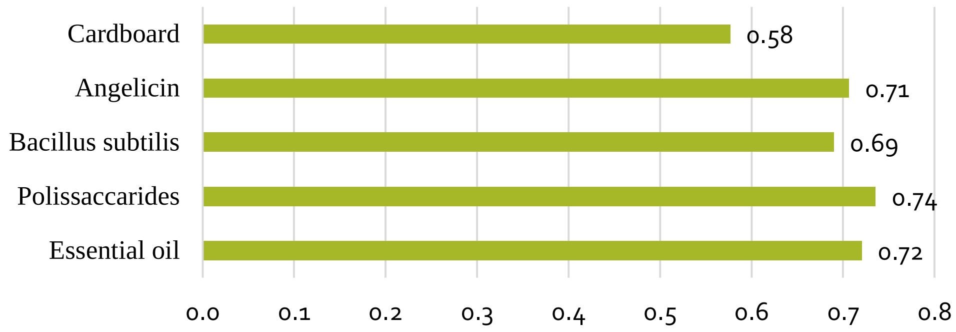


Fig. 3.41. Multicriteria analysis results for five selected products (author analysis)

According to the results of the multicriteria analysis (Fig. 3.41.), it appears that the greatest potential is polysaccharides that can be used in food and pharmacy and have high added value. Close results are for essential oils and angelicin, which, like polysaccharides, can be used in food and pharmacy and have high added value. Bacillus subtilis or bioinoculant is with slightly lower rating and can be used in agriculture as fertilizer or biopesticide, and the added value is slightly lower than the above mentioned. The selected product for the analysis - cardboard were with low added value but with the possibility to use large quantities of green mass. However, there are still a lot of problems to start the use of *Heracleum sosnowskyi* as bioresource. For example, lack of harvesting methods: how to collect effectively and safely the green mass of hogweed for manufacturing purposes.

3.3.2. Result of Experimental Analysis: Potential of Solid Biofuel

Evaluation has been done by experimentally determining biofuel parameters of two invasive plant species. In comparison to finding a new application, their use as a solid biofuel pellets would not require additional investments for the construction of new production plant.

Currently one of the main challenges of pellet industry is limitation of raw materials [253]. In the energy sector, one of the fastest growing markets is pellet production and consumption [254]. Pellets mostly are prepared from wood as raw material, but to satisfy growing demand new materials has to be integrated into production. Existing researches offers non-woody materials such as herbaceous biomass, fruit biomass and aquatic biomass [255]. In comparison with wood biomass, non-wood materials have higher compound variation which creates great challenge to the pellet production industry. Therefore, quality of the raw material is important [255].

Existing non-woody materials is agricultural biomass, wheat straw, rape straw, maize straw etc. [256]. Research for substitute solid biofuel availability and energy sources concludes that herbaceous biomass has the potential for energy production (e.g. common reed and *H.sosnowskyi*) [257], therefore the focus in this study is on herbaceous biomass, which is available, widely spread and unused in Latvia. Agricultural residues are abundant and inexpensive source of renewable energy [258]. Agricultural residues, such as straws do not contain an adequate amount of natural binding components – lignin, protein, starch or water soluble carbohydrates. One solution is to debond lignocellulosic matrix structure that free the lignin, but that involves pre-treatment (chemicals, additives, microwave, steam explosion or other method). Other solution is to add a binder, in that way improving pellet durability and strength [258]. Various types of natural binders are used for pellet improvement, e.g. rapeseed flour, coffee meal, bark, lignin powder, pine cones [259], potato flour, potato peel residue, lignosulphonate [260] and others [261]. The most important aspects are to find a binder that is at low cost, does not require additional treatment and is environmentally friendly.

Raw material selection is necessary to find a sustainable solid biomass fuel, which is not used in the production of higher added value product. This case study focus on finding good quality non-woody raw material for solid biofuel. According to presented methodology in chapter 2.3.1. solid biofuel raw materials and natural binder was chosen on sustainability criteria.

Invasive species that has invaded agricultural land and meadows have eligibility for sustainability criteria given above. Two of the most invasive plant species in Latvia has been selected for the case study: *Solidago Canadensis L*. and *Heracleum Sosnowskyi* Manden. Both have invaded agricultural land and meadows and are waste with no added value in Latvia. Both invasive species can grow on low nutrition land with no fertilizers or additional water, they are not used in food industry and are available at low cost as the main purpose is to eliminate these resources. Mowing and utilizing these plants to produce valuable product would help to control spreading, as well as improve biodiversity. Two possible binders have been selected: potato peel waste and spent coffee grounds. Chosen binders correspond to criteria of sustainability too.

Sample preparation

Raw materials have been collected in Riga. *H.sosnowskyi* have been collected at the end of October (2017) and *S.canadensis* have been collected at the end of August, (2017). Plant materials were initially pre-dried in the laboratory at ambient conditions and afterwards dried completely in a dryer for 18 hours at 105ºC. Afterwards samples were grinded in a mill (Vibrotehnik PM120) into particles smaller than 1 mm in diameter. To ensure that particle size is less than 1 mm, the mill contains a sieve with aperture size of 1 mm.

The binders were air dried for a week. The size of spent coffee grounds was already < 1 mm. It has been checked using the sieve Retsch AS 400 with sieve aperture size of 1 mm. However, potato peel waste was ground in the mill.

The first eight samples were prepared as following: pure *S.canadensis* (Sc), pure *H.sosnowskyi* (Hs), pure coffee grounds (CG), pure potato peel waste (PPW) and Sc with 6wt% CG, Sc with 6wt% PPW, Hs with 6wt% CG and Hs with 6wt% PPW.

All samples were prepared in accordance with the ISO (International Organisation for Standardisation) standard ISO 14780. The biofuel sample was pressed in a pellet press to produce compact and dense test piece weighing 1.0 g ± 0.2 g.

The main biofuel characteristics were tested according to ISO standards on biofuel testing: ash content, moisture content and calorific value.

After selecting samples for further analysis, new samples were made using the best material (higher calorific value shown for one of the species and increasing calorific value for binder) that contained 10 wt%, 30 wt% or 50 wt% binder accordingly.

Outcome

The results of moisture content (wt%), ash content (wt%) and calorific value (MJ/kg) have been determined during analysis. In order to be able to get reliable results of calorific value, there is a necessity to determine and calculate chemical composition for each sample. All results are corrected with chemical composition values for carbon (C), hydrogen (H), nitrogen (N) and sulphur (S).

Table 3.14.

Chemical composition of samples

	CG	PPW	S	H	S,PPW 6wt%	S,CG 6wt%	H,PPW 6wt%	H,CG 6wt%
C	52.95	43.90	44.80	46.52	44.75	45.29	46.36	46.91
H	6.76	7.20	6.46	5.79	6.50	6.48	5.87	5.84
N	2.10	0.80	0.37	0.59	0.40	0.47	0.60	0.68
S	0.12	0.10	0.20	0.00	0.19	0.19	0.01	0.01

Key: Sc, PPW 6wt% - *S.canadensis* (94 wt%) mixed with 6 wt% potato peel waste; Sc, CG 6 wt% - *S.canadensis* (94 wt%) mixed with 6 wt% coffee grounds; Hs, PPW 6wt% - *H.sosnowskyi* (94 wt%) mixed with 6 wt% potato peel waste; Hs, CG 6wt% - *H.sosnowskyi* (94 wt%) mixed with 6 wt% coffee grounds.

The chemical composition (*C, H, N, S)* of pure materials – coffee grounds (CG) [262], potato peel waste (PPW) [263] and *S.canadensis* (Sc) [233] were taken from the available literature, *H.sosnowskyi* (Hs) from experimental analysis by chromatograph and mixed samples were calculated according to proportions mixed, see Table 3.14. Samples that were tested after selecting suitable material and binder: *H.sosnowskyi* and spent coffee grounds accordingly. Proportions are as follows: Hs 90 wt%:CG 10wt%, Hs 70wt%:CG 30wt% and Hs 50wt%:CG 50wt% and calculated accordingly. According to EN plus pellet quality requirements for wood pellet quality classes, N and S amount is very important for solid biofuel quality. The highest acceptable N amount is 1.0 wt% and S is 0.05 wt% [264]. If the aim is to compete or to achieve the qualities similar to wood, then no more than 30wt% CG binder can be added.

Table 3.14. shows chemical composition of samples that were tested after selecting suitable material and binder: *H.sosnowskyi* and spent coffee grounds accordingly. The proportions are as follows: H 90 wt%:CG 10wt%, H 70wt%:CG 30wt% and H 50wt%:CG 50wt% and were calculated accordingly. According to EN plus pellet quality requirements for wood pellet quality classes, N and S amount is very important for solid biofuel quality. The highest acceptable N amount is 1.0 wt% and S is 0.05 wt% [264]. If the aim is to compete or to achieve the qualities similar to wood, then no more than 30wt% CG binder can be added.

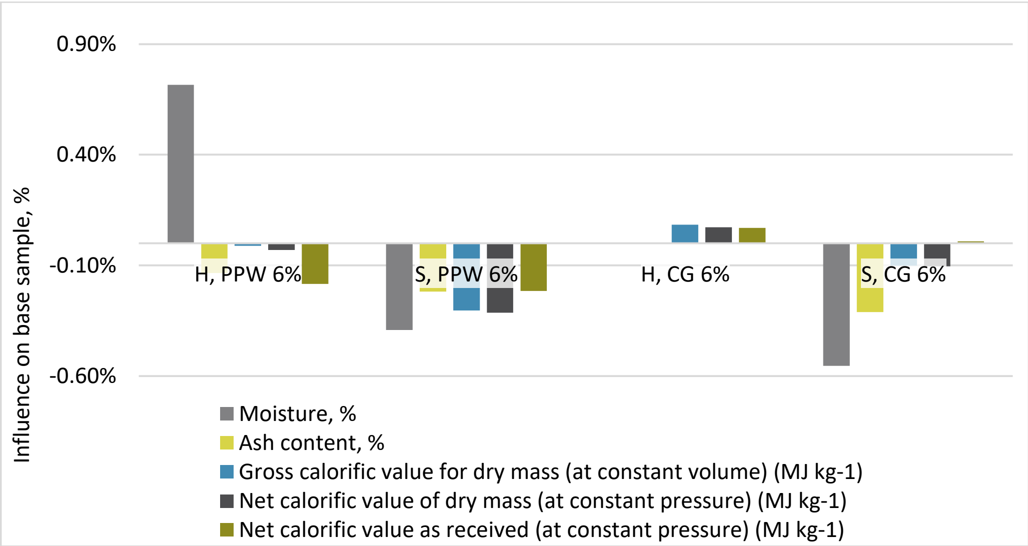


Fig. 3.42. Biofuel parameter changes by binder type (author analysis)

In Fig.3.42. changes in biofuel parameters are shown regarding pure material sample (no binder added). *H.sosnowskyi* and PPW (H, PPW 6 wt%) sample show increase in moisture content, small decrease in ash content and calorific values. *S.canadensis* with both binders (PPW and CG) show decrease in all parameters. Only *H.sosnowskyi* with CG binder show increase in calorific value and no important changes in moisture and ash content. Therefore, *H.sosnowskyi* and CG were selected for further testing using different proportions of binder. There are no similarities between both binders and their effect on biomass parameters, for example, PPW binder decreases moisture for one biomass, but increases it for other. Therefore, further experiments with other types of biomass are preferable.

Table 3.15.

Results of solid biofuel parameters for all samples

Sample	Moisture (%)	Ash content (%)	Gross calorific value* (MJ kg^{-1})	Net calorific value ** (MJ kg^{-1})	Net calorific value *** (MJ kg^{-1})
Sc, 0%	7.3%	6.8%	18.24	16.84	15.43
Hs, 0%	3.1%	3.4%	19.45	18.19	17.56
Hs, PPW 6%	3.8%	3.3%	19.44	18.16	17.37
Sc, PPW 6%	6.9%	6.6%	17.94	16.52	15.22
Hs, CG 6%	3.1%	3.4%	19.53	18.26	17.63
Sc, CG 6%	6.7%	6.5%	18.14	16.73	15.44
Hs 90%, CG 10%	3.7%	3.4%	19.64	18.36	17.59
Hs 70%, CG 30%	4.8%	3.1%	20.42	19.10	18.07
Hs50%, CG 50%	6.1%	2.9%	21.09	19.73	18.39
CG 100%	9.2%	2.3%	22.73	21.27	19.08
PPW100%	15.9%	5.8%	17.90	16.33	13.36

* for dry mass at constant volume
** for dry mass at constant pressure
*** for sample as received at constant pressure

For the final results from all samples show that the highest calorific value is for pure coffee ground sample, whilst the lowest is for potato peel waste. Potato peel waste has the highest moisture content. From these results potato peel waste is proven not to be very suitable binder. *Solidago canadensis* has a high moisture and ash content and although the calorific value is good for non-woody material, the *Heracleum* showed better results in all the parameters and therefore were selected for further experiments.

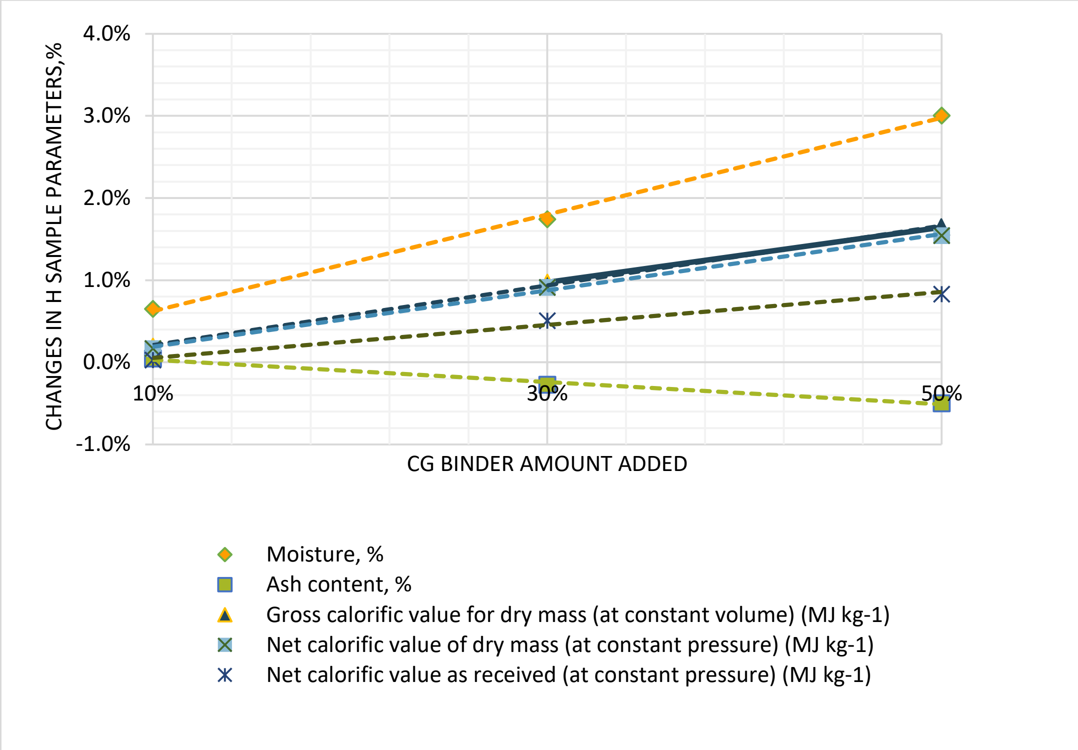


Fig. 3.43. Biofuel parameter changes by different proportion of CG binder (author analysis)

Figure 3.43. illustrates how the amount of CG binder (10 wt%, 30 wt%, 50 wt%) added influences biofuel parameters. In comparison to pure H sample, *H.sosnowskyi* with CG has higher calorific value (gross calorific and net calorific value of dry mass $R^2 = 0.99$; net calorific value as received $R^2 = 0.98$), lower ash content (R^2=0.98), and higher moisture content (R^2=0.99).

Analysing all parameters the optimal moisture content, ash content and calorific value is for *H.sosnowskyi* with 30 wt% CG binder. Thus determination of durability is necessary for sample with 30 wt% of CG binder.

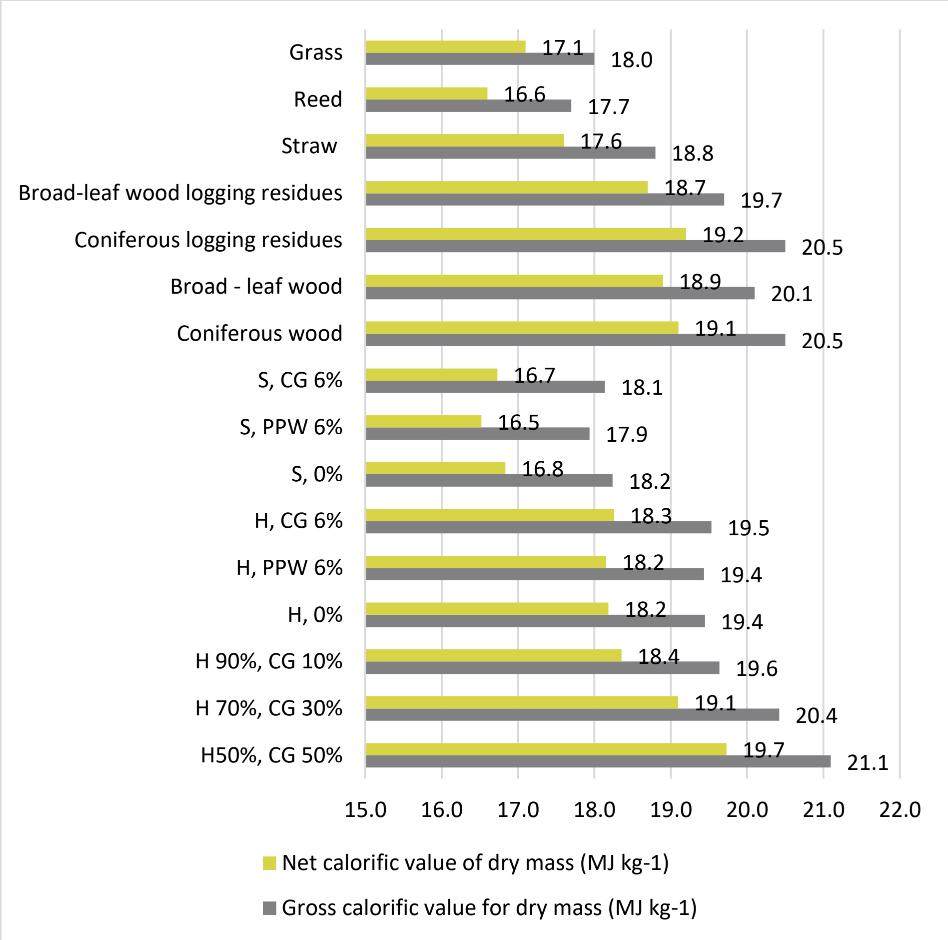


Fig. 3.44. A comparison of calorific values between existing solid biomass fuels and tested samples (author analysis)

In order to determine the quality of the tested sample, a comparison with other existing solid biomass fuels were carried out. Typical values have been taken from ISO 17225-1:2014 standard. The main values taken for comparison are grass (in general), virgin reed canary grass (summer harvest), virgin straw materials from wheat, rye, barley, virgin wood logging residues for coniferous and for broad-leaf wood, and virgin wood materials for broad-leaf wood and coniferous wood.

The results of all *Solidago* samples, see Fig.3.44., corresponds to reed and grass calorific values with and without binders, however *Heracleum* is competitive with broad-leaf logging residues. Moreover, mixed samples are even comparable with coniferous logging residues, broad-leaf wood and coniferous wood. Best results are for *Heracleum* sample with 50 wt% coffee grounds. To determine the optimal proportion, ash content should be taken into account.

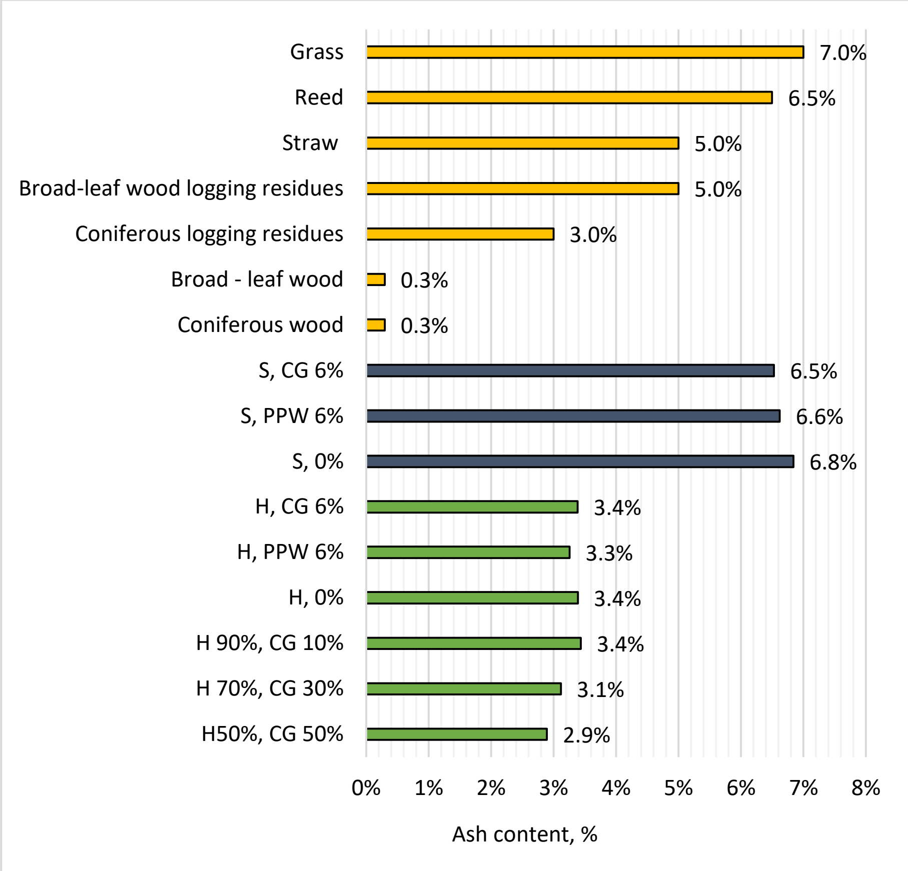


Fig. 3.45. A comparison of ash content between existing solid biomass fuels and tested samples (author analysis)

Figure 3.45. shows ash content values of existing solid biomass fuels and tested samples. Typical values of existing solid biomass fuels are taken from ISO 17225-1:2014 standard. Lowest ash content is for virgin wood material (broad-leaf and coniferous). Non-woody materials cannot compete with virgin wood materials. However, average ash content of logging residues is 3 wt% - 5 wt%, which is similar to ash content of *Heracleum*. Ash content of *Solidago* mixed samples are similar to virgin reed canary grass, but results of pure *Solidago* is similar to grass (in general).

The methodology can be improved by adding more biofuel-characteristic parameters into the selection and is effective in comparison with other solid biofuels. The optimum coffee ground binder percentage is no more than 30% as the moisture content increases significantly. The increasing moisture content in higher proportions with coffee grounds could be reduced by means of oven drying.

Overall, the experimental analysis turned out better for *H sosnowskyi* pellets with a coffee ground binder. The calorific value and ash content can be competitive against wood. Therefore, it is possible to use this bioresource as an effective energy source. From those conclusions it can be seen that the use of *H.sosnowskyi* with a coffee ground binder has been fully validated, and it is advisable to use this in industrial pellet production plants. However, from the energy balance and economics point of view, it is preferable to conduct further analysis. Further investigation for durability and bulk density for industrial pellets is clearly needed.

CONCLUSIONS

1. From the main multi–level methodology the conclusion is that bioeconomy should be assessed from bottom-up approach using micro- and meso-level assessment including transdisciplinary approach by working together with society (stakeholders), but top-down approach can help to determine the path for country level assessment in order to find drawbacks for bioresource transition towards sustainable bioeconomy, but top-down approach can help to determine the right path for country level assessment in order to find drawbacks – e.g. what necessary data should be collected in order to evaluate bioeconomy at international level.
2. The bioeconomy efficiency index allows to compare the level of bioeconomy development at international level. In this analysis no specific trend was distinguished between the bioeconomy development pathways in the EU 28 countries, but the overall evaluation indicates that the two highest ranked countries are Denmark and Ireland, mostly due to high investments in agriculture R&D and high labour productivity in bioeconomy. Bioeconomy efficiency index allows the decision makers to identify the most influencing indicators for each country to focus on strengthening the countries performance and could help in bioeconomy strategy development.
3. The main drawback of bioeconomy macro-level assessment is insufficient data, several good databases have been created for bioeconomy datasets, unfortunately the data is only till year 2015–2016, therefore the situation is the bioeconomy main growth years cannot be assessed because of lack of data.
4. The advantages of composite index include describing the multi-dimensional nature of the investigated phenomenon with a one-dimensional proxy that can be easily interpreted. In addition, composite indexes are easier to interpret than scoreboards of indicators; they can be used to follow the development of the phenomenon in time, they can include more information when there are limitations of size. The drawbacks, however, include potential misuse due to faulty interpretation.
5. With the developed meso-level framework it is possible to get an insight for innovation development potential for commercialization. Market factors clearly illustrate the situation even in early development stages and economic assessment is the first validation of innovation feasibility. These steps are advised to be repeated in next development stages when the technological readiness level is higher and there can be more precise evaluation. Also, it is important to repeat the economic and market assessment to see which stage in production process has the highest cost, and to reduce this stage or change the raw material within innovation development. The framework is successfully validated by the case of thermal packaging material and there is a clear vision which processes should be improved in next development stages.
6. Multicriteria analysis provides the ability to search for the use of invasive species to address the acute problems of agricultural land use. From invasive plants it is possible to produce a variety of products significant for national economy. Use of invasive species in products would create both economic and environmental benefits, but there should be certification scheme developed to exclude the possibilities from deliberate cultivation of the plants and non-invasive plant substitute that ensures long term product production.

7. The application of multicriteria methodology allows to find the priorities of use of *Heracleum sosnowskyi* as bioresource for the production of bioproducts with high added value. Based on the results of the multicriteria analysis, three pharmaceutical products have the best potential: polysaccharides, angelicin, and essential oil.
8. Countries with forest resources should focus on adding value to pulpwood and forest residues, as one possibility to invest in textile industry for fibre production as there are higher potential not only for adding value for bioresources, but also biorefinery and energy production or innovations from forest residues like thermal packaging material. Future assessments should focus on robust analysis for biorefineries implementation and market values.
9. From experimental studies it is concluded that bioresource potential for invasive plant species as for solid biofuel potential are advised if characteristics are closer to wood than plant, as it is in case of *Heracleum sosnowskyi*, but not in *Solidago Canadensis* case. Future development should be focused on added value for product validations, such as fibre or chemical substances and biorefinery.
10. From experimental studies, analysing all parameters the optimal moisture content, ash content and calorific value is for *H.sosnowskyi* with 30 wt% CG binder, from this experiment another residue potential rises, that is coffee ground use as effective pellet binder with high calorific value that could also solve coffee residue issue with potential for further research.

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ANNEXES

A.Research and Innovation Indicators

	Indicators	Reference
Economic	R&D expenditure by sector	[138]
	R&D expenditure as a proportion of GDP [5]	[265]
	Private and public spending on research and development [17]	[138]
	Investment in R&D (EUR) [13]	[138]
	Eco-innovation index (EII - composite index of 16 indicators- eco-innovation inputs/activities/outputs, resource efficiency and socio-economic output)	[266]
	Gross domestic expenditure on R&D by sector (sdg_09_10)	[267]
	Gross domestic expenditure on R&D by sector of performance and source of funds	[138]
Environmental	GHG emissions intensity (CO_2e/GDP)EII	[266]
	Material productivity (GDP/Domestic Material Consumption) part of EII	[266]
	Water productivity (GDP/total fresh water abstraction) part of EII	[266]
Technological	Number of patents on resource efficiency technologies [8]	[138]
	Key enabling technology (KET) R&D focus [2]	[265]
	Commercialization of innovative technologies (sales of innovation products) [2]	[265]
	Patents by technology (biotechnology, environmental-related technology), Nr of patents	[138]
	Development of advanced biorefinery technologies for producing materials/energy (yes/no)	[265]
	Number of environmental based technologies (or % of all technologies)	[268] [138]
	Patent applications to the European Patent Office (source: EPO) (sdg_09_40)	[267]
Social	Employment in eco-industries and circular economy (% of total employment across all companies) EII	[266]
	R&D personnel by sector and formal qualification, Nr of researchers, or total nr of internal personnel	[138]
	Capacity and flexibility of use of biomass kg of biomass used for variety of purposes	[269]
	Capacity and flexibility of use of bioenergy, kWh of energy used for variety of purposes	[269]

B. Policy factor evaluation indicators

No.	Description	Indicator	Dimension	Indicators source
1.	Bioeconomy turnover	Total bioeconomy turnover and relative to the national economy	euro/year euro/sector %	[270]
2.	Bioeconomy GDP	Bioeconomy GDP and share of total GDP	euro/year %	[270]
3.	Bioeconomy employment	Total workers employed in bioeconomy and relative to the national economy	euro/year %	[270]
4.	Bioeconomy added value	Total bioeconomy value added and relative to the national economy	euro/year %	Proposed by the author
5.	Bioeconomy turnover per capita	Bioeconomy turnover/national population	euro/year/per capita	Proposed by the author
6.	Bioeconomy added value per capita	Bioeconomy value added/ national population	euro/year/per capita	Proposed by the author
7.	Growth of bioeconomy and its importance in the national economy	Bioeconomy output/value added/the number employed and their share in the national economy	euro/euro/worker, % of total economy	[271]
8.	Added value produced for natural resource use (natural resource productivity)	Raw material input/value added to raw material streams	euro/kg	[271]
9.	Environmental benefits from the bioeconomy	Raw material inputs used/green-house gas emissions avoided	tCO_{2eq}/kg	[271]
10.	Sustainability of the bioeconomy	Total use of natural resources/growth and harvested volumes of standing timber, cereal crops, fish bag, endangered species, urban waste		[271]
11.	Existence of a Bioeconomy strategy	Existing/non existing national Bioeconomy strategy	[yes/no]	SAT-BBE, 2013)
	Bioeconomy strategy quality	Quality of bioeconomy strategy may be evaluated as accordance to numerous quality criteria, e.g., selected policy type, number of transformation pathways	quality indicator set	Proposed by the author

		included, number of bioeconomy sectors concerned		
12.	Production investments	Amount of investments into production	(euro/year), (euro/program)	
13.	Research and innovation investments	Amount of investments into research and innovation	(euro/year), (euro/program)	SAT-BBE, 2013)
14.	Public financing effectiveness	Effectiveness of public financing (program subsidies)	(euro of private investments/euro of public investments (program costs)	Proposed by the author
15.	Bio wastes diverted from landfills	Amount of bio-wastes diverted from landfills	t/year	Proposed by the author
16.	Increase of renewable energy use in bioeconomy related sectors		%	Proposed by the author
17.	Total GHG emission savings		tCO_{2eq}./year	Proposed by the author
18.	Raw material savings		t/year	Proposed by the author
19.	Fossil resource substitution, t/year		t/year	Proposed by the author

C. Calculations of economic justification

Return on own investment in real terms	12%	
Own investment part	30%	
Borrowed capital part	70%	
Borrowed capital % rate	4%	
Average long - term inflation	2,5%	
r_n	15%	
WACC	**10%**	
Investments		
Capital investments	4800000	together with the purchase of a license (300 000)
Annual expenditure		
Equipment maintenance	50000	
Electricity	25000	
Heat energy	10000	
Purchase of raw materials (with binder)	2537500	*Assumption: Increase for 2% every year (raw material 2500t/annual, price 115Eur/t, binder 2500t/annual, price 900Eur/t)
Remuneration of employees	250000	**Assumption: Increase for 2% every year (25 employees, average salary 10 000Eur/year)
VSAOI	58975	
Marketing costs	15000	
Other expenses	20000	
Total expenditure per year	**2966475**	
Revenue		
Price per item	1020	***Assumption: Increase for 1% year
Number of goods sold	3750	****Assumption: Increase for 1% year
Total revenue	**3825000**	

Years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Project	-4800000	858525	879657,5	901220,338	923222,276	945672,253	968579,391	991952,9966	1015802,567	1040137,792	1064968,559
Discount factor	1,000	0,909	0,826	0,751	0,683	0,621	0,564	0,513	0,467	0,424	0,386

PVA		780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48

	NPVi										
Project cash flow	-4800000	-4019522,73	-3292533,06	-2615432,88	-1984859,64	-1397671,58	-850933,76	-341905,03	131974,37	573094,33

NPV	IRR	PI	CF_{NPV}	Discounted payback period
983685,81	14%	1,20	259493,84	8 years

Sensitivity analysis				**Baseline scenario**			
Factor changes	**-30%**	**-20%**	**-10%**	**0%**	**10%**	**20%**	**30%**
Purchase of equipment (EUR)	3360000	3840000	4320000	4800000	5280000	5760000	6240000
Raw material costs (EUR)	1776250	2030000	2283750	2537500	2791250	3045000	3298750
Number of goods sold	2625	3000	3375	3750	4125	4500	4875
NPV depending on equipment purchase (EUR)	**2423686**	**1943686**	**1463686**	983686	**503686**	**23686**	**-456314**
NPV depending on raw material costs (EUR)	**6027204**	**4346031**	**2664858**	983686	**-697487**	**-2378660**	**-4059832**
NPV depending on the number of units sold (EUR)	**-6621753**	**-4086607**	**-1551461**	983686	**3518832**	**6053979**	**8589125**
NPV depending on the purchase of equipment	146%	98%	49%	0,00%	-49%	-98%	-146%
NPV depending on raw material costs	513%	342%	171%	0,00%	-171%	-342%	-513%
NPV depending on the number of units sold	-773%	-515%	-258%	0,00%	258%	515%	773%

Baseline scenario	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	858525	879658	901220	923222	945672	968579	991953	1015803	1040138	1064969	
Capital investments	4800000	0	0	0	0	0	0	0	0	0	0	
Equipment maintenance	0	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	
Electricity	0	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	
Heat energy	0	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	

Purchase of raw materials (with binder)	0	2537500	2588250	2640015	2692815	2746672	2801605	2857637	2914790	2973086	3032547	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975	58975	58975	58975	58975	58975	58975	58975	58975	58975	
Marketing costs	0	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	
Other expenses	0	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	
Total expenditure per year	0	2966475	3022225	3079090	3137092	3196255	3256600	3318153	3380936	3444976	3510296	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750	3788	3825	3864	3902	3941	3981	4021	4061	4101	
Total revenue	0	3825000	3901883	3980310	4060315	4141927	4225180	4310106	4396739	4485113	4575264	
NPV	-4800000	780477	726990	677100	630573	587188	546738	509029	473879	441120	410591	**983685,81**
***Purchase of equipment* +10%**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-5280000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	5280000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-5280000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**503685,81**
***Purchase of equipment* +20%**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	

Project	-5760000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	5760000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-5760000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**23685,81**
***Purchase of equipment* +30%**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-6240000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	6240000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	

Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-6240000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**-456314,19**
Purchase of equipment - 10%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4320000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	4320000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4320000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**1463685,81**
Purchase of equipment - 20%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-3840000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	3840000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	

Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-3840000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**1943685,81**
Purchase of equipment - 30%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-3360000	858525,00	879657,50	901220,34	923222,28	945672,25	968579,39	991953,00	1015802,57	1040137,79	1064968,56	
Capital investments	3360000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	

Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-3360000	780477,27	726989,67	677100,18	630573,24	587188,07	546737,82	509028,73	473879,39	441119,96	410591,48	**2423685,81**
Purchase of raw materials +10%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	604775,00	620832,50	637218,84	653940,75	671005,09	688418,89	706189,28	724323,58	742829,22	761713,82	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2791250,00	2847075,00	2904016,50	2962096,83	3021338,77	3081765,54	3143400,85	3206268,87	3270394,25	3335802,13	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	3220225,00	3281050,00	3343091,50	3406373,83	3470921,81	3536760,74	3603916,46	3672415,29	3742284,09	3813550,27	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	549795,45	513084,71	478751,94	446650,33	416641,37	388594,51	362386,76	337902,30	315032,10	293673,65	**-697486,88**
Purchase of raw materials +20%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	351025,00	362007,50	373217,34	384659,22	396337,93	408258,38	420425,57	432844,59	445520,66	458459,08	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	3045000,00	3105900,00	3168018,00	3231378,36	3296005,93	3361926,05	3429164,57	3497747,86	3567702,82	3639056,87	

Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	3473975,00	3539875,00	3607093,00	3675655,36	3745588,97	3816921,25	3889680,17	3963894,27	4039592,66	4116805,01	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	319113,64	299179,75	280403,71	262727,42	246094,67	230451,21	215744,79	201925,20	188944,25	176755,82	**-2378659,54**
Purchase of raw materials +30%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	97275,00	103182,50	109215,84	115377,69	121670,77	128097,88	134661,85	141365,60	148212,09	155204,34	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	3298750,00	3364725,00	3432019,50	3500659,89	3570673,09	3642086,55	3714928,28	3789226,85	3865011,38	3942311,61	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	3727725,00	3798700,00	3871094,50	3944936,89	4020256,13	4097081,75	4175443,89	4255373,26	4336901,23	4420059,75	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	88431,82	85274,79	82055,48	78804,51	75547,98	72307,91	69102,82	65948,10	62856,39	59837,99	**-4059832,21**

Purchase of raw materials -10%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	1112275,00	1138482,50	1165221,84	1192503,81	1220339,41	1248739,89	1277716,71	1307281,56	1337446,36	1368223,30	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2283750,00	2329425,00	2376013,50	2423533,77	2472004,45	2521444,53	2571873,42	2623310,89	2675777,11	2729292,65	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2712725,00	2763400,00	2815088,50	2867810,77	2921587,49	2976439,74	3032389,03	3089457,31	3147666,96	3207040,80	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	1011159,09	940894,63	875448,41	814496,15	757734,76	704881,12	655670,70	609856,49	567207,82	527509,31	**2664858,48**
Purchase of raw materials -20%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	1366025,00	1397307,50	1429223,34	1461785,34	1495006,57	1528900,40	1563480,42	1598760,54	1634754,93	1671478,04	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2030000,00	2070600,00	2112012,00	2154252,24	2197337,28	2241284,03	2286109,71	2331831,91	2378468,54	2426037,91	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	

Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2458975,00	2504575,00	2551087,00	2598529,24	2646920,32	2696279,23	2746625,32	2797978,32	2850358,39	2903786,06	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	1241840,91	1154799,59	1073796,65	998419,05	928281,46	863024,42	802312,67	745833,59	693295,67	644427,14	**4346031,15**
Purchase of raw materials -30%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	1619775,00	1656132,50	1693224,84	1731066,87	1769673,73	1809060,90	1849244,14	1890239,53	1932063,50	1974732,78	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	1776250,00	1811775,00	1848010,50	1884970,71	1922670,12	1961123,53	2000346,00	2040352,92	2081159,98	2122783,18	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2205225,00	2245750,00	2287085,50	2329247,71	2372253,16	2416118,73	2460861,60	2506499,33	2553049,82	2600531,32	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3750,00	3787,50	3825,38	3863,63	3902,27	3941,29	3980,70	4020,51	4060,71	4101,32	
Total revenue	0	3825000,00	3901882,50	3980310,34	4060314,58	4141926,90	4225179,63	4310105,74	4396738,87	4485113,32	4575264,09	
NPV	-4800000	1472522,73	1368704,55	1272144,88	1182341,96	1098828,16	1021167,72	948954,64	881810,69	819383,53	761344,97	**6027203,83**
Number of goods sold +10%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	1241025,00	1269845,75	1299251,37	1329253,73	1359864,94	1391097,35	1422963,57	1455476,45	1488649,12	1522494,97	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	

Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	4125,00	4166,25	4207,91	4249,99	4292,49	4335,42	4378,77	4422,56	4466,78	4511,45	
Total revenue	0	4207500,00	4292070,75	4378341,37	4466346,03	4556119,59	4647697,59	4741116,31	4836412,75	4933624,65	5032790,50	
NPV	-4800000	1128204,55	1049459,30	976146,79	907898,19	844369,14	785238,19	730205,31	678990,51	631332,55	586987,72	**3518832,25**
Number of goods sold +20%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	1623525,00	1660034,00	1697282,41	1735285,19	1774057,63	1813615,32	1853974,14	1895150,34	1937160,46	1980021,38	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	

Number of goods sold	0	4500,00	4545,00	4590,45	4636,35	4682,72	4729,55	4776,84	4824,61	4872,86	4921,58	
Total revenue	0	4590000,00	4682259,00	4776372,41	4872377,49	4970312,28	5070215,56	5172126,89	5276086,64	5382135,98	5490316,91	
NPV	-4800000	1475931,82	1371928,93	1275193,39	1185223,13	1101550,21	1023738,57	951381,88	884101,62	821545,14	763383,96	**6053978,65**
Number of goods sold +30%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	2006025,00	2050222,25	2095313,44	2141316,65	2188250,32	2236133,28	2284984,72	2334824,23	2385671,79	2437547,79	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	4875,00	4923,75	4972,99	5022,72	5072,94	5123,67	5174,91	5226,66	5278,93	5331,72	
Total revenue	0	4972500,00	5072447,25	5174403,44	5278408,95	5384504,97	5492733,52	5603137,46	5715760,53	5830647,31	5947843,32	
NPV	-4800000	1823659,09	1694398,55	1574240,00	1462548,08	1358731,29	1262238,94	1172558,46	1089212,73	1011757,72	939780,19	**8589125,05**
Number of goods sold -10%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	476025,00	489469,25	503189,30	517190,82	531479,56	546061,43	560942,42	576128,68	591626,46	607442,15	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	

Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3375,00	3408,75	3442,84	3477,27	3512,04	3547,16	3582,63	3618,46	3654,64	3691,19	
Total revenue	0	3442500,00	3511694,25	3582279,30	3654283,12	3727734,21	3802661,67	3879095,17	3957064,98	4036601,99	4117737,69	
NPV	-4800000	432750,00	404520,04	378053,57	353248,29	330006,99	308237,44	287852,16	268768,28	250907,37	234195,24	**-1551460,62**
Number of goods sold -20%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	93525,00	99281,00	105158,27	111159,36	117286,87	123543,46	129931,85	136454,79	143115,13	149915,74	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	3000,00	3030,00	3060,30	3090,90	3121,81	3153,03	3184,56	3216,41	3248,57	3281,06	
Total revenue	0	3060000,00	3121506,00	3184248,27	3248251,66	3313541,52	3380143,70	3448084,59	3517391,09	3588090,65	3660211,28	
NPV	-4800000	85022,73	82050,41	79006,97	75923,34	72825,92	69737,07	66675,58	63657,17	60694,79	57799,01	**-4086607,01**

Number of goods sold -30%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Project	-4800000	-288975,00	-290907,25	-292872,76	-294872,10	-296905,82	-298974,50	-301078,73	-303219,09	-305396,20	-307610,67	
Capital investments	4800000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Equipment maintenance	0	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	50000,00	
Electricity	0	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	25000,00	
Heat energy	0	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	10000,00	
Purchase of raw materials (with binder)	0	2537500,00	2588250,00	2640015,00	2692815,30	2746671,61	2801605,04	2857637,14	2914789,88	2973085,68	3032547,39	
Remuneration of employees	0	250000	255000	260100	265302	270608	276020	281541	287171	292915	298773	
VSAOI	0	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	58975,00	
Marketing costs	0	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	15000,00	
Other expenses	0	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	20000,00	
Total expenditure per year	0	2966475,00	3022225,00	3079090,00	3137092,30	3196254,65	3256600,24	3318152,74	3380936,30	3444975,52	3510295,54	
Price per item	0	1020,00	1030,20	1040,50	1050,91	1061,42	1072,03	1082,75	1093,58	1104,51	1115,56	
Number of goods sold	0	2625,00	2651,25	2677,76	2704,54	2731,59	2758,90	2786,49	2814,36	2842,50	2870,92	
Total revenue	0	2677500,00	2731317,75	2786217,24	2842220,20	2899348,83	2957625,74	3017074,02	3077717,21	3139579,32	3202684,87	
NPV	-4800000	-262704,55	-240419,21	-220039,64	-201401,61	-184355,15	-168763,31	-154500,99	-141453,94	-129517,80	-118597,23	**-6621753,43**