RĪGAS TEHNISKĀ UNIVERSITĀTE

Antra Kalnbaļķīte

ILGTSPĒJĪGA VIDES INŽENIERIJAS IZGLĪTĪBAS ATTĪSTĪBA

Promocijas darbs

RTU Izdevniecība
Rīga 2023

RĪGAS TEHNISKĀ UNIVERSITĀTE
Elektrotehnikas un vides inženierzinātņu fakultāte
Vides aizsardzības un siltuma sistēmu institūts

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Doktora studiju programmas “Vides inženierija” doktorante

ILGTSPĒJĪGA VIDES INŽENIERIJAS IZGLĪTĪBAS ATTĪSTĪBA

Promocijas darbs

Zinātniskās vadītājas:
Profesore *Dr. habil. sc. ing.*
DAGNIJA BLUMBERGA

Profesore *Dr. sc.ing.*
JEĻENA PUBULE

RTU Izdevniecība
Rīga 2023

Kalnbaļķīte, A. Ilgtspējīga vides inženierijas izglītības attīstība. Promocijas darbs. Rīga: RTU Izdevniecība, 2023, 230 lpp.

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SATURS

IEVADS

Promocijas darba aktualitāte

Vides izglītībai ir izšķiroša nozīme ilgtspējīgā attīstībā un *Zaļā kursa* klimatneitralitātes mērķu sasniegšanā. Vides izglītība ieņem vadošo pozīciju ilgtspējīgas un resursu ziņā efektīvas attīstības jomā. Zaļās inovācijas un esošo tehnoloģiju pārveidi var īstenot, izmantojot izglītību un pārveidojošas zināšanas, lai radītu ilgtspējīgu sabiedrību. Lai sekmīgi ieviestu ilgtspējīgas tehnoloģijas, ir vajadzīgas jaunas prasmes augstākās izglītības absolventiem, darba ņēmējiem, uzņēmējiem un politikas veidotājiem, pamatojoties uz pārskatītu intelektuālās pilnveidošanās modeli un uz zināšanām balstītu tehnoloģiju inovāciju. Intelektuālais kapitāls, kas iegūts, izmantojot uz zināšanām balstītu bioekonomiku, kļuvis izšķirošs Eiropas Savienības attīstības programmā. Tāpēc bioekonomikas īstenošana Eiropā būs ciešā saiknē ar izglītību un pētniecību.

Zaļajā kursā Eiropas dalībvalstīm ir noteikti vērienīgi mērķi: līdz 2050. gadam panākt klimatneitralitāti, īpašu uzmanību pievēršot daudzām nozarēm, kurām ir izšķiroša nozīme šo vērienīgo mērķu sasniegšanā: tīra enerģija, ilgtspējīga rūpniecība, būvniecība un renovācija, ilgtspējīga mobilitāte, bioloģiskā daudzveidība, "no lauka līdz galdam" un piesārņojuma novēršana. *Zaļā kursa* un bioekonomikas mērķu īstenošana būtu jāuztver no sistemātiskas perspektīvas, ņemot vērā dažādas ieinteresēto personu grupas. Videi nekaitīgāku tehnoloģiju radīšana ietver tehnoloģiskās iespējas, izmantojot labi sagatavotus augstas kvalitātes cilvēkresursus, aprīkojumu un laboratorijas, un tai ir nepieciešama uz inovācijām orientēta mācīšanās un īpašu prasmju apguve.

Vides izglītībai, tostarp akadēmiskajai augstākajai izglītībai, mūžizglītībai un zinātniskajai jaunradei, būtu jāpielāgojas dažādu rūpniecības nozaru mainīgajiem apstākļiem un tā būtu jāpārvērtē, lai nodrošinātu attiecīgus apmācības un mācīšanās apstākļus, metodes, stratēģijas un iegūtās prasmes un kompetences. Jāizstrādā jauna novērtēšanas metodoloģija, kas balstīta uz dažādu metožu kombināciju izglītības procesa novērtēšanai.

Darba mērķis un uzdevumi

Lai izpildītu Eiropas Savienības nospraustos mērķus, ir jāsaprot ilgtspējīgas izglītības attīstības virzieni, novērtējot esošo situāciju un potenciālās iespējas vides inženierzinātnes attīstībai.

Lai sasniegtu pētījuma mērķi, tika noteikti šādi uzdevumi:

1) analizēt un izvērtēt akadēmiskās augstākās izglītības esošo situāciju un potenciālās iespējas vides inženierijas studiju programmu īstenošanai, izmantojot inovatīvas metodes, līdzekļus un rīkus;
2) izstrādāt mūžizglītības studiju ietvaru *Zaļā kursa* un klimatneitralitātes mērķu sasniegšanai, veicinot kopradi, veiktspēju un politikas integrēšanu;
3) integrēt zinātnisko jaunradi, lai nostiprinātu uz kompetenci un zināšanām balstītu ilgtspējīgu augstāko izglītību, nodrošinot inovatīvu ideju attīstību un komercializāciju.

Pētījuma hipotēze

Daudzpusīgu metožu izmantošana ir vajadzīga pastāvīgai uz zināšanām un kompetencēm balstītai ilgtspējīgai vides inženierijas izglītības novērtēšanai un analizēšanai trijos līmeņos: akadēmiskās augstākās izglītības, mūžizglītības un zinātniskās jaunrades.

Zinātniskā novitāte

Ar sešu dažādu matemātisko instrumentu (daudzkritēriju lēmumu analīzes, studiju programmu vērtēšanas, veiktspējas, bibliometriskās, sistēmdinamikas, kvalitatīvās pētniecības) palīdzību ir izstrādāti, analizēti un aprobēti septiņi moduļi, ar kuriem vērtēt vides inženierijas izglītības ilgtspējīgas attīstības potenciālu un iespējas:

1) Ranžēšanas modulis;
2) Inovatīvs studiju procesa modulis;
3) Koprades īstenošanas modulis;
4) Uzvedības modulis;
5) Diplomātisko attiecību modulis;
6) Tālmācības modulis;
7) Zinātniskās inovācijas pārneses modulis.

Praktiskā novitāte

Šai disertācijai ir liela praktiska nozīme Latvijas un Eiropas kontekstā, jo tā ilustrē vides inženierijas iespējas iesaistīt plašu speciālistu loku, kuriem nepieciešamas šīs zināšanas visās tautsaimniecības nozarēs un sabiedrības slāņos, sākot no indivīda līdz uzņēmumu, pašvaldību un valdības līmenim. Pētījums sniedz praktiskus priekšlikumus vides inženierijas izglītības pilnveidei visās trīs dimensijās:

1) akadēmiskā augstākā izglītība – studiju programmas tiek īstenotas Rīgas Tehniskajā universitātē un var tikt izmantotas ilgtspējīgas zināšanu un kompetenču balstītas augstākās izglītības attīstībai nākotnē dažādās studiju programmās citās universitātēs;
2) mūžizglītība – ir svarīga uzņēmējiem un darbiniekiem, kas meklē jaunas prasmes un kompetences;
3) zinātniskā jaunrade – ir pamats inovāciju attīstībai, lai radītu inovatīvas tehnoloģijas, attīstītu jaunuzņēmumus, rosinātu inženierzinātņu izpēti doktorantūras studijās un pētniecībā vides inženierijas jomā Latvijā un Eiropā.

Pētījuma aprobācija

Promocijas darba rezultāti prezentēti deviņās konferencēs un 11 zinātniskajās publikācijās. Pētījuma rezultāti ir apspriesti un prezentēti vairākās konferencēs.

1) Kalnbaļķīte, A., Pubule, J., Blumberga, D. Education for Advancing the Implementation of the Green Deal Goals for Bioeconomy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2022, Riga Technical University, 2022.
2) Kalnbaļķīte, A., Červinska, E., Blumberga, A., Pubule, J. Development of Massive Online Open Course 'Energy Transition and Climate Change' // International Scientific Conference of Environmental and Climate Technologies – CONECT 2022, Riga Technical University, 2022.
3) Kalnbaļķīte, A., Vēciņa, A., Žihare, L., Rozakis, S., Blumberga, D. Biodiplomacy Attractiveness in Bioeconomy Education. Case Study // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
4) Kalnbaļķīte, A., Patel, N., Blumberga, D. An Analysis of the Extraction Technologies: Fruit Peel Waste Study // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
5) Kalnbaļķīte, A., Zlaugotne, B., Žihare, L., Balode, L., Khabdullin, A., Blumberga, D. Multi-Criteria Decision Analysis Methods Comparison // International Scientific Conference of Environmental and Climate Technologies – CONECT 2020, Riga Technical University, 2020.
6) Kalnbaļķīte, A., Pubule, J., Blumberga, A., Rozakis, S., Vēciņa, A., Blumberga, D. Education for Advancing the Implementation of the Bioeconomy Goals: An Analysis of Master Study Programmes in Bioeconomy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2020, Riga Technical University, 2020.
7) Kalnbaļķīte, A., Pubule, J., Teirumnieka, Ē., Blumberga, D. Evaluation of the Environmental Engineering Study Programme at University // International Scientific Conference of Environmental and Climate Technologies – CONECT 2019, Riga Technical University, 2019.
8) Rozentāle, L., Kalnbaļķīte, A., Blumberga, D. Aggregator as a New Electricity Market Player: (Case Study of Latvia) // 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020).
9) Valtere, M., Kalēja, D., Kudurs, E., Kalnbaļķīte, A., Terjaņika, V., Zlaugotne, B., Pubule, J., Blumberga, D. The Versatility of the Bioeconomy. Sustainability Aspects of the Use of Bran. // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.
10) Gerinoviča, S., Blumberga, D., Kalnbaļķīte, A., Vēciņa, A. To Be, or Not to Be – the Question of Forestry Resources in Bio-Diplomacy // International Scientific Conference of Environmental and Climate Technologies – CONECT 2021, Riga Technical University, 2021.

Zinātniskās publikācijas

1) Zlaugotne, B., Žihare, L., Balode, L., **Kalnbaļķīte, A.,** Khabdullin, A., Blumberga, D. Multi-Criteria Decision Analysis Methods Comparison. Environmental and Climate Technologies, 2020, Vol. 24, No. 1, pp. 454-471. ISSN 1691-5208. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2020-0028
2) Pubule, J., **Kalnbaļķīte, A.,** Teirumnieka, Ē., Blumberga, D. Evaluation of the Environmental Engineering Study Programme at University. Environmental and Climate Technologies, 2019, Vol. 23, No. 2, pp. 310-324. ISSN 1691-5208. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2019-0070
3) Pubule, J., Blumberga, A., Rozakis, S., Vēciņa, A., **Kalnbaļķīte, A.,** Blumberga, D. Education for Advancing the Implementation of the Bioeconomy Goals: An Analysis of Master Study Programmes in Bioeconomy. Environmental and Climate Technologies, 2020, Vol. 24, No. 2, pp. 149-159. ISSN 1691-5208. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2020-0062
4) **Kalnbaļķīte, A.,** Brakovska, V., Terjanika, V., Pubule, J., Blumberga, D. The tango between the academic and business sectors: use of co-management approach for the development of green innovation. Innovation and Green Development, 2023**,** Vol. 2, No. 4, pp., 100073, ISSN 2949-7531, Pieejams: https://doi.org/10.1016/j.igd.2023.100073.
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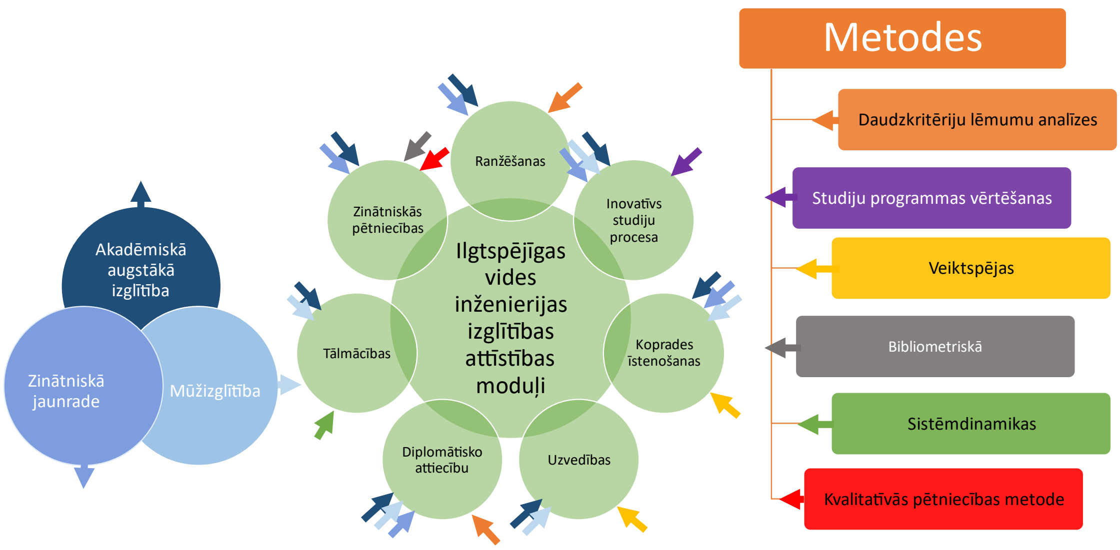
6) Gerinoviča, S., Blumberga, D., **Kalnbaļķīte, A.,** Vēciņa, A. To Be, or Not to Be – the Question of Forestry Resources in Bio-Diplomacy. Environmental and Climate Technologies, 2021, Vol. 25, No. 1, 1337.-1346.lpp. ISSN 1691-5208. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2021-0101
7) Červinska, E., Blumberga, A., **Kalnbaļķīte, A.,** Pubule, J. Development of Massive Online Open Course 'Energy Transition and Climate Change'. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp.1106-1117. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2022-0083
8) **Kalnbaļķīte, A.,** Pubule, J., Blumberga, D. Education for Advancing the Implementation of the Green Deal Goals for Bioeconomy. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp.75-83. ISSN 1691-5208. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2022-0007
9) Valtere, M., Kalēja, D., Kudurs, E., **Kalnbaļķīte, A.,** Terjaņika, V., Zlaugotne, B., Pubule, J., Blumberga, D. The Versatility of the Bioeconomy. Sustainability Aspects of the Use of Bran. Environmental and Climate Technologies, 2022, Vol. 26, No. 1, pp.658-669. e-ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2022-0050
10) Patel, N., **Kalnbaļķīte, A.,** Blumberga, D. An Analysis of the Extraction Technologies: Fruit Peel Waste. Environmental and Climate Technologies, 2021, Vol.

25, No. 1, pp.666-675. ISSN 2255-8837. Pieejams: https://doi.org/10.2478/rtuect-2021-0050

11) Rozentāle, L., **Kalnbaļķīte, A.,** Blumberga, D. Aggregator as a New Electricity Market Player: (Case Study of Latvia). In: 2020 IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2020): Proceedings, Latvia, Rīga, 5-7 November 2020. Piscataway: IEEE, 2020, pp.507-512. ISBN 978-1-7281-9511-7. e-ISBN 978-1-7281-9510-0. Pieejams: https://ieeexplore.ieee.org/document/9316486

Promocijas darba struktūra

Promocijas darbs ir vienpadsmit tematiski saistītu zinātnisko publikāciju kopa, kas publicētas dažādos zinātniskajos žurnālos un pieejamas citēšanai vairākās zinātnisko darbu datubāzēs. Galvenā uzmanība ir pievērsta vides inženierijas izglītības ilgtspējīgas attīstības novērtēšanai. Promocijas darbs (I) aplūko ilgtspējīgas vides inženierijas izglītības trīs līmeņus, (II) apvieno izstrādātus, analizētus un aprobētus ilgtspējīgas vides inženierijas izglītības septiņus attīstības moduļus, (III) ietver sešu pētniecības metožu izmantošanu.



1. att. Promocijas darba struktūra.

Promocijas darbā ir ievads un trīs nodaļas: literatūras apskats, pētījuma metodes un rezultāti un diskusijas.

Promocijas darba ievadā ir norādīts mērķis un uzdevumi šī mērķa sasniegšanai. Ievadā izvirzīta arī hipotēze, kā arī aprakstīta promocijas darba zinātniskā un praktiskā nozīme. Pēc tam sniegta informācija par pētījumu rezultātu aprobāciju, kas veikta, piedaloties starptautiskās zinātniskās konferencēs, un atspoguļota zinātniskajās publikācijās.

Promocijas darbā sākotnēji ir veikts literatūras apskats (1. nodaļa), kurā analizēta vides inženierijas ilgtspējīga attīstība, apskatītas un piedāvātas inovatīvas mācīšanas un mācīšanās pieejas, kā arī noteikta zinātnisko pētījumu loma vides inženierijas izglītības kontekstā. 2. nodaļā aprakstītas pētījuma metodikas, kuras izmantotas visās publikācijās, lai aprobētu ilgtspējīgas vides inženierijas izglītības attīstības moduļus. 3. nodaļā analizēti pētījuma rezultāti, kas sasniegti, izmantojot iepriekš minētās metodikas. Noslēgumā sniegti secinājumi pēc iegūto rezultātu analīzes.

1. LITERATŪRAS APSKATS

Klimata pārmaiņas ir liels drauds videi, ekonomikai un politikai. Starptautiskā sabiedrība ir atzinusi, ka izglītība, kas ir tiešs veids, kā izplatīt izpratni dažādos līmeņos, ir būtisks elements, lai identificētu un izceltu problēmu un apmācītu un mobilizētu jauniešus, lai viņi stātos pretī galvenajām klimata pārmaiņu problēmām [1]. Studiju kursiem, kas vērsti uz tēmām, kas saistītas ar klimata pārmaiņām, jāspēj sniegt labu saturu un koncepcijas, lai izprastu to apmērus, cēloņus un sekas. Ir būtiski sniegt informāciju par klimata pārmaiņu ietekmi gan vietējā, gan globālā mērogā. Studentiem ir jāsaprot sekas, kas rodas, nereaģējot un izvairoties no rīcības. Klimata pārmaiņas ir sarežģīts jautājums, kas prasa papildu tehniskus un zinātniskus avotus studiju procesā, bet sākotnējai informācijai jābūt skaidrai un vienkāršai [2].

Eiropas Savienības *Zaļā kursa* [3] ietvarā ir noteikti vērienīgi mērķi, uz kuriem Eiropas dalībvalstīm jātiecas, lai līdz 2050. gadam panāktu klimatneitralitāti, īpašu uzmanību pievēršot vairākām nozarēm, kas ir būtiskas tās vērienīgo mērķu sasniegšanai, kā, piemēram, tīrai enerģijai, ilgtspējīgai rūpniecībai, būvniecībai un renovācijai, ilgtspējīgai mobilitātei, bioloģiskai daudzveidībai, stratēģijas "no lauka līdz galdam" ieviešanai un piesārņojuma novēršanai. Tā kā bioekonomika pievienotās vērtības produktu ražošanā ir atkarīga no atjaunojamās biomasas un šie produkti tiks ražoti saskaņā ar kaskādes principu, bioekonomikas attīstība var palīdzēt sasniegt *Zaļā kursa* mērķus un uzdevumus.

Golembiewski et al. [4] identificēja trīs galvenās bioekonomikas problēmas: zināšanu bāzi, konverģējošas tehnoloģijas un komercializācijas jautājumus. Augstākās izglītības lomu visu trīs šo problēmu risināšanā, kas rada inovācijas un intelektuālā kapitāla attīstību, var palielināt tikai ar atbilstošām prasmēm un zināšanām. Saskaņā ar *Val Lancker et al.* [5] ir identificēti pieci faktori, kas ietekmē inovāciju attīstības īstenošanu bioekonomikā:

1) radikāla inovācija,
2) sarežģīta zināšanu bāze,
3) intensīva sadarbība,
4) komercializācija un pieņemšana,
5) sarežģītas un sadrumstalotas politikas shēmas [5].

Eiropas Savienība par vienu no saviem būtiskajiem mērķiem izvirza uz kompetencēm balstītu mācīšanu un uz kompetencēm balstītu izglītību. Eiropas augstākās izglītības telpa koncentrējas uz kvalifikāciju salīdzināmības un savietojamības nodrošināšanu starp absolventiem no dažādām Eiropas Savienības valstīm. "Pāreja no mācīšanas uz mācīšanos" ir bijusi ietekmīgs faktors jaunu studiju programmu izstrādē, kas ietver pāreju no saturiski orientētām mācību programmām uz kompetencēm vērstām mācību programmām [6]–[8], nosakot, ka nodarbinātība ir viena no galvenajām prioritātēm.

Izglītības modeli, kas koncentrējas uz mācību kursa rezultātu un tiek sasniegts, pārejot no uz zināšanām balstītas pedagoģijas uz prasmēs balstītu pedagoģiju, sauc par "kompetencēs balstītu izglītību" [9]. Kompetencēs balstīta izglītība galvenokārt ir vērsta uz to, lai noteiktu, ko studentam vajadzētu sasniegt programmas beigās. Tad tiek modelēts konkrētais kurss, virzoties atpakaļ uz katru darbību, lai nodrošinātu, ka katrs mērķis tiek sasniegts. Šī izglītības forma veicina prasmju un kompetenču attīstību, izmantojot uz studentiem vērstas un uz sevi vērstas metodes. Saskaņā ar definīciju kompetence ir "kognitīvo un metakognitīvo prasmju, zināšanu un izpratnes demonstrēšanas, starppersonu, intelektuālo un praktisko iemaņu un ētisko vērtību apvienojums" [10]. Kompetences piedāvā zināšanas, kas nepieciešamas veiksmīgai problēmu risināšanai dažādās situācijās un veicina rīcību noteiktā kontekstā. Šīs prasmes nevar iemācīt tikai teorētiskās lekcijās; tām ir jāattīstās, iegūstot pieredzi praktisko uzdevumu laikā [11]. Pamatkompetences, ko sauc arī par pamatprasmēm vai būtiskām prasmēm, ir elastīgi elementi, ko izmanto izglītības moduļos, kas atbalsta mācīšanos, veicot praktiskus uzdevumus reālās situācijās, lai saprastu visefektīvāko risinājumu konkrētas problēmas risināšanai. Koncentrēšanās uz dažādu kompetenču sasniegšanu ļauj studentiem izmantot savas zināšanas, prasmes un iepriekšējo pieredzi, veicot uzdevumu [9]. Integrētas zināšanas ietver dažādus jēdzienus, teorijas un datus, ko papildina prasmes un komponenti, kas rada labāku sociālo un kultūras ietekmi [12]. Saskaņā ar *Sistermans* publikāciju par kompetencēs balstītas izglītības integrēšanu tiešsaistes veselības zinātnēs, uz kompetencēm balstītas mācību programmas plānošanā ir seši soļi. Pirmkārt, izglītības programmas sastādītājiem ir jāsaprot un jādefinē spējas, kas studentiem jāattīsta studiju beigās. Tad ir iespējams norādīt precīzas kompetences un to sastāvdaļas. Pēc tam "ceļš" šo kompetenču sasniegšanai ir jāizstrādā ar galvenajiem pagrieziena punktiem. Kad programmas pamati ir noteikti, jāizvēlas atbilstošas izglītojošās aktivitātes, pieredze un izglītības metodes un piemērotākie novērtēšanas rīki. Pēdējais solis ir novērtēt rezultātus mācību programmas beigās [13].

Eiropas Savienībā *Zaļā kursa* mērķu sasniegšanas kontekstā studiju programmas par bioenerģiju, biodegvielām un bioproduktiem [14], tīru enerģiju [15], bioekonomiku [16], [17] ir izveidotas un īstenotas nesen.

Bioekonomika Eiropā ir kļuvusi par vienu no vadošajiem ilgtspējīgas un resursu ziņā efektīvas attīstības virzieniem. Bioekonomikas galvenos aspektus (jaunu tehnoloģiju un procesu izstrāde, kā arī tirgu attīstība un bioekonomikas konkurētspēju [18]) var īstenot ar augstāko izglītību un pārveidojošām zināšanām, lai veidotu ilgtspējīgu bioekonomiku.

Intelektuālais kapitāls, kas iegūts, izmantojot uz zināšanām balstītu bioekonomiku, kļuvis izšķirošs Eiropas Savienības attīstības programmā [19]. Tāpēc bioekonomikas īstenošana Eiropā būs ciešā saiknē ar izglītību un pētniecību [20]–[23]. Veiksmīgai bioekonomikas attīstībai ir vajadzīgas jaunas prasmes augstākās izglītības absolventiem, pamatojoties uz pārskatītu intelektuālās pilnveides modeli un uz zināšanām balstītu tehnoloģiju inovāciju [24], [25].

Latvija šobrīd neīsteno biodiplomātiju. Tāpēc paliek jautājums, kādās nozarēs to būtu iespējams attīstīt. Ir jāatrod niša, kurā Latvijas produkts izceltos, salīdzinot ar līdzīgu valstu piedāvājumiem un pakalpojumiem, izceļot savas unikālās idejas, pieredzi, kompetenci un aktivitātes. Biodiplomātijas izmantošana dotu atzinību, prestižu, vadošo lomu tirgū un valsts ietekmi. Tāpēc nākamais solis tās īstenošanā būtu likumīgu nišas biodiplomātijas stratēģiju iekļaušana likumdošanas dokumentos. Lai gan valdība šobrīd plāno izstrādāt rīcības plānu, kas definētu uzdevumus, kā padarīt Latviju pievilcīgu eksportējošiem uzņēmumiem starptautiskajā vidē, izveidojot vienotu zīmolu ārvalstu intereses piesaistei, šī biodiplomātijas definīcija ir vairāk nekā interpretācija, jo valdība nepiemin publisko diplomātiju nacionālās plānošanas politikas ietvarā [26].

Veidojot nišas biodiplomātiju, primārie mērķi, ko Latvija varētu piedāvāt citām valstīm, ir jāizvirza kā konkurētspējīgi, protams, ņemot vērā valsts primārās intereses. Jāuzsver, ka nišas biodiplomātija koncentrētos uz konkrētu nozares jomu, atsijājot citas jomas un precizējot, kas varētu izraisīt pretestību no dažādām jomām. Pozitīvu biodiplomātiju var īstenot tikai tad, ja ilgtermiņā ir sagaidāma veiksmīga sadarbība starp iestādēm un nozarēm un zinātniskajām institūcijām, jo tikai tad ir vēlamie rezultāti [27].

Augstākā izglītība ir viens no galvenajiem globālās konkurētspējas rādītājiem, un nākotnē, pateicoties globalizācijai un zināšanu pārnesei, mūsdienu studiju programmām, it īpaši maģistrantūras programmām, ir jābūt multidisciplinārai un starpdisciplinārai pieejai un jāspēj reaģēt uz vides inženierijas zināšanu pieprasījumu reģionālā mērogā [28].

Laikmets, kurā mēs dzīvojam, prasa pastāvīgu virzību uz lietišķo radošumu vides problēmu risināšanā [29], [30]. Daudzas organizācijas un kopienas ir vērstas uz zaļajām inovācijām, lai panāktu vides aizsardzību un ekonomisko izaugsmi [48]–[50]. Nozīmīga ir arī vides ilgtspēja un finansiālā rentabilitāte [34]. Zaļās inovācijas ieviešanas galvenais izaicinājums ir kvalificēta darbaspēka pieejamība un mijiedarbība starp akadēmiskajām aprindām un rūpniecību [52]–[54]. Abām pusēm ir jālīdzsvaro savas intereses jauno speciālistu izglītošanā un vides tehnoloģiju komercializēšanā, jo tas veicina ekonomikas virzību uz klimatneitralitāti [38], [39]. Zinātnei joprojām ir ievērojams potenciāls sadarbībai ar privāto sektoru abos jautājumos, taču ir vajadzīgi uzlabojumi, lai mijiedarbību padarītu efektīvāku [40], [41].

Šādas sadarbības nozīme ir bieži uzsvērts starptautiskajos dialogos un paziņojumos, kas iekļauti ilgtspējīgas attīstības mērķos, un to ir aizstāvējuši ievērojami uzņēmumu vadītāji un zinātnieki [59]–[62].

Lai veicinātu zaļo inovāciju ilgtspēju, abām pusēm ir kritiski jāizvērtē to loma jauno vides inženieru apmācībā un jāņem vērā dažādie faktori, kas ietekmē kopīgos sasniegumus [39], [63], [64]. Akadēmiskajam sektoram ir jāpieņem drosmīgāki risinājumi mūsdienīgai izglītībai un jākļūst par partneri proaktīvam dialogam ar nozari, ņemot vērā pastāvošo konkurenci starp augstākās izglītības iestādēm un iespējas, ko sniedz alternatīvas tiešsaistes izglītības platformas [65]–[67]. Paradigmas maiņa sabiedrībā ir ietekmējusi arī akadēmisko sektoru, kurā pieaug politikas veidotāju un nozares pieprasījums pēc atbilstošām mācību metodēm. Pētījumi arī liecina, ka akadēmiskajam personālam ir jāuzlabo savs sniegums [52], [53]. Unikālais izaicinājums, ar ko pedagogi saskaras vadības un tehnoloģiju mijiedarbībā, ir integrācijas nepieciešamība un atšķirība uzskatos starp vadītājiem un tehnologiem [54].

Lai kļūtu par proaktīvu dialoga partneri akadēmiskajam sektoram, nozīmē pārskatīt pašreizējo ārējās komunikācijas stratēģiju un strādāt ar akadēmiskā personāla motivāciju kļūt par pilnvērtīgu posmu, kas savieno universitātes studiju procesu un nozares gaidas [71]–[74]. Pārejas organizācijas nodrošina forumu, lai mijiedarbotos ar šiem dažādajiem zināšanu veidiem un koordinētu citus uzdevumus, kas ļauj sadarboties: piekļūt resursiem, apvienot dažādus dalībniekus, veidot uzticēšanos, risināt konfliktus un veidot tīklus [59]. Sociālā mācīšanās ir viens no šiem uzdevumiem, kas ir būtisks partneru sadarbībai un sadarbības rezultātam. Visefektīvāk tas notiek, izmantojot kopīgu problēmu risināšanu un pārrunas mācību veicināšanai [60].

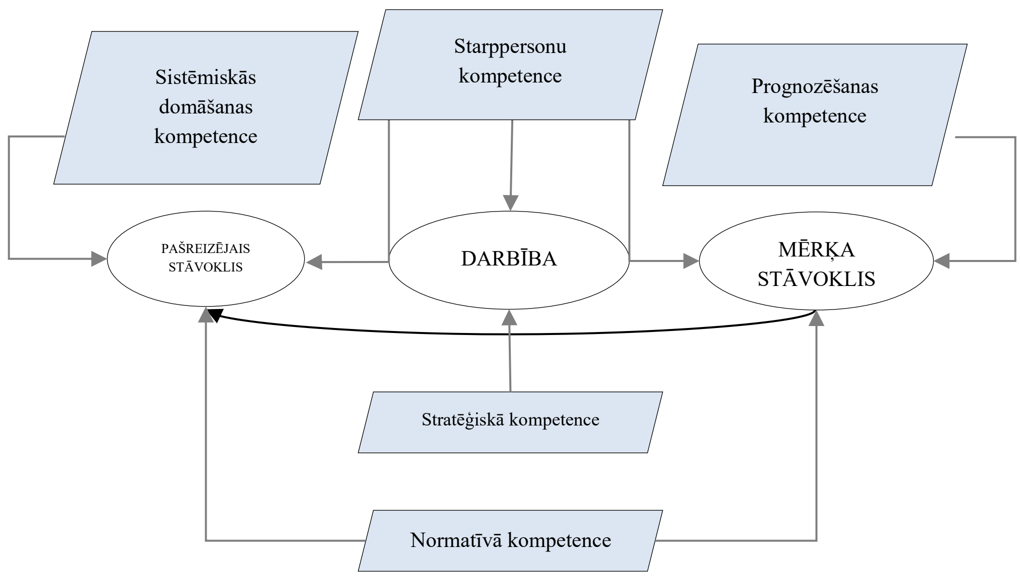
Savukārt nozares ieguldījums kvalificētā darbaspēka nodrošināšanā un zaļo tehnoloģiju attīstībā ir tās uzņēmējdarbības kompetence un izpratne par atbildību ilgtspējīgas attīstības mērķu sasniegšanā [61]. Privātā sektora vērtība ir uzņēmumu konkurētspēja un integrācija zaļās vērtības ķēdē. Uzņēmumiem ilgtspēja kļūst par komandējošu un būtisku principu [62], [63].

Ilgtspējīgai korporācijai būtu jārada peļņa saviem akcionāriem, vienlaikus aizsargājot vidi un uzlabojot to cilvēku dzīvi, ar kuriem tā mijiedarbojas. Tai jādarbojas tā, lai uzņēmējdarbības intereses un vides un sabiedrības intereses krustotos [64].

Ja katras puses pieredze tiek sinhronizēta, uzņēmumu pārliecība par savām līderības prasmēm, tostarp zaļo tehnoloģiju izstrādē, var novest pie veiksmīgu risinājumu izstrādes [65]. Tikmēr tehnologi bieži uzskata, ka tehnoloģijai ir nozīme un nepieciešama palīdzība attīstīties, pievēršot uzmanību klienta vēlmēm un citām biznesa (netehniskām) problēmām [82]–[84].

Lai izveidotu līdzsvarotu sadarbību starp divām pusēm, var izmantot kopīgas vadības pieeju, kuras viens no lietojumiem ir kopīga vadība problēmu risināšanā. To uzskata par kopīgu problēmu risināšanu, kas orientē uz uzdevumu, koncentrējoties uz funkciju, nevis uz formālo struktūru [85]–[88].

Pētījumu skaits bioekonomikas izglītībā pēdējo gadu laikā ir pieaudzis, lai uzsvērtu nepieciešamību šajā jomā izstrādāt inovatīvas tehnoloģijas un produktus [3], [73]–[78], raksta, ka bioekonomikas mērķu īstenošana un pāreja uz ilgtspējīgu bioekonomiku, kas balstīta uz zināšanām, būtu jāuzskata par transdisciplināru, mācīšanās, starpdisciplināru un sistēmisku domāšanu, prognozējošu, normatīvu, stratēģisku un starppersonu kompetenci, kur [79] norāda arī politikas un lēmumu pieņemšanas prasmes. Vēl vienā pētījumā minēts, ka lekcijas, objektu apmeklējumi, grupu kursa darbi, praktiskie laboratorijas darbi un lomu spēles atbalsta šīs kompetences. 1.1.attēlā ir ilustrēta problēmu risināšana – pamatstruktūra, kas saistīta ar ilgtspējas pamatkompetencēm, kas aprakstīta šajā pētījumā [75]



1.1. att. Problēmu risināšana — pamatstruktūra, kas saistīta ar ilgtspējības pamatkompetencēm [80].

[81] ir minēts, ka prasmes ir risinājums bioekonomikai un *Zaļā kursa* mērķa sasniegšanai. Programmā teikts, ka “divējādā pārkārtošanās”, kas atbalsta zaļās pārkārtošanās un digitālās

pārkārtošanās prasmes, paredz, kā Eiropas Komisija atbalstīs šīs prasmes. Šajā programmā ir izklāstīti nosacījumi, saskaņā ar kuriem Eiropas Komisija atbalstīs zaļajai pārejai vajadzīgās prasmes, piemēram, nosakot prasmju sistēmu un vienojoties ar ES dalībvalstīm par rādītāju kopumiem, lai uzraudzītu un analizētu zaļo prasmju attīstību.

Latvijai, tāpat kā visām pārējām Eiropas Savienības (ES) valstīm, valsts politika ir jāveido tā, lai sasniegtu *Zaļā kursa*, enerģētikas, klimatneitralitātes un citos saistošajos dokumentos izvirzītos mērķus. Politika ir jāpakārto tā, lai nodrošinātu visas ekonomikas attīstību un virzību uz šo mērķu sasniegšanu. Tā kā šis jautājums ir saistīts ar globāliem risinājumiem, ir jāatjaunina biodiplomātu darbs, lai nodrošinātu mērķu sasniegšanu. Biodiplomāti ir starptautiski eksperti, kas bioekonomikā ieviesīs inovatīvas paradigmas, lai nodrošinātu jaunus un inovatīvus produktus, izmantojot jaunas tehnoloģijas un procesus. [82] ir pētījuši biodiplomātijas jēdzienu un definējuši galvenās īpašības.

Termins "biodiplomātija" sākotnēji ir bijis saistīts ar bioloģisko izglītību. *Vlavianos-Arvanitis* [1993] mudina pārstrukturēt izglītības sistēmu, lai "pārvarētu draudus *bios* (grieķu val. dzīvība) saglabāšanai, ko izraisa vērtību krīze". Starptautiskā sadarbība un tādu problēmu risinājumu meklēšanas veicināšana, kas prasa ātru un izlēmīgu rīcību, ir izcils gadījums vides jautājumos [83]. Turpmākajā gandrīz 20 gadu periodā arvien sarežģītākās problēmas, kas saistītas ar resursu pārvaldību sociāli ekoloģiskajās sistēmās, lika politikas veidotājiem un praktiķiem arvien vairāk izmantot tā sauktās nopietnās spēles (angļu val. *serious games*), kā parādīts sistemātiskajā pārskatā par attiecīgajām *Edwards et al*. publikācijām [2019] [84]. Attiecībā uz visuresošo klimata pārmaiņu izaicinājumu *Ahamer* [2013] apgalvo, ka spēles labāk kalpo stratēģijas veidošanai nekā cīņai tādā nozīmē, ka pirmā attiecas uz "nestabila līdzsvara pārvaldību, vienlaikus saglabājot sabiedrības ilgtspēju". Turpretī pēdējais atsāk saprast tikai savu viedokli, bet ne pretinieku viedokli [85]. *Blanchard* un *Buchs* [2015] ilustrē lomas spēju izskaidrot studentiem ilgtspējīgu attīstību un biedējošu koncepciju ar starptautiskām sekām. *Thomas et al.* [2018] sīki apraksta lomu spēles izmantošanu, pieņemot ar enerģiju saistītus lēmumus pilsētu un lauku pašvaldībās [86], [87]. Dažādas ieinteresētās personas iesaistījās kā dalībnieki ar enerģiju saistītām neskaidrībām sešās dažādās vietās ASV, iejūtoties citu vietā, gūstot vērtīgu ieskatu sarežģītu lēmumu pieņemšanā. Biodiplomātijas un tās darbības izpratnes kontekstā lomu spēle studiju procesā sniedz neatsveramu ieguldījumu jauno speciālistu sagatavošanā. Tas ļauj ieviest transdisciplinaritāti klasē, simulējot un uzlabojot zināšanu kopražošanu [88]. Lomu spēle studiju procesā ir viens no veidiem, kā nodrošināt studentiem iespēju lietot iegūtās teorētiskās zināšanas praktiskajā realitātes simulācijā, jo piedāvātais veids nodrošina dinamisku vidi. Tomēr iepriekš tiek izdotas vadlīnijas, kas nosaka tēmu un problēmu; studentiem ir jāpiedāvā savi risinājumi. Lomu spēle ir viens no svarīgākajiem mācību līdzekļiem pieredzes apguvei ar ilgtspēju saistītās augstākās izglītības programmās [89]–[92]. Attiecīgajās publikācijās lomu spēles kopā ar mācību apmeklējumiem vai objektu apmeklējumiem tiek vērtētas kā visefektīvākie instrumenti, jo īpaši, integrējot sociālo ilgtspēju inženierzinātņu mācību programmā Kembridžas Universitātē [89] un Zviedrijas Karaliskajā Tehnoloģiju institūtā, kā redzams *Björnberg et al.* [2015] [90]. Lomu spēle izmantota arī, "lai sniegtu risinājumu faktiskām vietējām problēmām" kapacitātes stiprināšanas kursā, lai izglītotu pedagogus par ilgtspēju *Monterrey Tech* [91]. Lomu spēle ir ērts rīks, kad nepieciešams atrisināt problēmu [92].

Interaktīvas mācību vides pieejas, kas izstrādātas, lai padarītu izglītību ērtāku, pieejamāku un par pieņemamu cenu ikvienam interesentam, sauc par masveida atvērtajiem tiešsaistes kursiem (angļu val. *Masive open online course* (*MOOC)*). Dažādi pētījumi par MOOC efektivitāti ir parādījuši, ka lietotāji veiksmīgāk apgūst kursa saturu, izmantojot pašvadītu mācīšanos (angļu val. *self-regulated learning*), kad viņiem pašiem ir jāmācās un jālasa kursa materiāli [93]–[95]. *MOOC* tiešsaistes vide ir atrodama visdažādākajos formātos, un dažas kopīgas iezīmes apkopo [96]. *MOOC*, pateicoties to plašajām iespējām iegūt saturu, materiālus un prasmes, atspoguļo izmaiņas studiju procesā, kas drīzumā varētu kļūt par būtisku izglītības sistēmas sastāvdaļu [97]–[99]. Masveida atvērto tiešsaistes kursu kategorizācija ir ļoti daudzveidīga [93]. *MOOC* ir balstīti uz tradicionālo pedagoģiju un aprobāciju ar lekcijām un praktiskiem uzdevumiem un biežāk izmantotu studiju modeli [100]. Būtu jārisina tādas problēmas kā liels priekšlaicīgas mācību pārtraukšanas gadījumu skaits un zema sadarbība starp lietotājiem [100] Tomēr, lai gan *MOOC* paver plašas tehnoloģiskās iespējas un dažādu mācīšanas metožu izmantošanu, praksē tā bieži ir saglabājusi standarta izglītības pieeju, kurā mācību saturu pārstāv un novērtē skolotājs, nevis mijiedarbība starp lietotājiem [101].

Kā izmērīt inovāciju bioekonomikā? *Wydra* [102] analizēja inovācijas rādītājus bioekonomikā, tostarp pētniecības un attīstības aktivitātes, bibliometriju un patentus, cilvēkresursus un komercializāciju, kā arī inovāciju ietekmi. *Ribeiro* un *Cherobim* [38] aprakstīja inovācijas procesa posmus, un *Van Lancker et al.* [5] analizēja universitāšu lomu inovācijā bioekonomikā.

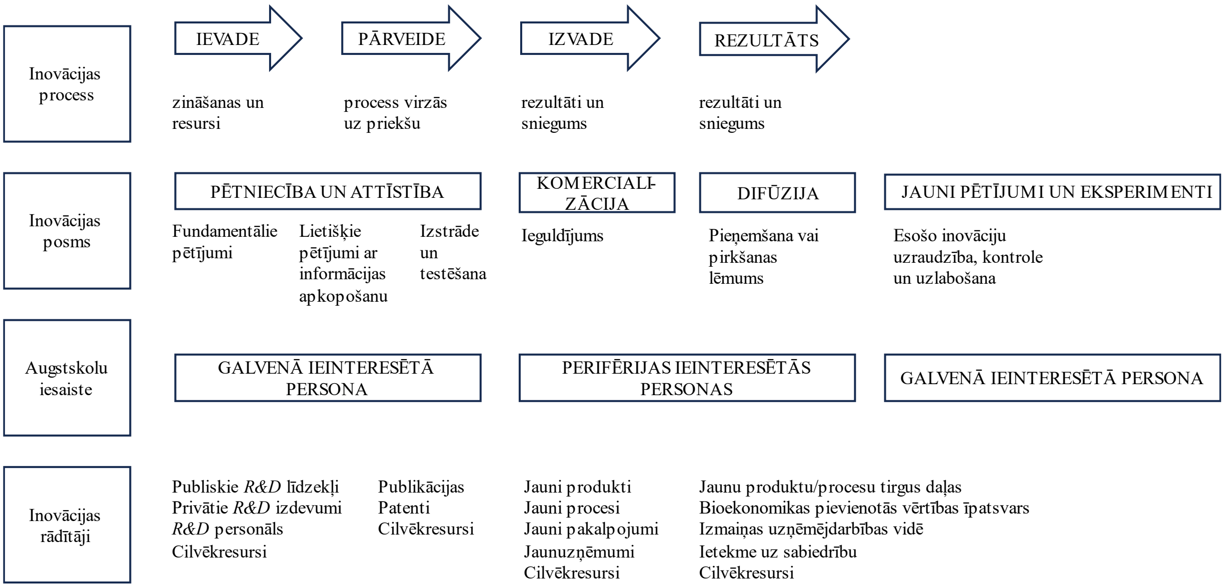
Eiropas Komisija ir definējusi teorētisko uz zināšanām balstītas bioekonomikas (TZBB) koncepciju kā dzīvības zinātņu zināšanu pārveidošanas procesu ekoloģiski efektīvos, jaunos un ilgtspējīgos produktos [103]. Esošās ražošanas sistēmas pārveidošanas process TZBB virzienā palielinās pieprasījumu pēc ļoti prasmīgiem un augsti kvalificētiem darbiniekiem. Lai analizētu nepieciešamo kvalifikāciju, tika analizēta konkurence un zināšanas ilgtspējīgas bioekonomikas veidošanai. Ņemot vērā globālās pārmaiņas un pāreju uz bioekonomiku un aprites ekonomiku, būtu jāizstrādā jauni zināšanu radīšanas un lēmumu pieņemšanas veidi universitāšu līmenī [104].

Segalas et al. [105] uzsver, lai gan izglītība ir svarīgs nosacījums, tā negarantē pārmaiņas ilgtspējas jomā. Inženierzinātņu studentiem pēc absolvēšanas jābūt sistēmiskai domāšanai un transdisciplinārai kompetencei. To pašu nosacījumu var attiecināt uz bioekonomiku. Inženierizglītības transdisciplinārais konteksts tiek uzskatīts par ilgtspējības kompetenci [61]. *Lambrechts et al.* [106] analizēja ilgtspējīgas attīstības kompetenču integrāciju augstākajā izglītībā, izmantojot holistisku, starpdisciplināru un transdisciplināru pieeju un uz kompetencēm balstītu izglītību. Pētījumā tika analizēts, kā vadības bakalaura studiju programmās tika integrētas ilgtspējīgas attīstības kompetences, piemēram, atbildība, emocionālā inteliģence, orientācija uz sistēmu, orientācija uz nākotni, personīgā iesaiste un rīcības prasmes. *Weak et al.* [107] kā galvenās ilgtspējas kompetences definēja sistēmdomāšanas kompetenci, paredzamo kompetenci, normatīvo kompetenci, stratēģisko kompetenci un starppersonu kompetenci.

Pārejai uz bioekonomiku ir vajadzīgi labi sagatavoti bioekonomikas speciālisti ar pamatkompetencēm un galvenajām kompetencēm, kas tiek iegūtas starpdisciplinārā izglītības procesā un jaunā mācību vidē. Ilgtspēja tiek uzskatīta par bioekonomikas pamatprincipu; tāpēc ilgtspējības kompetences var izmantot par pamatu bioekonomikas kompetencēm [77].

Ņemot vērā masveida augstāko izglītību, vides inženierijas studiju programmu efektivitātes un atbilstības novērtēšanai būtu jākļūst par svarīgu jautājumu. Zinātnieki dažādos reģionos ir meklējuši veidus, kā novērtēt vides inženierijas studiju programmas universitātēs [73], [108]–[117]. Energoefektivitātes novērtējumos galvenā uzmanība tiek pievērsta gan attieksmes, ietekmes vai efektivitātes novērtēšanai, gan uz izmantošanu vērstai novērtēšanai, konsolidētajiem novērtējumiem un līdzdalīgām novērtēšanas pieejām [118], [119].

Universitātēm ir galvenā loma inovāciju procesā (1.2. attēls).



1.2. att. Inovācijas process un rādītāji bioekonomikā.

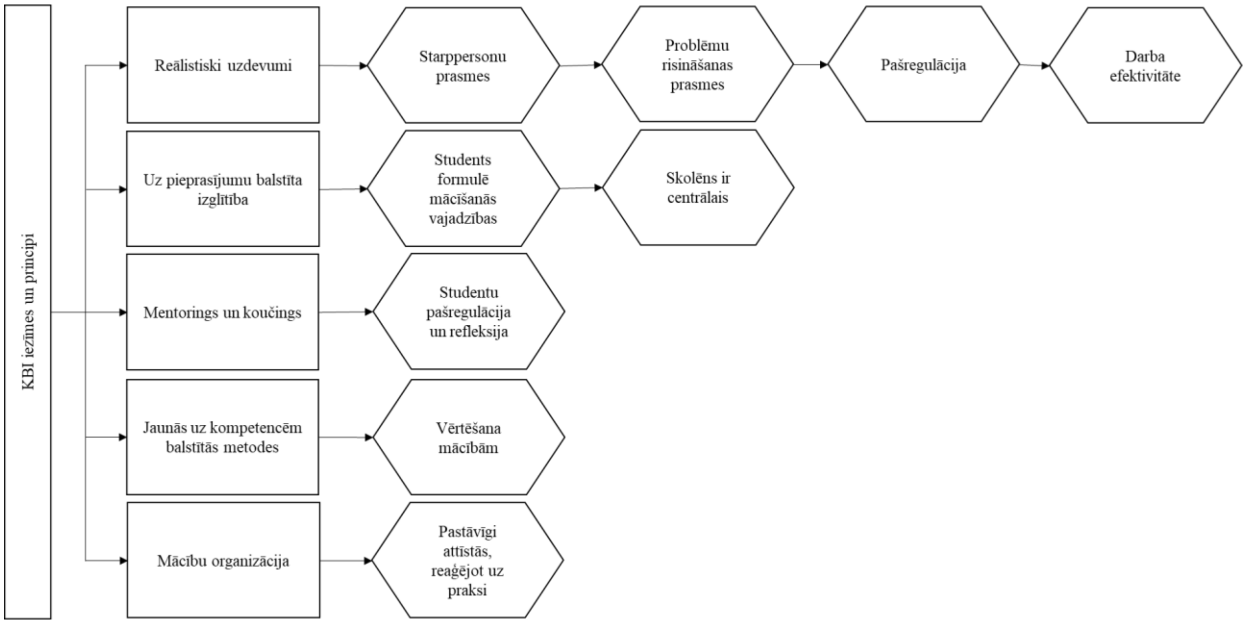
Inovāciju attīstība nav iedomājama bez tehnoloģiskajām, ekonomiskajām, vides un sociāli ekonomiskajām zināšanām.

Lai vides inženierijas studenti iegūtu prasmes un kompetenci, studiju process ir jāizveido atbilstoši šī brīža un nākotnes vajadzībām.

2020. gadā Rīgas Tehniskās universitātes Vides aizsardzības un siltuma sistēmu institūts akreditēja maģistra studiju programmu “Vides inženierija” ar virzienu “Bioekonomika”. “Bioekonomikas” virziena izveidošana nodrošina padziļinātāku izpratni un nozīmi bioekonomikas speciālistiem un viņu lomai nākotnē un bioekonomikas mērķu sasniegšanā. Tāpēc izglītības pārmaiņu kontekstā būtiska loma ir studentu iegūtajām kompetencēm (zināšanām).

Rīgas Tehniskajā universitātē ir akreditēta vides inženierijas bakalaura, maģistra un doktorantūras programma. Profesori aktīvi piedalās skolu un mūžizglītības programmās.

Gandrīz 20 gadu akadēmiskās izglītības pieredze ļauj analizēt studiju procesu un to virzīt uz priekšu, ieviešot inovācijas. Ar kompetencēs balstītu izglītību var palīdzēt studentam stāties pretī mūsdienu pasaules izaicinājumiem: analizēt datus, būt atbildīgam, iemācīties mācīties un novērtēt, pamatojoties uz rūpīgu analīzi. Kompetencēs balstītas izglītības (KBI) galvenās iezīmes un principi augstākajā izglītībā [8] ir parādīti 1.3. attēlā.



1.3. att. Kompetencēs balstītas izglītības iezīmes un principi.

Pamatojoties uz galvenajām iezīmēm un principiem, kompetencēs balstīta mācīšana ietver darbu ar zināšanām, prasmēm un attieksmēm.

Inovācijas meklētas apmācības procesa papildināšanā ar inovatīvām metodēm, kā piemēram, anonīmi atsauksmju novērtējumi, vienotu e-mācību sistēmu (iekštīkls), datu vākšanu, grupas kursa darbi, grupu darbi, individuālo pētniecības projektu, lekcijām, tiešsaistes uzdevumiem un kursa darbiem, laboratorijas darbiem, semināriem un darbnīcām, objektu apmeklējumiem, konsultācijām, lomu spēlēm un kopradi.

Dažādi autori ir veikuši pētījumus, saskaņā ar kuriem videi ilgtspējīgu inovāciju un zaļo inovāciju attīstībai nepieciešama uz inovācijām orientēta mācīšanās un specifisku prasmju apguve [120]–[123].

Svarīgi ir nepārtraukti analizēt studiju procesu un attīstīties, balstoties uz globālajām un nacionālajām attīstības tendencēm.

Saskaņā ar *Oversberg et al.* pašreizējais novērtējums ir balstīts uz kvalitātes pasākumiem, kas vērsti uz akadēmisko personālu, mācību metodēm un studentu apmierinātību, nevis koncentrējas uz izglītības programmu mācību rezultātiem. Attiecīgi nav viena vienota novērtēšanas instrumenta kompetencēs balstītas izglītības novērtēšanai kopumā un konkrēti vides inženierijas studiju programmu novērtēšanā. Trūkst skaidra redzējuma par studiju programmu vērtēšanas metodēm un MKA integrēšanu kompetenču novērtēšanā. Tādēļ, lai uzlabotu un pilnveidotu studiju procesu, ir jāmainās:

- metodēm,
- paņēmieniem.

Ņemot vērā iepriekš izklāstīto, šajā disertācijā tiek piedāvāti daudzpusīgi vides inženierijas izglītības ilgtspējības veicināšanas novērtēšanas moduļi.

2. METODOLOĢIJA

Promocijas darbā tiek izmantotas sešas dažāda veida pētījuma metodes, lai novērtētu vides inženierijas izglītības ilgtspējīgu attīstību. 2.1. attēlā redzamas promocijas darbā izmantotās metodes.

2.1. att. Promocijas darbā izmantotās metodes.

2.1. Daudzkritēriju lēmumu analīzes metode

MCDA metodi var izmantot, lai salīdzinātu vairākas iespējas, izmantojot dažādus kritērijus. Šī metode palīdz konsekventi apstrādāt lielu informācijas daudzumu [124]. *MCDA* ievades dati var būt kvantitatīvi un kvalitatīvi [125]. *MCDA* metodes var izvēlēties pēc to īpašībām un prasībām.

Visbiežāk vides inženierijas kontekstā tiek izmantotas *TOPSIS*, *VIKOR*, *COPRAS*, *MULTIMOORA*, *PROMETHEE-GAIA* un *AHP* metodes, kuru detalizētāks izklāsts ir dots turpmāk.

AHP

AHP metodē svarīgs rādītājs ir kritēriju skaits, un tas ietekmē rezultātu konsekvenci, jo vairāk nekā septiņi kritēriji palielina nekonsekvenci [126].

AHP metode atvieglo dažādu mainīgo lielumu organizēšanu hierarhijas līmeņos un palīdz ekspertiem novērtēt kritēriju pēc kritērija [127].

Sākotnēji AHP metodē 2 tiek definēti un novērtēti kritēriji skalā no 1–9 un aprēķināta normalizētā matrica, izmantojot 2.1. vienādojumu [126]:

$$X_{ij} = \frac{C_{ij}}{\sum C_{ij}}, \tag{2.1.}$$

kur

Cij– kritēriju vērtība;

$\sum Cij$ – kolonnu summa.

Nākamajā solī tiek aprēķināts prioritātes vektors ar 2.2. vienādojumu:

$$W_{ij} = \frac{\sum X_{ij}}{n}, \tag{2.2.}$$

kur

$\sum Xij$ – normalizētās matricas kolonnas summa;

n – kritēriju skaits.

Piemērojot šo *AHP* metodi svara aprēķināšanai, ir svarīgi izmantot ekspertus, lai novērtētu kritērijus, jo tas ietekmē alternatīvas vērtības turpmāk, kad citas *MCDA* metodes izmanto kritēriju svaru. Ja svarus aprēķina, izmantojot *AHP* metodi, šīs vērtības var izmantot katrā *MCDA* metodē. Arī pēc *AHP* metodes rezultātiem var izdarīt secinājumus par norādītajām vērtībām un to, kurš kritērijs var atrisināt problēmu.

TOPSIS

TOPSIS metodes pilns nosaukums ir Pasūtījuma izvēles paņēmiens pēc līdzības ar ideāliem risinājumiem. Šī metode novērtē alternatīvu attālumu līdz ideālajam un antiideālajam punktam, un alternatīva ar īsāko attālumu līdz ideālajam punktam ir vislabākā alternatīva. *TOPSIS* metodē ir trīs distances: Manhetenas distance, Čebiševa distance un Eiklīda distance.

Sākotnēji *TOPSIS* metodē tiek aprēķināta normalizētā matrica, izmantojot 2.3. vienādojumu [128].

$$R = \frac{x}{\sqrt{\sum x^2}}, \tag{2.3.}$$

kur

x – kritēriju vērtība;

$\sum x$ – kritēriju vērtības summa.

Turpinājumā tiek aprēķināta normalizētā svērtā matrica, izmantojot 2.4. vienādojumu:

$$V = R \times W, \tag{2.4.}$$

kur

R – normalizēta matricas vērtība;

W – kritēriju svars.

Pēc tam definējiet kritēriju labākās un sliktākās vērtības: labākās vērtības V^{+}= max un sliktākās vērtības V^{-} = min; labākās vērtības V^{+} = min un sliktākās vērtības V^{-} = max, izmantojot 2.5. un 2.6. vienādojumus, lai atšķirtu vērtību no labākās vai sliktākās:

$$d_a^+ = \sqrt{\sum(V^+ - v_a)^2}, \qquad (2.5.)$$

kur

V^{+} – ideāla vai vislabākā vērtība;

v_a – normalizēta svērtā matricas vērtība.

$$d_a^- = \sqrt{\sum(- v_a)^2}, \qquad (2.6.)$$

kur

V^{-}– neideāla vai sliktākā vērtība;

v_a – normalizēta svērtā matricas vērtība.

2.7 vienādojums tiek izmantots, lai atrastu relatīvo tuvumu un sarindotu alternatīvas.

$$C_a = \frac{d_a^-}{d_a^+ - d_a^-}, \qquad (2.7.)$$

kur

d^-_a – neideāla vai sliktākā vērtība;

d^+_a – ideāla vai vislabākā vērtība.

Galvenā atšķirība starp šo un citām metodēm ir tā, ka *TOPSIS* izmanto katra kritērija labāko un sliktāko vērtību un aprēķina alternatīvu vērtību, izmantojot starpību starp labākajiem un sliktākajiem kritērijiem. Mazākā atšķirība starp labākajām un sliktākajām vērtībām ir tuvākās vērtības alternatīvu rezultātiem.

VIKOR

Metodes pilns nosaukums serbu valodā ir *VlseKriterijumskaOptimizacija I KompromisnoResenj*. Šajā metodē svarīgs faktors ir alternatīvs tuvums ideālajam risinājumam, un pēc tam tiek sarindotas alternatīvas [129]. Šajā metodē tiek izmantots Eiklīda attālums [130].

Sākotnēji tiek definēta kritēriju labākā un sliktākā vērtība un pēc tam ar 2.8. vienādojumu tiek atrastas vērtības labāko un sliktāko vērtību matricai [131].

$$S = w\frac{f^* - f}{f^* - f^-}, \qquad (2.8.)$$

kur

w– kritēriju svars;

f – kritēriju vērtība;

f^*– kritēriju labākā vērtība (max vai min);

f^- – sliktākā kritēriju vērtība (min vai max).

Ar 2.9. vienādojumu tiek atrasta vērtība *S*, *R* un *Q* katrai alternatīvai:

$$Q = v \frac{S_j - S^*}{—S^*} + (1 - v)\frac{R_j - R^*}{R^- -}, \quad (2.9.)$$

kur v ir lēmuma pieņemšanas faktors (ja liela vienošanās, tad $v \geq 0,5$, ja vienprātīga vienošanās, tad $v = 0,5$, ja vienošanās ar veto tad $v \leq 0,5$), šajā gadījumā, $v = 0,5$;

$$S_j = \sum w \frac{f^* - f_i}{f^* - f^-}, S^* = \min S_j, S^- = \max S_j; Rj = \max\left[w \frac{f^* - f_i}{f^* - f^-}\right], R^* = \min R_j, R^- = max\ R_J$$

Šajā metodē netiek izmantota normalizētā un normalizētā svērtā matrica kā *TOPSIS*, *COPRAS* un *MULTIMOORA* metodē.

COPRAS

Metodes pilns nosaukums ir Kompleksais proporcionālais novērtējums. Šī metode izmanto pakāpenisku šķirošanu un lietderības pakāpes aprēķinu, kas palīdz, ja ir pretrunīgi kritēriji [132]. Lai panāktu alternatīvu sekvencēšanu pēc lietderības pakāpes, alternatīvas ir jāsakārto dilstošā secībā [133].

Sākumā *COPRAS* metodē tiek atrasta normalizētā matrica, izmantojot 2.10. vienādojumu [134].

$$\overline{x_{JJ}} = \frac{x_{jj}}{\sum x_{jj}} \quad (2.10.)$$

Nākamajā solī tiek atrasta normalizētā svērtā matrica, izmantojot 2.11. vienādojumu:

$$\widehat{x_{JJ}} = \overline{x_{JJ}} \times w, \quad (2.11.)$$

kur

$\overline{x_{JJ}}$ – normalizētas matricas vērtības;

w – kritēriju svars.

Pēc tam tiek maksimizēts indekss ar 2.12. vienādojumu un minimizēts – ar 2.13. vienādojumu.

$$P_j = \sum \widehat{x_{\iota J}}, \quad (2.12.)$$

$$R_j = \sum \widehat{x_{\iota J}}, \quad (2.13.)$$

kur

Pj – indeksa maksimizēšana;

Rj – indeksa minimizēšana;

$\widehat{x_{JJ}}$ - svērtā normalizētā matrica.

Izmantojot. 2.14. vienādojumu, tiek atrasti relatīvie svari katrai alternatīvai:

$$Q_j = P_j + \frac{\sum R_j}{R_j \sum \frac{1}{R_j}} \quad (2.14.)$$

kur

Pj – indeksa maksimizēšana;

Rj – indeksa minimizēšana.

Tiek aprēķināta lietderības pakāpe, izmantojot 2.15. vienādojumu:

$$N = \frac{Qi}{Q_{max}} \times 100\% \quad (2.15.)$$

Šajā metodē kritēriju vērtība un visas alternatīvās summas tiek izmantotas, lai atrastu normalizētās matricas vērtības, bet citās metodēs, piemēram, *TOPSIS*, alternatīvu vērtību aprēķināšanai tiek izmantota kritēriju vērtība un kvadrātsakne no kvadrāta summas.

MULTIMOORA

Metodes pilns nosaukums ir Daudzmērķu optimizācija, pamatojoties uz attiecību analīzi. *MULTIMOORA* ir sistēma, kas optimizē konfliktējošas alternatīvas, lai atrastu labāko rezultātu, un ir viegli lietojama dažādu problēmu risināšanai [133]. Šai metodei ir paplašināta versija, kurā ir iespējams strādāt ar vērtības intervālu [135].

MULTIMOORA metode iesākas ar normalizētās matricas aprēķināšanu, izmantojot 2.16. vienādojumu [136].

$$X^* = \frac{x_i}{\sqrt{\sum x_i^2}}, \quad (2.16.)$$

kur x_i ir kritērija vērtība.

Tiek aprēķināta normalizētā svērtā matrica, izmantojot 2.17. vienādojumu:

$$Y = x_i \times w, \quad (2.17.)$$

kur:

xi – normalizēta matrices vērtība;

w – kritēriju svars.

Starpību starp maksimālo un minimālo vērtību katrai alternatīvai tiek aprēķināta, izmantojot 2.18. vienādojumu:

$$y_i = \sum \max x_{ij}^* - \sum \min x_{ij}^* , \quad (2.18.)$$

Alternatīvās vērtības tiek aprēķinātas, izmantojot 2.19. vienādojumu.

$$U_i = \frac{\sum \max X_{ij}^*}{\sum \min X_{ij}^*}. \quad (2.19.)$$

Šajā metodē ir iespējams izmantot apgriezto vienādojumu (2.19.) un izmantot minimālo vērtību kā labāko alternatīvu, ja tā ir jāsalīdzina ar citām metodēm, kurās minimālās vērtības ir labākās alternatīvas, kā tas ir *VIKOR* metodes gadījumā.

Šajā metodē ir diezgan svarīgi aprēķināt starpību starp kritēriju minimālajām un maksimālajām vērtībām un alternatīvas vērtību.

PROMETHEE-GAIA

PROMETHEE apzīmē Preferenču ranžēšanas organizēšanas metodi novērtējumu bagātināšanai, un *GAIA* apzīmē Interaktīvo atbalstu grafiskā analīzē [137].

PROMETHEE metodē kritēriju svērumam ir lielāka ietekme nekā preferenču funkcijas sliekšņa vērtībām [137]. Ir iespējams izvēlēties preferenču funkcijas, un programmatūru var izmantot, lai sakārtotu kritērijus un to svarus [137]. Aprēķini tiek veikti programmā *Visual PROMETHEE academic*.

2.2. Studiju programmu vērtēšanas metode

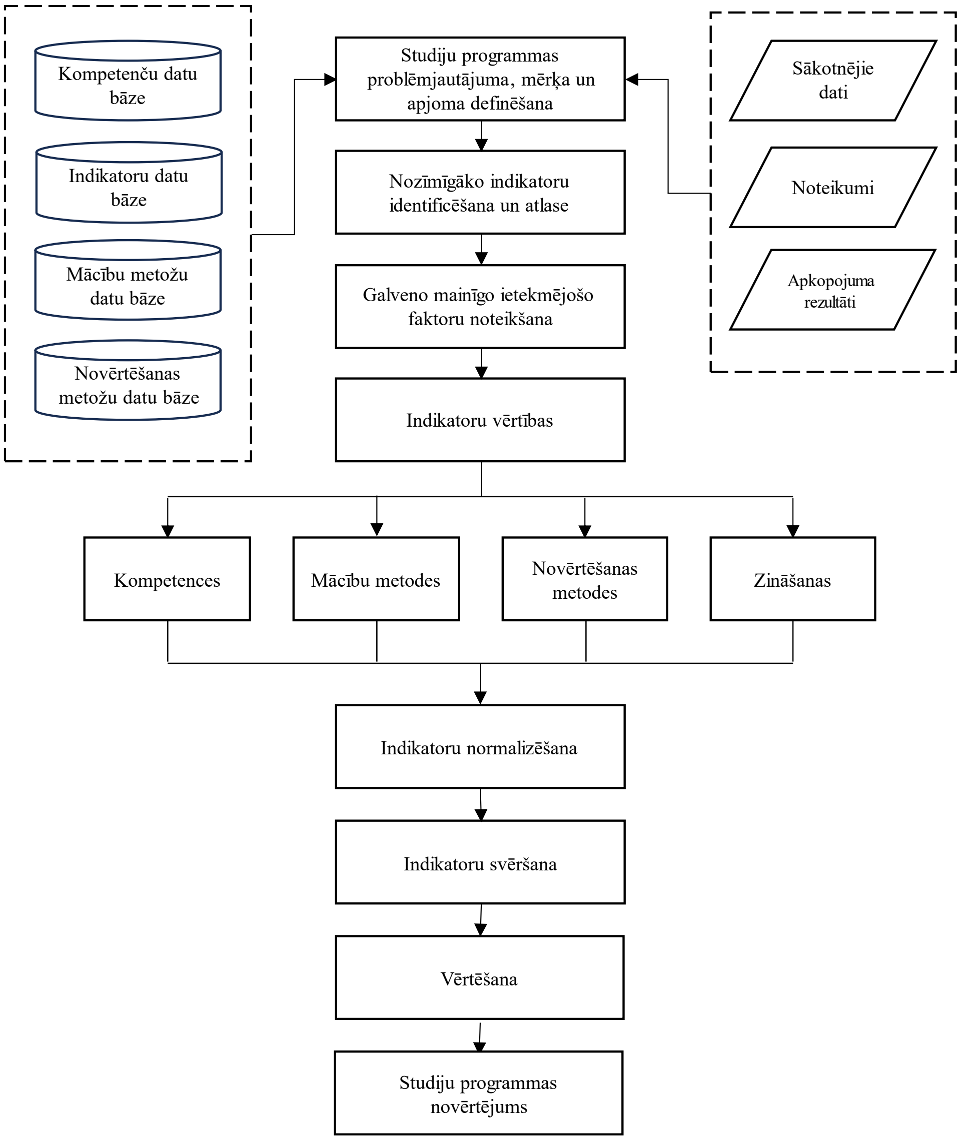
Saskaņā ar *Bergsmann et al.* [7] esošajām novērtēšanas metodēm ir daži galvenie ierobežojumi:

1) galvenā uzmanība tiek pievērsta katra studenta kompetencēm;

2) vērtēšanas uzmanības centrā ir konkrēti mācību procesa aspekti;

3) metodes ir balstītas uz statusa novērtējumiem, kuros netiek ņemtas vērā ieinteresēto personu vajadzības.

Studiju programmu vērtēšanas metode ir parādīta 2.2.attēlā.



2.2. att. Studiju programmu vērtēšanas metode

Metodes pirmajā daļā tiek apzināta un analizēta esošā situācija, kas balstās uz literatūras apskatu par mācību metodēm, novērtēšanas metodēm, kompetencēm un rādītājiem, kuri izmantoti studiju programmu novērtēšanā. Tiek veikta noteikumu un tiesiskā regulējuma analīze, kā arī veikts studiju programmu apkopojums. Otrajā daļā ir studiju programmas probēmjautājuma, mērķa un apjoma definēšana, kam seko nozīmīgāko indikatoru identificēšana un atlase un galveno mainīgo ietekmējošo faktoru definēšana, kas ietekmē pāreju uz kompetencēs balstītu izglītību. Ņemot vērā galvenos mainīgo ietekmējošos faktorus, tiek definētas kompetences, mācību metodes, novērtēšanas metodes un zināšanas. Nākamajā daļā tiek lietota *MCDA* metode *TOPSIS*, lai atrastu un izvērtētu optimālo mācību metožu kombināciju.

2.3. Veiktspējas metode

Vides inženierijas studentiem ir jāapgūst ne tikai inženiertehnisku un tehnoloģisku risinājumu izstrāde, bet arī to analīze un prezentēšana sabiedrības locekļiem. Tāpēc svarīgu lomu izglītības ieguves procesā spēlē performances jeb veiktspējas metodes izmantošana: iemācīties pievērst uzmanību jebkurai darbībai un atšķirt svarīgākās problēmas no nesvarīgām. Veiktspējas metodi izmanto lomu spēlēs.

Metode ietver trīs posmus:

1) sagatavošanās stadijā studenti iegūst priekšzināšanas noteiktā jomā un problēmā;
2) lomu spēles stadija sastāv no pašreizējās situācijas analīzes, priekšlikumu un risinājumu analīzes, sabiedriskās apspriešanas un lēmumu pieņemšanas. Lomu spēles mērķis ir vairot ieinteresēto personu zināšanas un izpratni par attiecīgās nozares ilgtspējīgu attīstību, tās mērķiem un to sasniegšanu;
3) pēcspēles stadija sniedz atgriezenisko saiti studentiem un apspriež studenta un studentu grupas sniegumu atsevišķās epizodēs, pamatojot studentu sasniegto līmeni.

Veiktspējas novērtēšanā tiek izmantota matrica (2.1. tabula), ar kuru tiek novērtētas biodiplomātijas kompetences vērtēšanas kritēriji. Izvēlētais kritēriju daudzums tiek pielāgots atbilstoši un konkrētajai kompetencei, jo piedāvātais kritēriju klāsts ir plašs. Vēlams izmantot četrus kritērijus, jo atbilstošākie un mērķtiecīgākie kritēriji konkrētajai kompetencei jāizvēlas no plaša iespējamo kritēriju klāsta. Kompetences tiek vērtētas no 1 līdz 4, kur 1. līmenis atspoguļo tikai nelielu darbību (neprecīza, viduvēja, nepilnīga kompetences sasniegšana). 2. līmenis jau nosaka virzienu uz vispārēju kompetences sasniegšanu. 3. līmenis nosaka kompetences sasniegšanu, kur studentu līdzdalība ir precīza. 4. līmenis norāda, ka students ir kompetents šajā jomā un var analizēt sarežģītas sistēmas.

2.1. tabula

Matrica par veiktspējas novērtēšanu vispārīgā forma

	Mēģina sasniegt / nesasniegt	**Tuvojas**	**Panāk atbilstību**	**Pārsniedz prasības**
Vērtēšanas kritēriji	1	2	3	4
	Studentu aktivitātes ir neprecīzas un aptuvenas; sniegumu var tikai daļēji attiecināt uz iegūto kompetenci.	Studentu sniegums ir vispārīgs, parasti saistīts ar apgūstamo kompetenci.	Studentu sniegums ir precīzs; tas ir balstīts uz spriedumiem par šo kritēriju.	Skolēnu sniegums ir precīzs un pārliecinošs; tas parāda kompetences ierobežojumus un sarežģītību.

Veiktspējas metode kombinācijā ar tehnoloģijas gatavības līmeni

Veiktspējas metodes izmantošana kombinācijā ar tehnoloģiju gatavības līmeni tiek vērsta uz sadarbības moduļa veidošanu starp akadēmisko sektoru un industriju, kuras mērķis ir apmācīt kvalificētus vides zinātniekus, lai izstrādātu zaļās inovācijas, kas atbilst tautsaimniecības prasībām [4], [5], [138]. Šīs metodes galvenā priekšrocība ir piemērošana dažādām disciplīnām, kur kvalificētu speciālistu pieejamība tieši ietekmē tautsaimniecības attīstību un veicina globālo problēmu risināšanu.

Metodes plašāka piemērošana ļauj universitātēm pastiprināt centienus attīstīt zaļās inovācijas, tādējādi apliecinot savu ieguldījumu klimata pārmaiņu negatīvās ietekmes mazināšanā un pasaules iedzīvotāju dzīves kvalitātes uzlabošanā [106], [139].

Metodei ir vairāki praktiski lietojumi. Augstskolas veicinās kvalificētu speciālistu sagatavošanu, lai veicinātu zaļo inovāciju izstrādi, izmantošanu un atzīšanu. Savukārt vides nozares uzņēmumi iegūs kvalificētu darbaspēku un, iesaistoties metodiskajā procesā kā stratēģiskais partneris, spēs efektīvāk sasniegt korporatīvās sociālās atbildības mērķus. Tikmēr valstu politikas veidotāji vides aizsardzības jomā varēs īstenot labāku zaļās ekonomikas kursu un stiprināt savu līdzdalību starptautiskā līmenī ilgtspējīgas attīstības mērķu sasniegšanā, kas saistīti ar vidi un klimatu [120]–[122], [140]

Veiktspējas metode tiek izmantota identificēto dalībnieku novērtēšanai koprades īstenošanas laikā. Noslēgumā tiek identificēti piedāvāto tehnoloģiju gatavības līmenis.

Tehnoloģiju gatavības līmenis (TGL) ir metode, ko izmanto, lai novērtētu jaunas idejas brieduma fāzi un nepieciešamās darbības tās izstrādes procesā. TGL sastāv no deviņiem līmeņiem, kurus var uzskatīt par šāda novērtējuma mērījumu. Šīs metodes priekšrocības ir strukturēts un visaptverošs skatījums uz prototipa statusu tā pētniecības un ražošanas procesā [264]. TGL metodes mērķis ir izstrādāt un pārbaudīt prototipus to reālajā lietojuma vidē, un tā ir sadalīta trīs fāzēs:

1) pētniecība;
2) prototipa izstrāde;
3) produktu ieviešana.

TGL metodes kopsavilkums saskaņā ar pētījumu ir sniegts 2.2. tabulā.

2.2. tabula

TGL metodes kopsavilkums

TGL	Apraksts	Mērķis	Produkts/novērtējums
1	Ievads projekta esošajā situācijā un mērķos	Pētniecība	Koncepcijas iespējamība
2	Pētniecības jautājumu definēšana	Pētniecība	Koncepcijas iespējamība
3	Analītiskie pētījumi un literatūras apskats	Attīstība	Prototips
4	Pamatkomponenti ir integrēti, lai pārbaudītu projekta veiktspēju	Attīstība	Prototips
5	Pamatkomponenti ir integrēti, lai pārbaudītu projekta veiktspēju	Attīstība	Prototips
6	Reprezentatīva prototipa veidošana	Attīstība	Prototips
7	Prototipa testēšana	Īstenošana	Prototips
8	Pētniecības projekts projekta pabeigšanai	Īstenošana	Sertificēts produkts
9	Produkta darbības uzsākšana	Īstenošana	Izvietotais produkts

2.4. Bibliometriskā metode

Zinātnisko datu apjomu analizēšanai plaši izmanto bibliometriskās analīzes metodi. Pētnieki izmanto šo metodi, lai identificētu tendences dažādu publikāciju un žurnālu sniegumā. Šī metode ļauj izpētīt konkrētas jomas intelektuālo struktūru esošajā literatūrā [17].

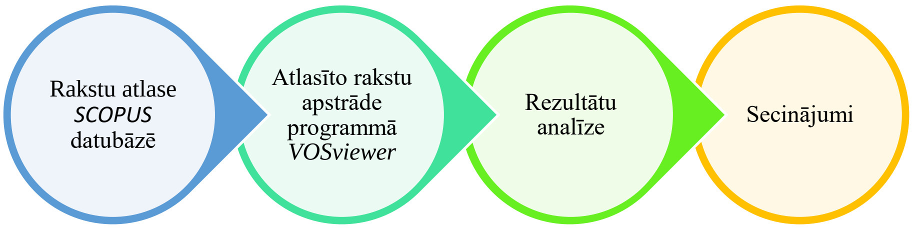
Bibliometriskā analīze ir īpaši noderīga, ja pārskata apjoms ir plašs un ja datu kopa ir pārāk liela, lai to analizētu manuāli.

Datubāzēs, piemēram, *SCOPUS*, *Web of Science* un *Google Scholar*, var atrast datus bibliometriskiem pētījumiem. Datubāzes atšķiras pēc publikāciju apjoma, iebūvēto analīzes rīku metodēm un aptvertajām pētniecības jomām. Piemēram, *Google Scholar* ir visplašākais datu pārklājums visās jomās, bet *SCOPUS* un *Web of Science* tiek īpaši izmantotas inženierzinātņu jomā.

VOSviewer izveidoja *Nees Jan van Eck* un *Ludo Waltman* [141]. Šis rīks vizualizē bibliogrāfiskos avotus, kas sniedz lasītājam vispārīgu priekšstatu par pētījuma tēmas virzieniem un sakarībām. Iepriekšējos pētījumos par ilgtspējīgu attīstību, aprites ekonomiku un citiem vides politikas jautājumiem *VOSviewer* ir izmantots, lai identificētu kritiskos atslēgvārdus, galvenos pētniekus un zinātniekus, izstrādājot pētniecības virzienus, kā arī pētījumus konkrētajā reģionā un žurnālos [38], [142].

Pētījuma metode sastāv no:

1) rakstu atlases no *SCOPUS* datubāzes;
2) rakstu apstrādes, izmantojot bibliogrāfijas vizualizācijas programmu *VOSviewer*;
3) rezultātu analīzes;
4) secinājumiem (sk. 2.3. att.).



2.3. att. Bibliometriskā metode.

Pētījumi atlasīti, izmantojot *SCOPUS* datubāzi un ievadot '*Article title*, *Abstract*, *Keywords*' vārdu kombinācijas meklēšanas laukos. Šīs vārdu kombinācijas ir:

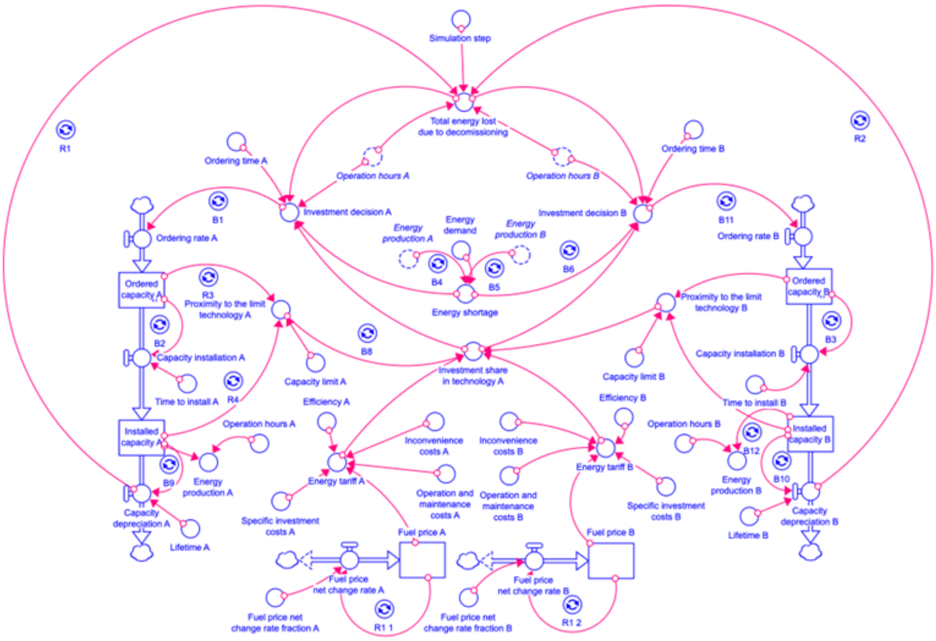
1) '*Education' AND 'Bioeconomy'*;
2) *'Education' AND 'Bioeconomy' AND 'Competences'*;
3) *'Education' AND 'Bioeconomy' AND 'Innovation'*;
4) '*Education' AND 'Bioeconomy' AND 'Skill'*;
5) '*Education' AND 'Green deal*';
6) '*Education' AND 'Green deal' AND 'Innovation'*.

Raksti atlasīti laika posmā no 2012. gada, ja tika iekļauts vārds "bioekonomika", jo 2012. gadā tika izvirzīti bioekonomikas mērķi. Ja vārdu salikums saturēja "zaļais kurss", tad raksti tika izvēlēti, sākot ar 2019. gadu, jo *Zaļā kursa* mērķi stājās spēkā no 2019. gada.

2.5. Sistēmdinamikas metode

Sistēmdinamikas metode ir novērtēšanas metode, kas izstrādāta 20. gadsimta piecdesmito gadu beigās un sešdesmito gadu sākumā Masačūsetsas Tehnoloģiju institūtā. Pamatā metode ir vērsta uz aģentiem vai vadītājiem kā informācijas pārveidotājiem, kuri interpretē jaunu informāciju vai atgriezenisko saiti par notiekošo procesu un pārveido to atbilstīgās turpmākās darbībās.

Kursa "Enerģētikas pārkārtošana un klimata pārmaiņas" ietvarā studentiem tiek dotas gadījuma cilpas diagrammas (GCD), kas tika izstrādātas *Stella Architect 2.1.5* programmatūrā. Šie divi enerģētikas nozares piedāvājuma un pieprasījuma puses CSD tika izveidoti Rīgas Tehniskās universitātes Vides aizsardzības un siltuma sistēmu institūta veiktā pētījuma "Enerģētikas pārkārtošanas politikas apspriešanas platforma: kā padarīt sarežģītas lietas vienkāršas" laikā, kurā tika izveidots internetā bāzēts saskarnes rīks nacionālajam energosimulācijas modelim kā "hibrīda foruma' rīks [143]. Ņemot vērā gadījuma rakstura cilpu, diagrammas tika pārveidotas par vispārējām krājumu un plūsmu struktūrām un izmantotas kā pētījuma rīki, lai izskaidrotu, kā vairākas enerģijas piedāvājuma un pieprasījuma puses mijiedarbojas enerģētikas nozarē, atjauninot un pielāgojot to esošajai situācijai (sk. 2.4. att.).



2.4.att. Krājumu un plūsmu struktūra energoapgādes nozarē [96].

Veidojot interaktīvus stāstus, kas vizualizē, kā krājumu un plūsmas struktūru elementi ietekmē dažādus rādītājus, piemēram, enerģijas tarifus, uzstādīto tehnoloģiju jaudu, izmantojot dažādus kurināmos, un investīciju iespējamību, lietotāji ar sistēmdinamikas palīdzību uzzina, kā enerģijas pārejas procesā rodas šķēršļi.

2.6. Kvalitatīvās pētniecības metodes vides inženierijā

Jebkura zinātniskā pētniecība virza uz inovācijām un jaunām tehnoloģijām. Zinātniskajai izpētei vides inženierijas jomā ir augsta pievienotā vērtība, jo tā palīdz izvērtēt dažādu procesu ietekmi uz vidi un klimata pārmaiņām. Uz zināšanām balstīta vides inženierijas attīstība ar zinātniskās pētniecības palīdzību nodrošina ilgtspējīgu inovatīvu inženiertehnisko risinājumu attīstību. Tāpēc vides inženierijas studiju programmās tiek iekļauti ekoloģisko pētījumu studiju kursi divās vides inženierijas apakšnozarēs:

- vides tehnoloģijās;
- bioekonomikā.

Šajā darbā lielāks uzsvars likts uz kvalitatīvajām zinātniskās izpētes metodēm, kuras plaši lieto vides inženierzinātņu izglītības programmās. Par kvalitatīvajām zinātniskās izpētes metodēm šeit tiek definētas metodes, kurās kvantitatīvās vērtības nespēlē galveno lomu, jo tās tiek izmantotas galvenokārt kvalitatīvajam salīdzinājumam. Kaut arī kvantitatīvās pētniecības metodes ir līdzvērtīgas, tās ir dārgākas un prasa lielākus ieguldījumus zinātniskās aparatūras iegādei un uzturēšanai. To apstiprina četri gadījuma rakstura zinātniskās izpētes piemēri.

Bioekonomikas integrācija. Blakusprodukti

Ar bioekonomikas integrācijas metodi tiek identificēti un novērtēti produkti, kurus var izgatavot, izmantojot graudu blakusproduktus. Tiek izmantota daudzkritēriju lēmumu pieņemšanas metode. Darbības algoritms sastāv no pieciem soļiem, kas visi ir svarīgi, un, lai iegūtu precīzus rezultātus, tos nedrīkst izlaist.

1. Produktu identifikācija. Solis, kas nepieciešams, lai noteiktu galveno produktu, tā nepieciešamās īpašības un kvalitātes.
2. Informācijas vākšana pieejamajā literatūrā un tās analīze, lai padziļināti izpētītu izvēlēto produktu, tā pieejamību un daudzveidību tirgū.
3. Pamatojoties uz literatūras analīzi, turpmākai analīzei ir jāizvēlas kritēriji. Pareiza kritēriju izvēle ļauj visaptveroši novērtēt produktu, pamatojoties uz nepieciešamajām īpašībām. Tehnoloģijām šie kritēriji var būt tās gatavības līmenis, pieejamība tirgū un ilgtspēja.
4. *MCDA* analīzes veikšana, pamatojoties uz izvēlētajiem kritērijiem.
5. Produkta realizācija, balstoties uz *MCDA* analīzes rezultātiem (skat. 2.5. att.).

2.5. att. Pētījuma metodoloģijas posmi.

Literatūras pārskatā tika izmantotas zinātniskās datubāzes *ScienceDirect* un *Web of Science*. Publikācijas tika meklētas, izmantojot šādus atslēgvārdus: "graudu produkti", "blakusprodukts", "dīglis", "mīkstums", "miziņa", "pelavas", "klijas", "salmi" un "sieti". Divdesmit deviņi pētījumi, kas publicēti no 2006. līdz 2021. gadam, tika atlasīti nākamajam posmam, kurā raksti tika sagrupēti un analizēti. Izvēlētie darbi bija angļu valodā un atbilda šī pētījuma tēmai.

Atlasītie raksti tika sagrupēti, pamatojoties uz pētījumā izmantoto blakusproduktu un galaproduktu. Visi galaprodukti tika sadalīti sešās grupās, kas parādītas 2.3. tabulā. Izvēlētie raksti ir par kviešu blakusproduktiem, jo lielākajā daļā rakstu par šo tēmu pētītas kviešu atliekas. Kvieši ir arī Latvijā un pasaulē izplatītākais graudaugu veids [144].

2.3. tabula

Produktu klasifikācija grupās

Produktu grupa	Kviešu blakusprodukti	Galaprodukts
Iepakojuma materiāli	Klijas, salmi, putekļi un miziņa	Biobāzēts kompozīts ar polipropilēnu (PP) [145], [146], pārtikas plēve ar antioksidantu īpašībām [147], bioloģisks pārtikas iepakojums [148], Biokompozīts – plēve svaigas pārtikas iepakojumam [149], termoplastiska [150].
Būvmateriāli	Salmi, miziņa	Betons [151], vieglais betons [152], [153].
Adsorbenti	Klijas, salmi un miziņa	Silīcija lignīna mikrodaļiņas kā adsorbents [154], adsorbents *Reactofix* zeltaini dzeltenai 3 RFN krāsvielai [155], oglekļa mikrosfēras [156], un absorbents, lai likvidētu krāsvielas un citus toksiskus notekūdeņus no tekstilrūpniecības [157].
Kurināmais	Klijas, salmi	Kurināmā granulas [158], fenola bioeļļa un biokokogles [159], biodegviela [160], [161].
Siltumizolācijas materiāli	Klijas, salmi un miziņa	Siltumizolācijas biokompozīts [162], māla ķieģeļi [163], kompozītmateriāls uz micēlija bāzes [164], poliuretāna putas [165].
Ķimikālijas	Klijas, salmi un miziņa	Silīcijs [166], ūdeņradis [167], organiskās skābes – ferulīnskābe, pienskābe, itakonskābe un fumārskābe [160], [168], fermenti [160], olbaltumvielas [160], zāles un vitamīni [160], kosmētika [160], vienšūnu eļļa [169], antioksidantu un pretmikrobu ekstrakti [170], ksilanāze [171], lignīns [172], mezoporas biogēnās silīcija dioksīda nanodaļiņas [173].

Lai salīdzinātu dažādus produktus un noteiktu optimālo variantu, tika izmantota *TOPSIS* metode. Iegūtais rezultāts ir alternatīvu attālums līdz ideālam punktam. Alternatīva, kura ir vistuvāk ideālajam punktam, ir vislabākā. Pētījuma aprēķini tika veikti *MS Excel*. *MCDA* ir trīs soļi.

1. Ievades dati. Neatkarīgi no izvēlētās *MCDA* metodes ievades dati ir būtiska analīzes daļa, jo visi aprēķini ir balstīti uz tiem. Ir jānosaka kritēriji un alternatīvas [288]. Alternatīvas mūsu pētījumā ir produkti, kurus var iegūt no graudu blakusproduktiem, un kritēriji ir no četrām kategorijām: vides, ekonomiskā, tehniskā un sociālā. Atlasītie seši kritēriji ir parādīti 2.4. tabulā.
2. Kritēriju svars. Kritērijiem ir nepieciešams svērums, kas atspoguļo to nozīmi salīdzinājumā ar citiem kritērijiem. Šajā posmā var izmantot analītiskās hierarhijas procesa metodi. Šajā metodē iegūtos svarus var tālāk izmantot visās *MCDA* metodēs [288]. Konkrētajā gadījumā kritēriju svars tika iegūts, izmantojot jutīguma analīzi. Jutīguma analīzi var veikt, lai izpētītu kritēriju svaru ietekmi uz alternatīvām [289]. Iegūtie svari tiek izmantoti *TOPSIS* aprēķinos, lai iegūtu jutīguma analīzes rezultātus.

Tas tika darīts visiem kritērijiem, un, pamatojoties uz rezultātiem, galīgajai TOPSIS analīzei tika atlasīti kritēriju svērumi.

3. *TOPSIS* metodes aprēķini. *TOPSIS* metode tika izmantota pēc ievades datu un kritēriju svaru noteikšanas.

Tā rezultātā labāko alternatīvu var noteikt, salīdzinot relatīvo tuvumu ideālajam risinājumam.

2.4. tabula

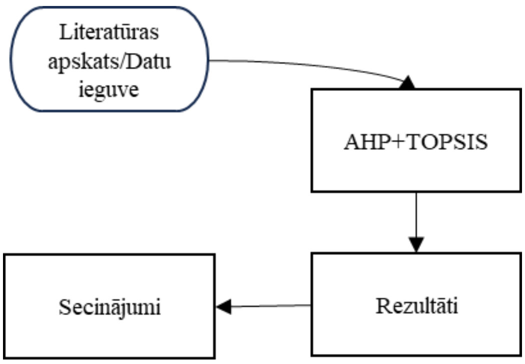
Daudzkritēriju analīzes kritēriji

Kritēriju kategorija	Kritēriji
Vides aspekti	Ilgtspēja — atbilstība 12 ANO ilgtspējas mērķiem (1–5)*
	Ietekme uz vidi – jaunā un esošā produkta ražošanas procesa emisiju salīdzinājums (1–5)*
Ekonomiskie aspekti	Preces cenu salīdzinājums – cenu starpība starp šobrīd lietoto un jauno preci (%)
	Tirgus pieprasījums – pasaules tirgus lieluma novērtējums (1–5)*
Tehniskie aspekti	Tehnoloģiju pieejamība – jaunā produkta ražošanas novērtējums, ņemot vērā tehnoloģiskās gatavības līmeni (TGL) (1–5)*
Sociālie aspekti	Sociālie aspekti – produkta darba vietu radīšanas novērtējums (1–5)*

* Kritērijs tiek vērtēts 5 ballu sistēmā: 1 – neatbilst prasībām; 5 – atbilst prasībām

Bioekonomikas risinājumi. Tehnoloģijas

Pieprasījumu puses pārvaldības metodē tiek izmantota daudzkritēriju lēmumu pieņemšanas analīzes metode AHP un *TOPSIS*.



2.6. att. Bioekonomikas tehnoloģisko risinājumu metode.

Tiek analizēta labākā ekstrakcijas metode, lai iegūtu ēterisko eļļu no augļu atkritumiem, izmantojot daudzkritēriju analīzi.

2.5. tabula

Pārskats par izvēlēto kritēriju

Ekstrakcijas metodes	**Tehniskais aspekts**	**Vides aspekts**	**Ekonomiskais aspekts**	**Avots**
Destilācija ar tvaiku	Nepieciešams konteiners zem spiediena	Mazāk degvielas & Nepieciešama augsta temperatūra	Augsts aprīkojums un ekspluatācijas izmaksas	[174]
Aukstā presēšana	Augstas kvalitātes ražošanas iespēja	Bīstamo organisko šķīdinātāju trūkums un videi draudzīgs	Zemas izmaksas un mazāk nepieciešamā darbaspēka	[175]
Šķīdinātāja ekstrakcija	Vienkāršs aprīkojums, zema efektivitāte	Augsta temperatūra un bīstamo atkritumu ražošana	Zemas izmaksas	[175]
Hidrodestilācija	Vienkārši instrumenti	Liels enerģijas patēriņš, bez organiskā šķīdinātāja	Zemas izmaksas	[176]

Tiek salīdzinātas četru dažādu zaļo ekstrakcijas metožu veiktspēja: tvaika destilācija, aukstā presēšana, ekstrakcija ar šķīdinātāju un hidrodestilāciju. Kritēriji, t.i., tehniskie, vides, ekonomiskie un sociālās pieņemamības, tiek izvēlēti analizējot literatūru. 2.5. tabulā parts detalizēts pārskats par atlasītajiem kritērijiem un apakškritērijiem. Ar šo metodi tiek novērtētas ekstrakcijas metodes, ar kurām var iegūt ēterisko eļļu no augļu atkritumiem. Destilācija ar tvaiku ir atdalīšanas metode, ko var izmantot gaistošo organisko savienojumu atdalīšanai [177]. Iepriekšējie pētījumi liecina, ka 93 % no ēteriskās eļļas īpatsvara var ekstrahēt ar tvaiku, destilējot ar tvaiku [178]. Aukstās presēšanas metode ir standarta metode, ko izmanto, lai iegūtu ēterisko eļļu no augu un augļu sēklām. Arī šo procesu var veikt temperatūrā zem 60 °C [179]. Šķīdinātāja ekstrakcijas metode, kas pazīstama arī kā šķidruma-šķidruma ekstrakcija, ir metode savienojumu atdalīšanai, pamatojoties uz to daļu šķīdību [180]. Hidrodestilācija ir tradicionāla metode, ko izmanto, lai no augiem iegūtu eļļu vai bioaktīvus savienojumus [181]. Kopumā salīdzinoši visām četrām metodēm ir atšķirīga funkcionalitāte un aparāts.

Energoresursu pieprasījumu puses pārvaldība

Gadījuma izpētes pamatā ir pieprasījuma reakcijas un apkopošanas tiesisko un ekonomisko aspektu izpēte un to piemērošana situācijai Latvijā.

Kā atzīmējis J. K. Jufermans [182], ir grūti paredzēt, cik liela daļa no tradicionālās ražošanas spēs palīdzēt nodrošināt elastību nākotnē, jo to var pilnībā balstīt uz politiskiem lēmumiem par to, vai šīs tradicionālās ražošanas vienības turpinās darboties (piemēram, koģenerācijas stacijas).

Lai nodrošinātu elastību, pieprasījuma reakcija nevar balstīties uz neparedzamām patērētāju darbībām, jo tās nav organizētas darbības, bet balstītas uz katra indivīda personīgajām interesēm. Lai nepārprotamu pieprasījuma reakciju organizētu, ir ieviests jauns elektroenerģijas tirgus dalībnieks – agregators. Turklāt direktīvas 2012/27/EU 17. pantā ir precizēts, ka:

1) visiem tirgiem (nākamās dienas, esošās dienas) vajadzētu būt atvērtiem pieprasījumreakcijai, tostarp papildpakalpojumiem (balansēšana, rezerves utt.);

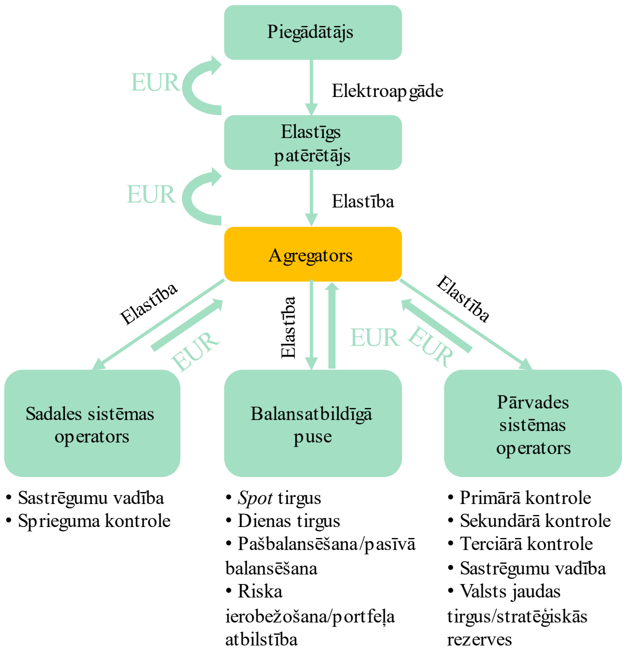
2) no visiem elektroenerģijas uzņēmumiem vai patērētājiem var prasīt izmaksāt kompensāciju tiem tirgus dalībniekiem, kurus tieši ietekmē pieprasījumreakcija;
3) ja kompensācija tiek ieviesta, tā nav šķērslis pieprasījumreakcijai un sedz tikai izmaksas, kas radušās piegādātājiem vai piegādātāja balansatbildīgajai pusei [183].

Ir divu veidu agregatori – neatkarīgi un kombinēti. Kombinētais agregators nozīmē, ka elektroenerģijas piegādātājs vai balansatbildīgā puse, vai sadales sistēmas operators ir arī agregators, tāpēc agregēšana ir jau esoša tirgus dalībnieka papildu funkcija. No otras puses, neatkarīgs agregators ir atsevišķs uzņēmums, kas strādā neatkarīgi no iepriekš minētajiem elektroenerģijas piegādātājiem, balansatbildīgajām pusēm vai sistēmu operatoriem. Pašlaik ES izplatītāks ir apvienotais agregators, jo to ir vieglāk iesaistīt tirgū. Tas ir mazāk sarežģīti ne tikai no likumdošanas viedokļa, bet arī no elektroenerģijas patērētāju viedokļa gadījumos, kad agregators ir patērētāja elektroenerģijas piegādātājs [19].

Tajā pašā laikā autore var apgalvot, ka agregatoru var uzskatīt kā draudu citiem tirgus dalībniekiem, piemēram, elektroenerģijas piegādātājiem. Tas nozīmē, ka pieprasījuma reakciju var uzskatīt par izmaksām mazumtirgotājiem, jo:

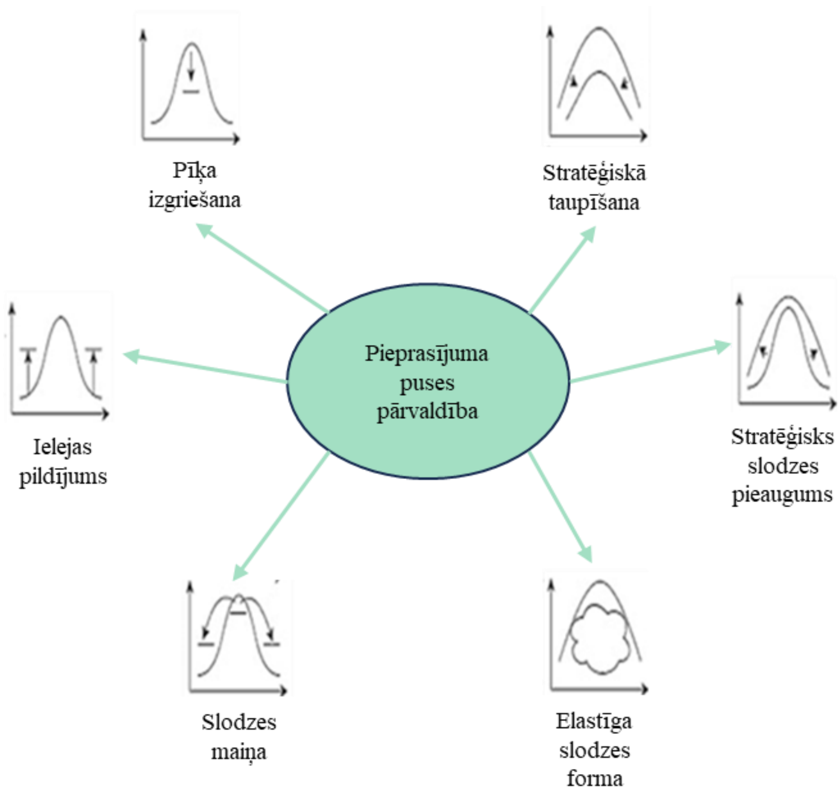
1) elektroenerģijas mazumtirgotāji (balansatbildīgās puses) pērk šo virtuālo elektroenerģiju elektroenerģijas biržas tirgū, ko nodrošina agregatori. Tā nav īsta elektrība, bet gan elektrības ietaupījums konkrētā laikā. Mazumtirgotāji (balansatbildīgās puses) pērk šo elektroenerģiju, lai apmierinātu pieprasījumu, bet viņi nevar par to izrakstīt rēķinu patērētājiem;
2) pieprasījumreakcija veicina elektroenerģijas tirgus fizisku līdzsvarošanu, taču mazumtirgotāji to uzskata par finansiālu nelīdzsvarotību.

2.7. att. atspoguļo visus elastības mehānismus, ko nodrošina agregators dažādos vairumtirdzniecības tirgus segmentos, kur agregators var darboties kā veicinātājs, lai vajadzības gadījumā nodrošinātu elastību [184].



2.7. att. Agregatora sniegtie elastības pakalpojumi [184].

Ir sešas pieprasījuma puses elektroenerģijas patēriņa pārvaldības veidi, kas parādīti 2.8. att. Šie dažādie pieprasījuma pārvaldības veidi, kurus var apvienot kopā, ļauj ļoti cieši saistīties ar ražošanu [185].



2.8. att. Pieprasījuma puses pārvaldības veidi [185].

Pieaugot elektroenerģijas pieprasījumam, tas var aizstāt daļu no ražošanas, kas būs vajadzīga, lai apmierinātu šo nākotnes pieprasījumu. Šie pieprasījuma pārvaldības veidi parāda mums visas iespējas, ko agregators var izmantot – tā ir ne tikai slodzes novirzīšana uz citu periodu, bet arī elektroenerģijas patēriņa samazinājums kopumā, efektīvāk izmantojot patērētāja ierīces un tādējādi sniedzot ieguvumus arī ES klimata politikai un klimata mērķiem. [185].

3. REZULTĀTI UN DISKUSIJA

Šajā nodaļā ir apkopoti iepriekšējā nodaļā aprakstīto metožu rezultāti pielietotos septiņos vides inženierijas izglītības attīstības moduļos. Vides inženierijas ilgtspējīgas attīstības moduļi ir apskatāmi 3. attēlā.

3. att. Promocijas darba aprobētie moduļi

3.1. Ranžēšanas modulis

Ranžēšanas modulis atspoguļo daudzkritēriju lēmumu pieņemšanas analīzes metožu salīdzināšanu un izvēlēšanos par atbilstošāko turpmāk moduļu ieviešanā. Tika sagatavots kopsavilkums par īpašībām, kuras tika izmantotas, un tās ir aprakstītas salīdzinošā veidā 3.1. tabulā.

Šis salīdzinājums tika veikts, lai redzētu līdzības un atšķirības starp metodēm.

3.1. tabula

MCDA metožu kopsavilkums

	TOPSIS	**VIKOR**	**COPRAS**	**MULTIMOORA**	**PROMETHEE-GAIA**	**AHP**
Normalizācijas Veids	Vektoru normalizācija (summas kvadrātsakne (L2 normalizācija)	Lineārā normalizācija (L1 normalizācija)	Vektoru normalizācija (summa)	Vektoru normalizācija (summas kvadrātsakne)	Normalizācija tiek veikta automātiski	Vektoru normalizācija (summa)
Piemērotība	Izvēles problēmas, ranžēšanas problēmas	Izvēles problēmas, ranžēšanas problēmas	Izvēles problēmas, ranžēšanas problēmas	Izvēles problēmas, ranžēšanas problēmas	Izvēles problēmas, ranžēšanas problēmas, apraksta problēmas (*GAIA*)	Izvēles problēmas, ranžēšanas problēmas, kārtošanas problēmas (*AHPsort*)
Ievaddati	Ideāls un anti-ideāls izvēles svars	Labākie un sliktākie variantu svari	Labākie un sliktākie variantu svari	Labākie un sliktākie variantu svari	Indifference un preferenču sliekšņu svari	Pāra salīdzinājums attiecību skalā (1–9)
Rezultāti	Pilnīgs rangs ar tuvuma punktu skaitu ideālam un attālumu līdz anti-ideālam	Pilnīga ranžēšana ar tuvuma punktu skaitu labākajam variantam	Pilnīga ranžēšana	Pilnīga ranžēšana	Daļēja un pilnīga ranžēšana (pāra pārsvara grādi)	Pilnīga ranžēšana ar rezultātiem
Preferenču Funkcija	Attāluma metrika (Eiklīda attālums, Manhetenas attālums, Čebiševa attālums)	Attāluma metrika (Manhetenas attālums)	Min Max	Min Max	Parastā, lineārā, U-veida, V-forma, Līmenis, Gausa	
Pieeja	Kvalitatīvs un/vai kvantitatīvs	Kvantitatīvs	Kvantitatīvs	Kvantitatīvs	Kvalitatīvs un/vai kvantitatīvs	Kvalitatīvs
Ranžēšanas skala	0 līdz 1	Pozitīvas vērtības	Pozitīvas vērtības	Pozitīvas vērtības	−1 līdz 1	0 līdz 1
Labākā alternatīva	Maksimālā vērtība	Min vērtība	Max vērtība	Max vērtība	Max vērtība	Max vērtība
Konsistences līmeņi	bez ierobežojumiem	bez ierobežojumiem	bez ierobežojumiem	bez ierobežojumiem	7±2	9
Programmatūra	*MS Excel, Matlab, Decerns*	MS Excel	MS Excel	MS Excel	*Visual Promethee, Decision Lab, D-Sight, Smart Picker Pro*	*MS Excel, MakeItRational, ExpertChoice, Decision Lens, HIPRE 3+, RightChoiceDSS, Criterium, EasyMind, Questfox,ChoiceResults, 123AHP, DECERNS*

Metožu salīdzināšanai kā ievaddati – kritēriji ar vērtībām un alternatīvām – tika ņemti no "Atjaunojamo energoresursu tehnoloģiju progress: inovāciju potenciāls Latvijā" [186], un tie parādīti 3.1. tabulā. Šie dati tika izmantoti, lai atrastu labāko alternatīvu atjaunojamās enerģijas ražošanai. Katrā metodē dati ir vissvarīgākais elements, lai sarindotu alternatīvas, jo šīs vērtības tika izmantotas aprēķinos.

3.1. tabula

Ievaddati

Kritēriji		Alternatīvas			
		Saules fotoelementi	**VP**	**HES**	**Bioenerģijas koģenerācija**
C1	Uzstādītā elektriskā jauda, MW	1	77	1565	**155**
C2	Ieguldījumu izmaksas, €/kW	1238	3565	1388	**1113,5**
C3	Ekspluatācijas un uzturēšanas izmaksas, €/kW	12,37	26,7	2,67	**0,00446**
C4	AER iekārtu cenas pēc ražotāja, €/kW	430	1380	1290	**3787,5**
C5	Izlīdzinātās elektroenerģijas izmaksas, €/kW	0,08	0,06	0,09	**0,075**
C6	Aprites cikla CO_2 emisijas, gCO_2 ekv/kWh	200	150	150	**200**
C7	**Darbvietu radīšana, tūkstošos**	**3095**	**1155**	**865**	**528**

Dati par uzstādīto elektrisko jaudu (C1) parāda elektrostaciju maksimālo neto ražošanas jaudu Latvijā un ņemti no *IRENA* ziņojuma par atjaunojamās jaudas statistiku [187]. Dati par ieguldījumu izmaksām (C2) ir no *IRENA* ziņojuma par atjaunojamās enerģijas ražošanas izmaksām [188]**,**un tie ir atkarīgi no alternatīvās jaudas un kritērijiem, elektroenerģijas izmaksu līmeņa (C5) datiem, kas ir vidējās vērtības katrai alternatīvai Eiropā. Ekspluatācijas un uzturēšanas izmaksu (C3) un AER iekārtu cenu kritēriju dati pēc ražotāja (C4) ir iegūti no *IRENA* ziņojuma par atjaunojamās enerģijas ražošanas izmaksām [188] un no *Energy Outlook* [189], un tie attiecas uz Eiropu. Dzīves cikla CO_2 emisiju (C6) dati ir par Eiropu, un tie ir no Eiropas Vides aģentūras (EVA) ziņojuma par atjaunojamo enerģiju Eiropā – 2017 [190] un Pasaules kodolenerģijas asociācijas ziņojuma datiem [191]. Darbavietu radīšanas (C7) kritēriju dati ir no *IRENA* pārskata par atjaunojamo enerģiju un nodarbinātību [192], un tie attiecas uz alternatīvām Eiropā.

Ar AHP metodi tiek salīdzināti kritēriju pāri, novērtējot kritērija nozīmīgumu pār otru kritēriju, un rezultāti ir parādīti 3.1. attēlā. Pāru salīdzinājumā 1. vērtība norāda, ka abi kritēriji ir vienlīdz svarīgi, vērtība 5 norāda, ka viens kritērijs ir ļoti svarīgs salīdzinājumā ar citiem kritērijiem, un 9. vērtība norāda, ka viens kritērijs ir vissvarīgākais par citiem kritērijiem. Pretējiem kritērijiem salīdzināšanas vērtības ir proporcionāli pretējas. Šo pāra salīdzinājumu veica trīs vides zinātnes jomas eksperti.

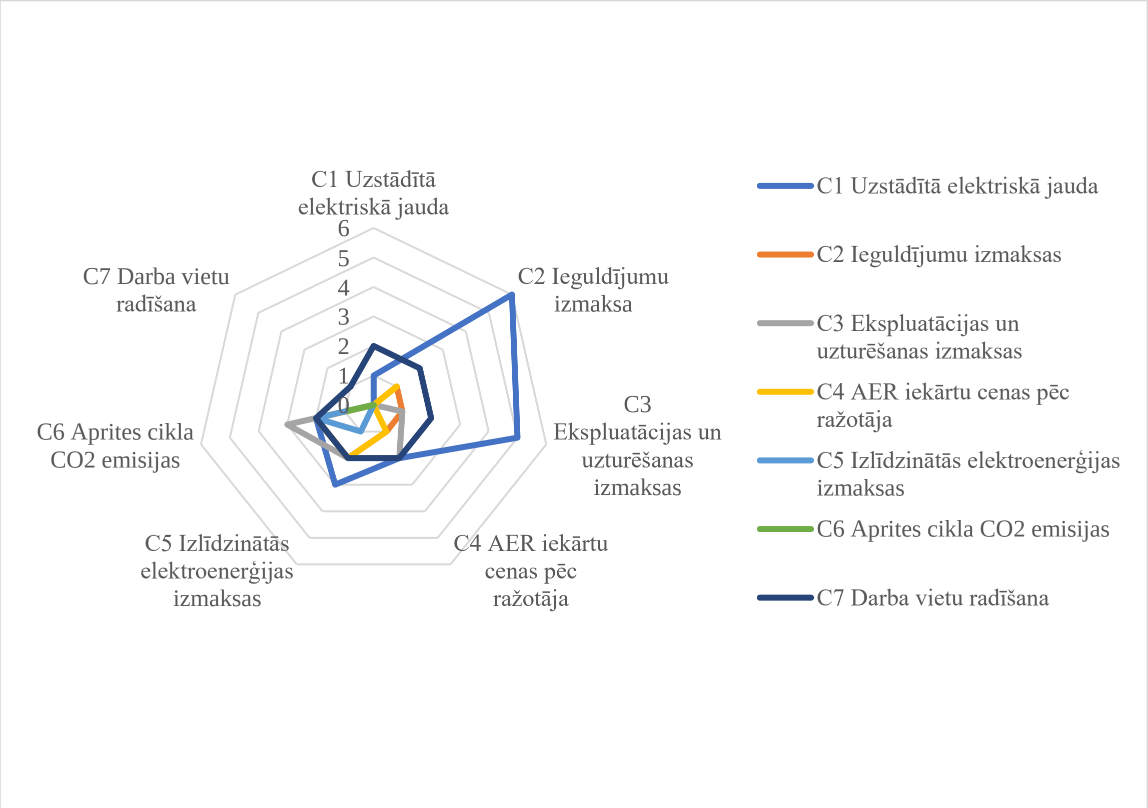
Pēc aprēķina un kritēriju svēršanas ļoti svarīgi ir pārbaudīt, vai $\sum Wij = 1$ un konsekvences vērtības šim AHP konsistences indeksam (CI) ir 0,127, un konsekvences attiecība (CR) ir 0,097. Ja CR > 10 %, tad pāra salīdzinājumi ir nekonsekventi [224].

3.2. attēlā ir redzami visi kritēriji un to svērumi. Vissvarīgākais kritērijs ir uzstādītā elektriskā jauda ar svaru 27 %, un nākamais ir darbavietu radīšanas kritērijs ar 22 % svaru. Vismazākā ietekme uz alternatīvām ir kritērijiem par elektroenerģijas izlīdzinātajām izmaksām un aprites cikla CO_2 emisijām.

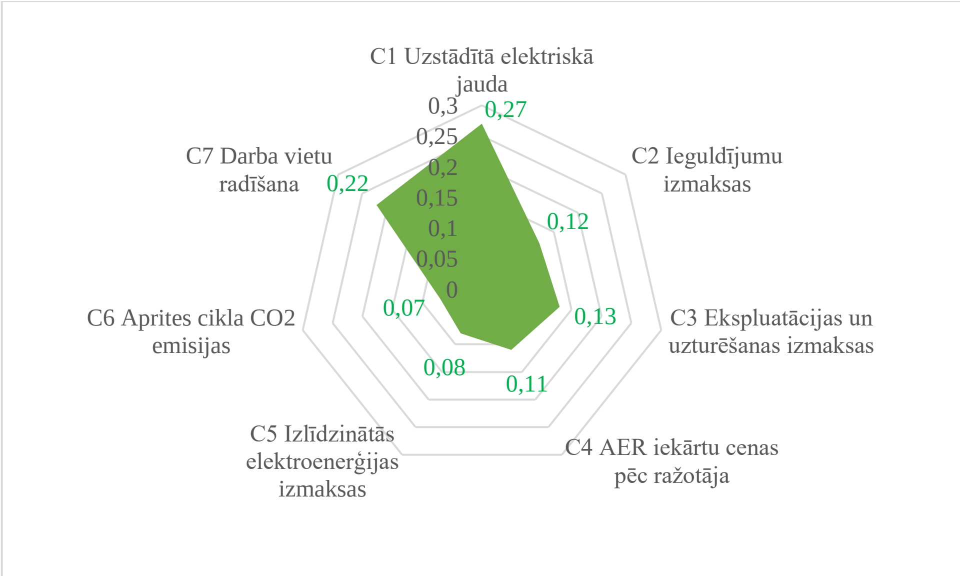
TOPSIS metodē svarīga vērtība ir alternatīvais tuvuma indikators, kas ir alternatīvās vērtības galīgā vērtība un ir 3.3. a) attēlā. Pamatojoties uz *TOPSIS* metodes rezultātiem, vislabākā alternatīva ir hidroelektrostacija (HES), kam seko biomasas un biogāzes koģenerācijas stacija (bioenerģijas koģenerācija). Ar *VIKOR* metodi vislabākā alternatīva ir tā, kurai ir minimāla vērtība. Šīs metodes rezultāti ir parādīti 3.3. b) attēlā, un vislabākā alternatīva ir hidroelektrostacija (HES), tad saules fotoelementu enerģija.

Lai salīdzinātu *VIKOR* un citas metodes, ir svarīgi atcerēties, ka šajā metodē svarīgs solis ir samazināt visus kritērijus, lai veiktu salīdzinājumus.

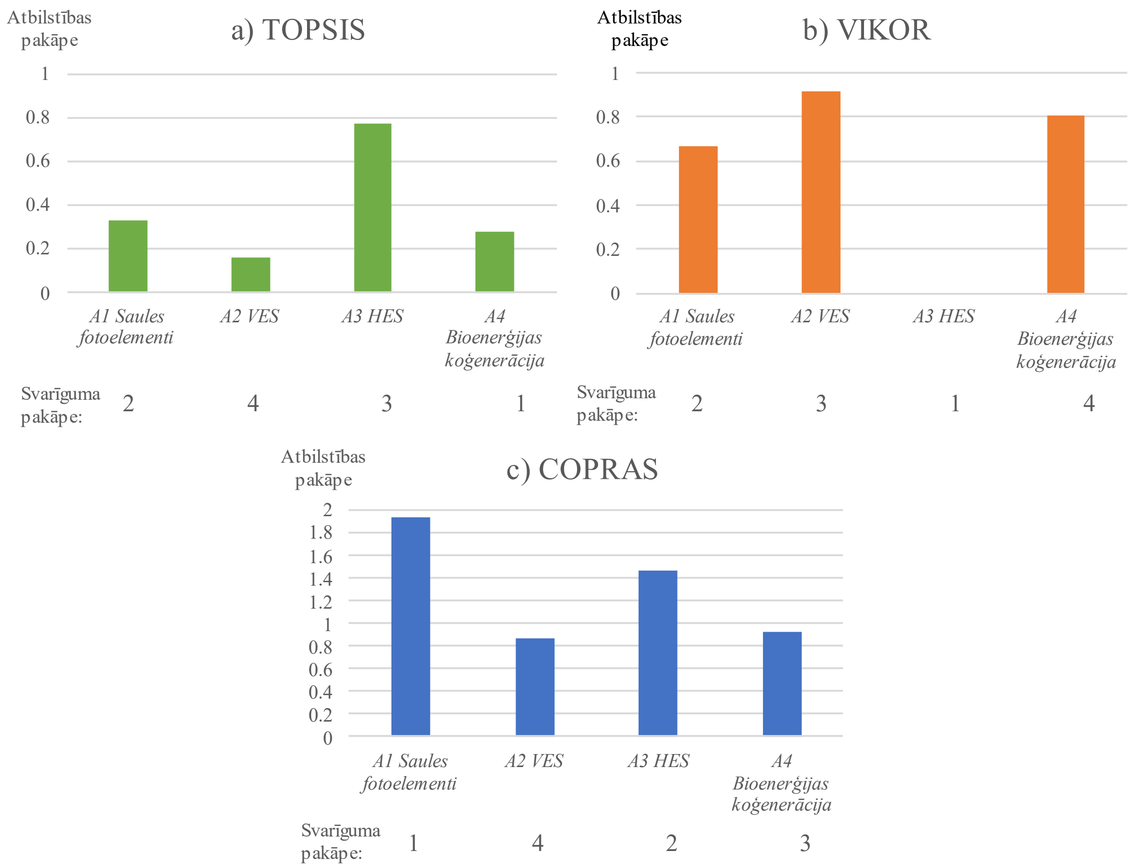
COPRAS metode ir vienkārša, un vislielākā ietekme uz vislabāko alternatīvu ir kritērijiem, svara un indeksa vērtībām. Pamatojoties uz šo metodi, vislabākā alternatīva ir saules fotoelementi (saules fotoelementu enerģija) un hidroelektrostacija (HES). Alternatīvu vērtības ir parādītas 3.3. c) attēlā. Vislabākā alternatīva šajā metodē ir saules fotoelementu enerģija, un vissliktākā alternatīva ir vēja elektrostacijas (VES). Abām alternatīvām ir lielas atšķirības to galīgajās vērtībās, un tas varētu būt saistīts ar katra kritērija alternatīvajām vērtībām.



3.1. att. Kritēriju pāru salīdzinājumam.

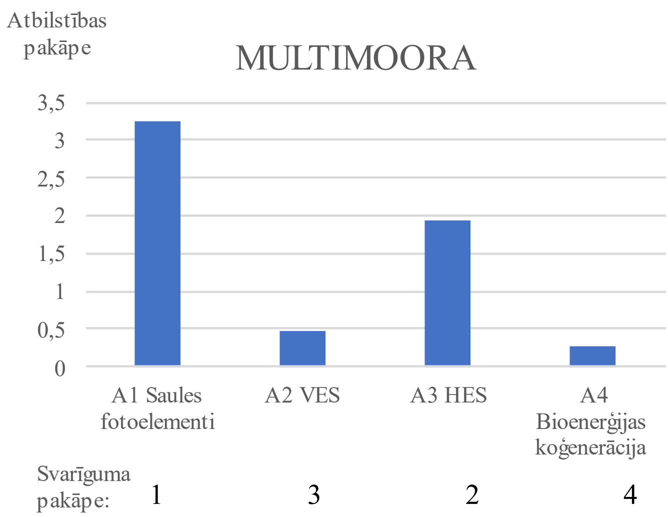


3.2.att. Kritēriju vērtības un svari.



3.3. att. a) *TOPSIS,* b) *VIKOR* un c) *COPRAS* rezultāti un rangs.

MULTIMOORA metodes rezultāti ir parādīti 3.4. attēlā, un vislabākā alternatīva ir saules fotoelementu (saules fotoelementu enerģija) un hidroelektrostacija (HES). Gala vērtībām ir liels diapazons. Tas ir tāpēc, ka galīgās vērtības tiek aprēķinātas no starpības starp minimālajām un maksimālajām vērtībām.



3.4.att. *MULTIMOORA* rezultāti un rangs.

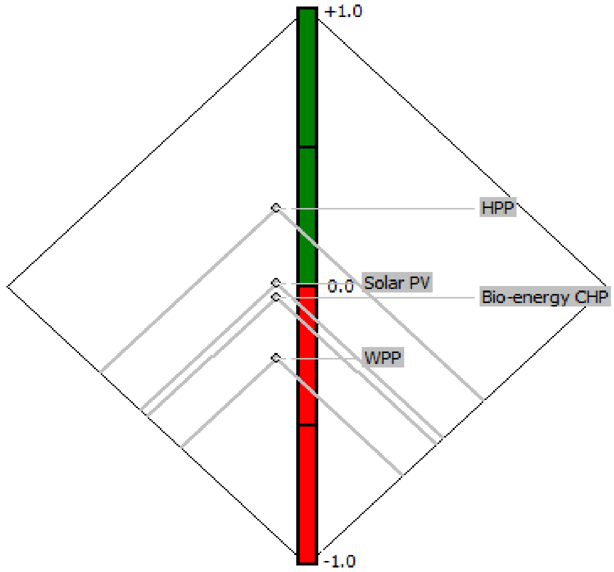
3.2. tabula satur *PROMETHEE-GAIA* metodes rezultātus. Pilnīga ranžēšana ir balstīta uz neto preferenču plūsmu (Phi), kas ir līdzsvars starp pozitīvo preferenču plūsmu (Phi+), kas mēra stiprumu, un negatīvo preferenču plūsmu (Phi−), kas apzīmē vājumu. Šajā gadījumā preferenču funkcija ir lineāra un sliekšņi ir absolūti. Izmantojot šo metodi, vislabākā alternatīva ir hidroelektrostacija (HES) un saules fotoelementi.

3.2. tabula

Pilnīga svarīguma pakāpe

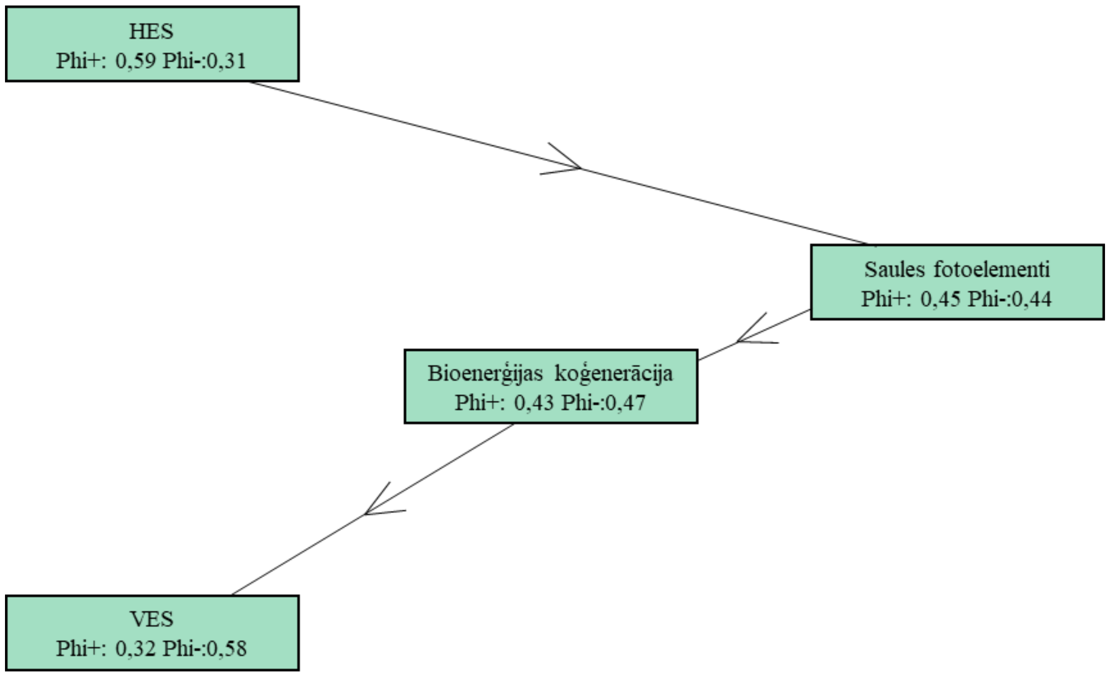
	A1	A2	A3	A4
	Saules fotoelementi	VES	HES	Bioenerģijas koģenerācija
Phi	0,0100	−0,2567	0,2833	−0,0367
Phi+	0,4533	0,3200	0,5900	0,4300
Phi−	0,4433	0,5767	0,3067	0,4667

PROMETHEE klasifikācijas rezultātus var parādīt kā *PROMETHEE Diamond* 3.5. attēlā. *PROMETHEE Diamond* katrai alternatīvai ir punkts uz (Phi+, Phi−) plaknes, un vertikālā dimensija (zaļa-sarkana ass) atbilst Phi neto plūsmai, kas ir līdzsvara punkts [193].



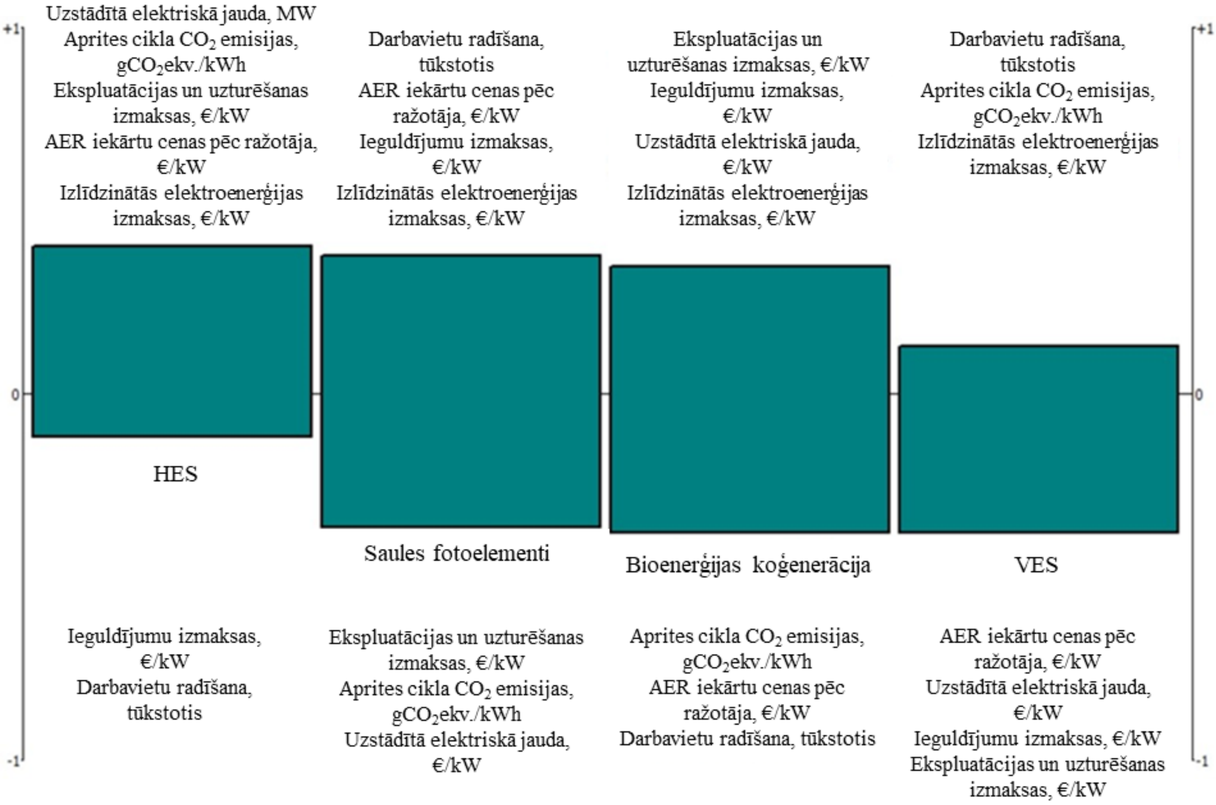
3.5.att. *PROMETHEE Diamond* rezultāti

3.6. attēls ilustrē *PROMETHEE* tīklu un parāda, kura alternatīva ir labāka, un palīdz salīdzināt alternatīvas. Tīkla attēlojums ir kā Dimanta skata tuvplāns, kurā tiek parādīti attālumi starp alternatīvām [137].



3.6. att. *PROMETHEE* tīkls

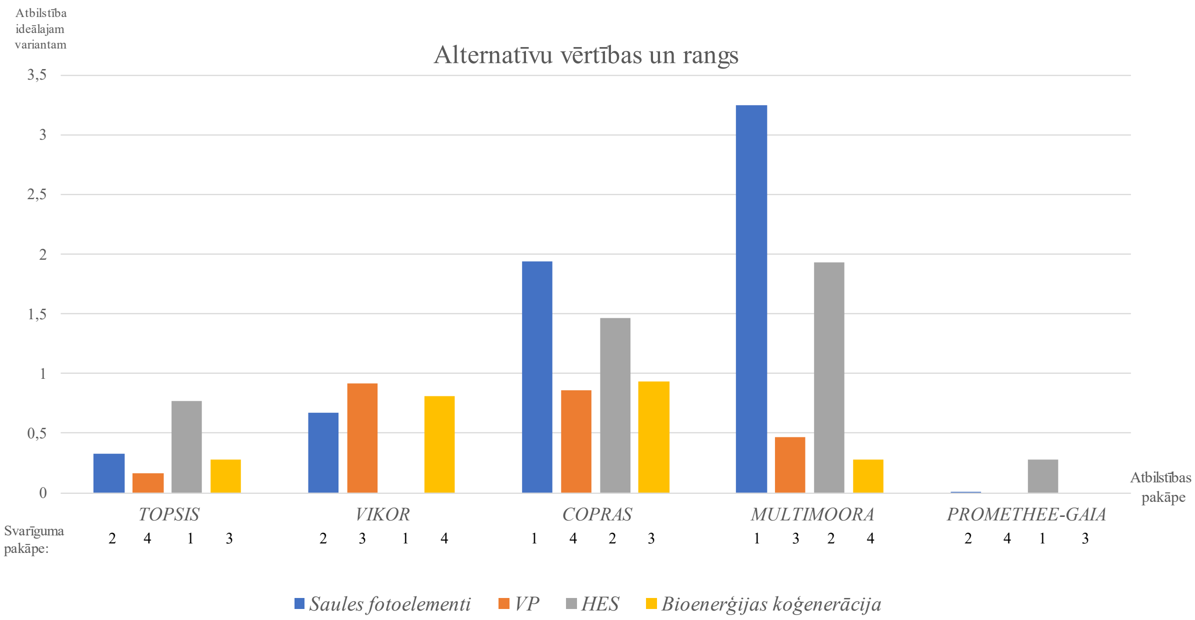
PROMETHEE rezultāti ir parādīta 3.7.attēlā, kur attēlots katras alternatīvas stiprais un vājais kritērijs. Pozitīvās (augšupejošās) bloki ir kritēriji, kas pozitīvi ietekmē alternatīvo, un negatīvās (lejupvērstās) bloki ir kritēriji, kas negatīvi ietekmē alternatīvu [193].



3.7. att. *PROMETHEE* rezultāti

Hidroelektrostacijas (HES) alternatīvai vājākie kritēriji rodas no investīciju izmaksām un darbavietu radīšanas, bet pēc šīs metodes tā ir labākā alternatīva. Vēja elektrostacijām, kas ir vissliktākā alternatīva, ir tikai trīs labi kritēriji: – darbvietu radīšana, aprites cikla CO_2 emisijas un izlīdzinātās elektroenerģijas izmaksas.

Pēc piecām daudzkritēriju lēmumu analīzēm – *TOPSIS*, *VIKOR*, *MULTIMOORA*, COPRAS un *PROMETHEE-GAIA* – 3.8. attēls sniedz kopsavilkumu par visām katras alternatīvas galīgajām vērtībām. *TOPSIS*, *VIKOR* un *PROMETHEE-GAIA* metodēm labākā alternatīva ir hidroelektrostacija (HES) un pēc pārējām divām metodēm HES ir ierindota otrajā vietā. Savukārt *COPRAS* un *MULTIMOORA* metodē vislabākā alternatīva ir saules fotoelementi (*Solar PV*). Vislielākā ietekme uz galarezultātiem ir kritērijiem, svariem un metodēm, vislabākās alternatīvas definīcijas – tuvuma ideālajam attālumam, labākā varianta tuvuma rādītāja, pāra pārsvara vai ranžēšanas ar punktiem. Svarīgs rādītājs ir arī kritēriju labākā vērtība – minimālā vai maksimālā.



3.8. att. Alternatīvas vērtības un svarīguma pakāpe.

MCDA metožu rezultāti ir atspoguļoti 3.8. attēlā, un tie tiek vērtēti no labākās līdz sliktākajai alternatīvai. Pēc tam, kad šis rezultāts ir parādīts diagrammā, ir vieglāk redzēt tendenci, pēc kuras alternatīvas tiek ierindotas augstāk nekā citas. Vislabākā alternatīva būtu hidroelektrostacija (HES) un pēc tam saules fotoelementi (saules fotoelementi), jo šīs alternatīvas ir pirmajā vai otrajā vietā salīdzinājumā ar lielāko daļu citu alternatīvu. Zemākais rangs ir vēja elektrostaciju (VES) alternatīvai, jo trīs no piecām metodēm tā ir pēdējā vietā.

3.2. Inovatīvs studiju procesa modulis

Studiju programmu vērtēšanas metode tiek izmantota vides inženierijas un bioekonomikas studiju programmu analizēšanai.

Vides inženierijas studiju modulis

Vides inženierijas studiju moduļa ietvarā sākotnēji tika apkopotas maģistra studiju programmas. Kā ģeogrāfiskā atrašanās vieta tika norādīta Eiropa. Tā izvēlēta, jo dažādām reģiona universitātēm ir līdzīgas izglītības sistēmas. Tika analizēta labā prakse energoefektivitātes jomā, tādēļ tika pētītas akadēmiskās iestādes ar izcilu sniegumu. Studiju programmu atlasei tika izmantotas reitingu vietnes [194], [195]. Kopumā tika analizētas 110 studiju programmas, bet vērtēšanai tika izvēlētas 35 studiju programmas. Izvēlētās daudznozaru maģistra studiju programmas ietver maģistra programmas tādās jomās kā Vides inženierija (22 studiju programmas), Ūdens un atkritumu apsaimniekošana (trīs studiju programmas), Vides tehnoloģijas (divas studiju programmas), Vides zinātne (divas studiju programmas), Zemes plānošanas inženierija, Projektu vadība, Bioloģiskā inženierija, Enerģētika un Bioekonomika (skatīt 3.3. tabulu). Lai varētu izmantot labāko praksi, tika pārbaudītas maģistra programmas, kurām ir augsti rezultāti QS (*Quacquarelli Symonds*) globālajā pasaules rangā. 10 no analizētajām studiju programmām ir ierindotas top 100, 12 no 100 līdz 200, trīs no 200 līdz 300, sešas no 300 līdz 400, divas no 400 līdz 500 un divas no 500 līdz 600. Studiju ilgums ir viens (13 no 35 studiju programmām), pusotrs (divas studiju programmas) vai divi (20 studiju programmas) pilna laika gadi.

3.3. tabula

Multidisciplinārās studiju programmas vides inženierijā

Universitāte	**Maģistra programma**	**Rangs**	**Gadi**
ETH Zurich	Vides inženierija	3	2
Delftas Tehnoloģiju universitāte	Vides inženierija	16	2
Dānijas Tehniskā universitāte	Vides inženierija	45	2
TUM – Minhenes Tehniskā universitāte	Vides inženierija	61	2
Notingemas Universitāte	Vides inženierija	82	1
Dublinas Trīsvienības koledža	Vides inženierija	104	1
Ālto Universitāte	Vides inženierija	140	2
Ņūkāslas Universitāte	Vides inženierija	141	2
Barselonas Universitāte	Vides inženierija	166	1
Boloņas Universitāte	Vides inženierija	180	2
Karalienes Universitāte Belfāstā	Vides inženierija	180	1
Kranfīldas universitāte	Vides inženierija	251–300	1
Štutgartes Universitāte	Vides inženierija	260	2
Katalonijas Politehniskā universitāte	Vides inženierija	275	2
Valensijas Politehniskā universitāte	Vides inženierija	310	1
Čehijas Tehniskā universitāte Prāgā	Vides inženierija	317	2
Porto Universitāte	Vides inženierija	328	1
Lisabonas Universitāte	Vides inženierija	355	2
Norvēģijas Zinātnes un tehnoloģiju universitāte	Vides inženierija	363	2
Madrides Politehniskā universitāte	Vides inženierija	470	1
Brēmenes Universitāte	Vides inženierija	511–520	1.5
Santjago de Kompostelas Universitāte	Vides inženierija	581–590	1.5
KTH Karaliskais tehnoloģiju institūts	Vides inženierija un ilgtspējīga infrastruktūra	104	2
Gentes Universitāte	Vides tehnoloģija un inženierija	138	2
Vīnes Dabas resursu un lietišķo dzīvības zinātņu universitāte	Ūdenssaimniecība un vides inženierija	151–200	2
Milānas Politehniskā universitāte	Vides un zemes plānošanas inženierija	156	2
Barselonas autonomā universitāte	Bioloģiskā un vides inženierija	193	1
Dublinas Universitātes koledža	Ūdens, atkritumu un vides inženierija	193	1
Olborgas Universitāte	Ūdens un vides inženierija	343	2
Hohenheimas Universitāte	Bioekonomika	495	2

Esošo studiju programmu novērtēšanai tika izmantota informācija par studiju kursiem, mācību metodēm, vērtēšanas metodēm un kompetencēm. Pamatojoties uz šo informāciju, tika izvēlēts kompetenču, rādītāju, prasmju, vērtēšanas metožu, zināšanu un mācību metožu kopums Vides inženierijas maģistra studiju programmu novērtēšanai.

Vides inženierijas programmas rādītāju noteikšanai tika analizēti zinātniskajos žurnālos publicēto esošo pētījumu rādītāji vides izglītības programmu kartēšanai augstākajā izglītībā.

Pētījuma laikā pieci rādītāji tika atzīti par piemērotiem vides inženierijas studiju programmu novērtēšanai:

1) multidisciplināra pieeja;
2) sadarbība ar citām institūcijām;
3) iekšējais process;
4) izglītība un pētniecība;
5) simulācijas darbības [110].

Multidisciplinārai pieejai ir ļoti liela nozīme vides inženierijā, jo studiju programmas ietvaros studentiem ir jārisina sarežģītas problēmas ar dažādu ieinteresēto pušu interesēm, un mijiedarbojoties starp dažādām interesēm. Starpdisciplinārie pētījumi tiek augstu novērtēti vadošajās universitātēs un palīdz studentiem attīstīt kritisko domāšanu un radošumu [196], [197]. Tajā pašā laikā ir jāņem vērā līdzsvars starp multidisciplinaritāti un starpdisciplinaritāti un dziļām zināšanām par dažādiem kursiem [198].

Sadarbību ar citām institūcijām var organizēt, izmantojot pētījumus, projektus un kopīgas (kopīgas vai dubultas) studiju programmas. Sadarbība ļauj dalīties zināšanās, pieredzē un spējās [40], [199]. Daudzas universitātes piedāvā kopīgas studiju programmas vides inženierijā, piemēram, Ziemeļvalstu maģistra studijas vides inženierijā sadarbībā ar Ālto universitāti, KTH Karalisko tehnoloģiju institūtu, Dānijas Tehnisko universitāti, Norvēģijas Zinātnes un tehnoloģijas universitāti un Čalmersa Tehnoloģiju universitāti, veidojot viena reģiona piecu universitāšu sadarbību. Vēl viens piemērs ir sadarbība starp Valensijas Universitāti un Valensijas Politehnisko universitāti, kur tiek piedāvāts kopīgs maģistra grāds vides inženierijā.

Var ieviest iekšēju procesu, pieņemot vides pārvaldības stratēģijas, nodrošinot un izprotot vides jautājumus un ilgtspējīgu attīstību universitātēs [200].

Izglītība un pētniecība ir augstākās izglītības iestāžu pamats, tāpēc būtu jāanalizē pētījumu rezultāti.

Simulācijas aktivitātes un praktiskās mācības ļauj sasniegt labākos rezultātus studiju programmās, ļaujot dienaskārtībā ieviest kompetencēs balstītu izglītību.

Šie pieci rādītāji (daudzdisciplīnu pieeja, sadarbība ar citām iestādēm, iekšējais process, izglītība, pētniecība un simulācijas darbības) var palīdzēt novērtēt, vai ir sasniegta zināšanu triāde: izglītība, inovācija un pētniecība, kā arī kompetencēs balstīta izglītība.

Eiropas Inženieru izglītības akreditācijas tīkls (*EUR-ACE*) ir ietvars un akreditācijas sistēma, kas nodrošina standartu kopumu inženierzinātņu grādu programmām Eiropā un ārpus tās. Vides inženierijas maģistra studiju programmu mācīšanās rezultātu kopas ir parādītas 3.4. tabulā.

3.4. tabula

Mācīšanās rezultāti EUR-ACE robežās [201]

Jomas	**Mācīšanās rezultāti**
Zināšanas un izpratne	Zināšanas un izpratne par zinātniskajiem un matemātiskajiem principiem, kas ir to inženierzinātņu nozares pamatā
	Sistemātiska izpratne par to inženierzinātņu nozares galvenajiem aspektiem un jēdzieniem
	Saskaņotas zināšanas par viņu inženierzinātņu nozari, tostarp dažas no tām ir filiāles priekšgalā
	Izpratne par inženierzinātņu plašāku daudznozaru kontekstu
Inženiertehniskā analīze	Spēja pielietot savas zināšanas un izpratni, lai identificētu, formulētu un risinātu inženiertehniskās problēmas, izmantojot izveidotās metodes
	Spēja lietot savas zināšanas un izpratni, lai analizētu inženiertehniskos produktus, procesus un metodes
	Spēja izvēlēties un lietot atbilstošas analītiskās un modelēšanas metodes
Inženierdizains vai tehniskais risinājums	Spēja lietot savas zināšanas un izpratni, lai izstrādātu un realizētu dizainus, kas atbilst definētajām un noteiktajām prasībām
	Izpratne par projektēšanas metodiku un prasme tās izmantot
Izpēte	Spēja veikt literatūras meklēšanu un izmantot datubāzes un citus informācijas avotus
	Spēja plānot un veikt atbilstošus eksperimentus, interpretēt datus un zīmēt mācīšanās prasmju darbnīcu un laboratorijas prasmes
	Seminārs un laboratorijas prasmes
Inženiertehniskā prakse	Spēja izvēlēties un izmantot atbilstošu aprīkojumu, instrumentus un metodes
	Spēja apvienot teoriju un praksi, lai atrisinātu inženiertehniskās problēmas
	Izpratne par piemērojamiem paņēmieniem un metodēm un to ierobežojumiem
	Izpratne par inženiertehniskās prakses netehniskajām sekām
Tālāk nododamas prasmes	Efektīvi darboties kā indivīdam un kā komandas loceklim
	Izmantojiet dažādas metodes, lai efektīvi sazinātos ar inženieru kopienu un sabiedrību kopumā
	Demonstrēt izpratni par inženiertehniskās prakses veselības, drošības un juridiskajiem jautājumiem un atbildību, inženiertehnisko risinājumu ietekmi sabiedrības un vides kontekstā, kā arī ievērot inženierprakses profesionālo ētiku, atbildību un normas
	Demonstrēt izpratni par projektu vadību un uzņēmējdarbības praksi, piemēram, risku un izmaiņu pārvaldību, un izprotiet to ierobežojumus

Galvenās kompetences, kas jāsasniedz studiju beigās, var iedalīt četrās kategorijās:

1) ar tēmu saistītās kompetences;

2) zinātniskās un metodoloģiskās kompetences;

3) sociālās kompetences;

4) personīgās kompetences [6].

Pakāpei, kādā studentiem jāsasniedz attiecīgās zināšanas studiju programmas beigās, jāatbilst paplašināšanas līmenim (sk. 3.5. tabulu). Studiju programmas noslēgumā studentiem jāsasniedz noteikti kognitīvie aspekti, piemēram, a) jātestē specifiski pētniecības jautājumi un b) jāsniedz ieguldījums pētniecībā un praktiskie aspekti, kā arī a) jāizstrādā noteiktas metodes un b) jāpārbauda noteiktas metodes.

Lai sasniegtu šos kompetenču un zināšanu līmeņus, var izmantot dažādas mācību metodes. Lai novērtētu, kuras mācību metodes ir piemērotākas vides inženierijas studijām, tika izmantota *MCDA*.

3.5. tabula

Kompetenču līmeņi

0. līmenis	1. līmenis	2. līmenis	3. līmenis	4. līmenis	5. līmenis	6. līmenis
Nav zināšanu	Slieksnis	Pamats	Starpsavienojumu	Kontekstualizācija	Paplašināšanas	Paaudze

Studentu, ieinteresēto pušu un sabiedrības interese par multidisciplinārajām maģistra programmām noveda pie lēmuma īstenot jaunas maģistra studiju programmas vides inženierijā un bioekonomikā Rīgas Tehniskās universitātes Vides aizsardzības un siltuma sistēmu institūtā. Vides inženierijas studiju programmu novērtēšanai ir izstrādāta *MCDA* ietvara izmantošana studiju programmu novērtēšanai un vides inženierijas studiju programmu efektivitātes un atbilstības novērtēšanai.

Tika analizēta iepriekš minēto augstskolu pieredze studiju programmu organizēšanā. Tika atzītas trīspadsmit mācību metodes, kas ir piemērotas, lai sasniegtu labākos rezultātus studiju procesā un nodrošinātu kompetencēs balstītu vides inženierijas izglītību maģistra studiju līmenim: anonīma atgriezeniskās saites vērtēšana, vienota e-mācību sistēma (tiešsaiste), apsekojuma datu vākšana, grupu kursa darbi, grupu uzdevumi, individuāls pētniecības projekts, lekcijas, tiešsaistes uzdevumi un kursa darbi, praktiskas laboratorijas, semināri un darbnīcas, objektu apmeklējumi, konsultācijas un lomu spēles.

Šīs mācību metodes ir izmantotas pamatstudiju un augstākās studiju programmās studiju procesā Rīgas Tehniskajā universitātes Vides aizsardzības un siltuma sistēmu institūtā (RTU VASSI).

Izglītības nolūkos izvēlētās mācību metodes būtiski ietekmē studiju procesa efektivitāti [5], [48], [120], [138], [202] un iegūtās prasmes.

Anonīma atgriezeniskās saites izvērtēšana, kā arī tiešā atgriezeniskā saite [309] no studentiem var būt noderīga un efektīva metode studiju procesa pilnveidošanai, īpaši kompetencēs balstītai izglītībai, kur studenti var formulēt savas studiju vajadzības un gūt labākus rezultātus studiju procesā.

Rīgas Tehniskajā universitātē vienota e-mācību sistēma (iekštīkls) ir ORTUS. Daudzfunkcionāla augstākās izglītības iestādes vietne ir būtiska kompetencēs balstītai izglītībai. Ja šādu sistēmu izmanto visaptveroši, tā var būtiski uzlabot studentu elastību un palīdzēt attīstīt radošo domāšanu [203], [204].

Grupu darbs tiek organizēts kursa darba vai grupu vingrinājumu veidā, izprot komandas darbu, stimulē multidisciplināru koncepciju u. c. [205].

Objektu apmeklējumi un datu vākšana, semināri un darbnīcas, kā arī laboratorijas darbi ļauj mācību procesā iepazīstināt ar kompetencēs balstītas izglītības iezīmēm un koncepcijām. Lekcijas un konsultācijas kopā ar individuāliem pētniecības projektiem ir jebkura augstākās izglītības procesa neatņemama sastāvdaļa, bet ne vienīgā. Lekcijas un konsultācijas ir tikai daļa no mācību metodēm, kuras būtu jāizmanto studiju procesā.

Lomu spēļu simulācijas attīsta pamata konkurētspēju vides inženierijas studiju programmas studentiem un kopumā tiek uzskatītas par bagātu un autentisku mācību vidi [205]. Šo mācību metožu kombinācija var palīdzēt mainīt ceļu no mācīšanas uz mācīšanos un nodrošināt KBI principus studiju procesā.

MCDA tika izstrādāti četri rādītāji, lai analizētu šādus konkurences rādītājus: inženiertehniskās prasmes, nododamās prasmes, vides aizsardzības prasmes un sociālekonomiskās prasmes. *MCDA* mērķis bija novērtēt, kuras mācību metodes ir piemērotākas un kādās proporcijās, lai uzlabotu vides inženierijas maģistra studiju programmas absolventu konkurētspēju. Šie rādītāji tika izstrādāti, izvērtējot literatūru un apkopojot nozares akadēmiskā personāla vērtējumu. *MCDA* izmantotie rādītāji mācību metožu novērtēšanai ir parādīti 3.6. tabulā.

3.6.tabula

Mācību metožu vērtēšanā izmantotie rādītāji

Indikators	**Vienība**	**Vēlamais iznākums**
Inženiertehniskās prasmes	Kompetences līmenis	Max
Tālāk nododamas prasmes	Kompetences līmenis	Max
Vides aizsardzības prasmes	Kompetences līmenis	Max
Sociālekonomiskās prasmes	Kompetences līmenis	Max

Pētījuma laikā tika izvērtētas un salīdzinātas trīspadsmit mācību metodes, lai atrastu efektīvākās metodes labāko rezultātu sasniegšanai studiju procesā (3.7. tabula).

3.7. tabula

Mācību metožu apzīmējums

Apzīmējums	**Vides inženierijas mācību metodes**
A1	Anonīmi atsauksmju novērtējumi
A2	Vienota e-mācību sistēma (iekštīkls)
A3	Datu vākšana
A4	Grupas kursa darbs
A5	Grupu darbi
A6	Individuālais pētniecības projekts
A7	Lekcijas
A8	Tiešsaistes uzdevumi un kursa darbi
A9	Laboratorijas darbi
A10	Semināri un darbnīcas
A11	Objektu apmeklējumi
A12	Konsultācijas
A13	Lomu spēles

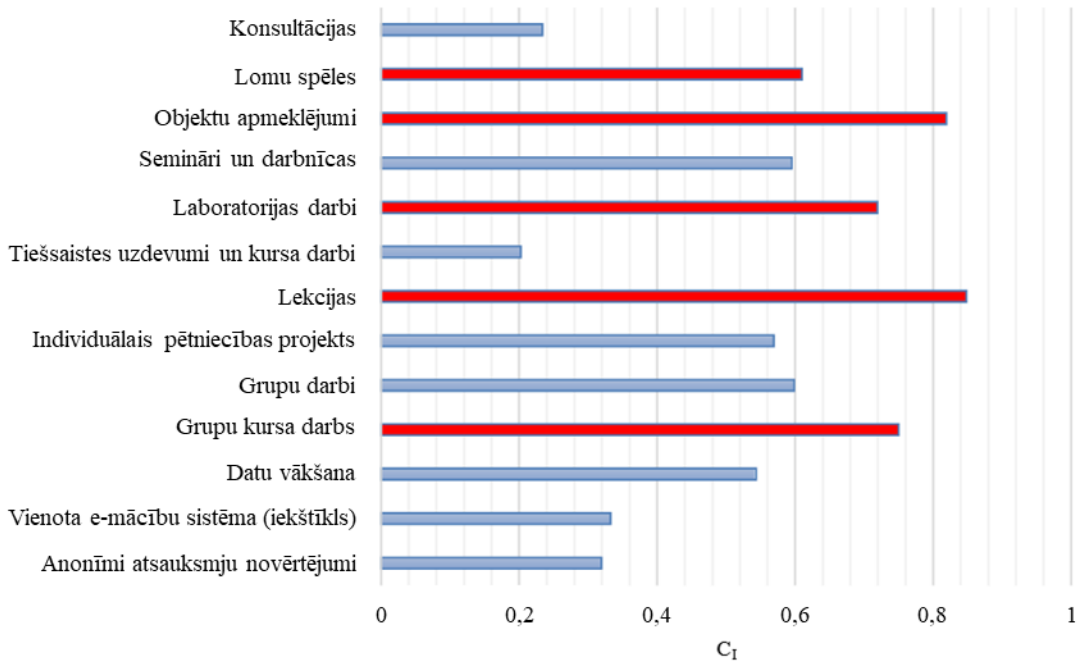
Kritēriju svarus (w_{1bi1}, w_{2bi2}, w_{3bi3}, w_{nbin}) vērtēja RTU VASSI eksperti. Normalizētās un svērtās vērtības no lēmumu pieņemšanas matricas mācību metožu novērtēšanai ir parādītas 3.8. tabulā.

3.8. tabula

Normalizēta un svērtā lēmumu pieņemšanas matrica

Kritērijs / Mācību metode	Inženiertehniskās prasmes	Tālāk nododamās prasmes	Vides aizsardzības prasmes	Sociālekonomiskās prasmes
	$w1bi1$	$w2bi2$	$w3bi3$	$w3bi3$
A1	0,0015625	0,005625	0,003125	0,00375
A2	0,0046875	0,00375	0,003125	0,00375
A3	0,0078125	0,001875	0,00625	0,00125
A4	0,00625	0,0075	0,00625	0,005
A5	0,0046875	0,0075	0,0046875	0,005
A6	0,00625	0,005625	0,0046875	0,00375
A7	0,0078125	0,0075	0,0078125	0,00625
A8	0,003125	0,00375	0,0015625	0,0025
A9	0,0078125	0,005625	0,0078125	0,005
A10	0,003125	0,009375	0,0046875	0,00625
A11	0,00625	0,009375	0,00625	0,0025
A12	0,0015625	0,009375	0,0078125	0,00625
A13	0,0046875	0,001875	0,0015625	0,00125

Iegūtie rezultāti parādīja, ka lekcijas, objektu apmeklējumi, grupu kursa darbi un laboratorijas darbi kopā ar lomu spēlēm ļauj iegūt nepieciešamās zināšanas, prasmes un sacensties (3.9. att.).

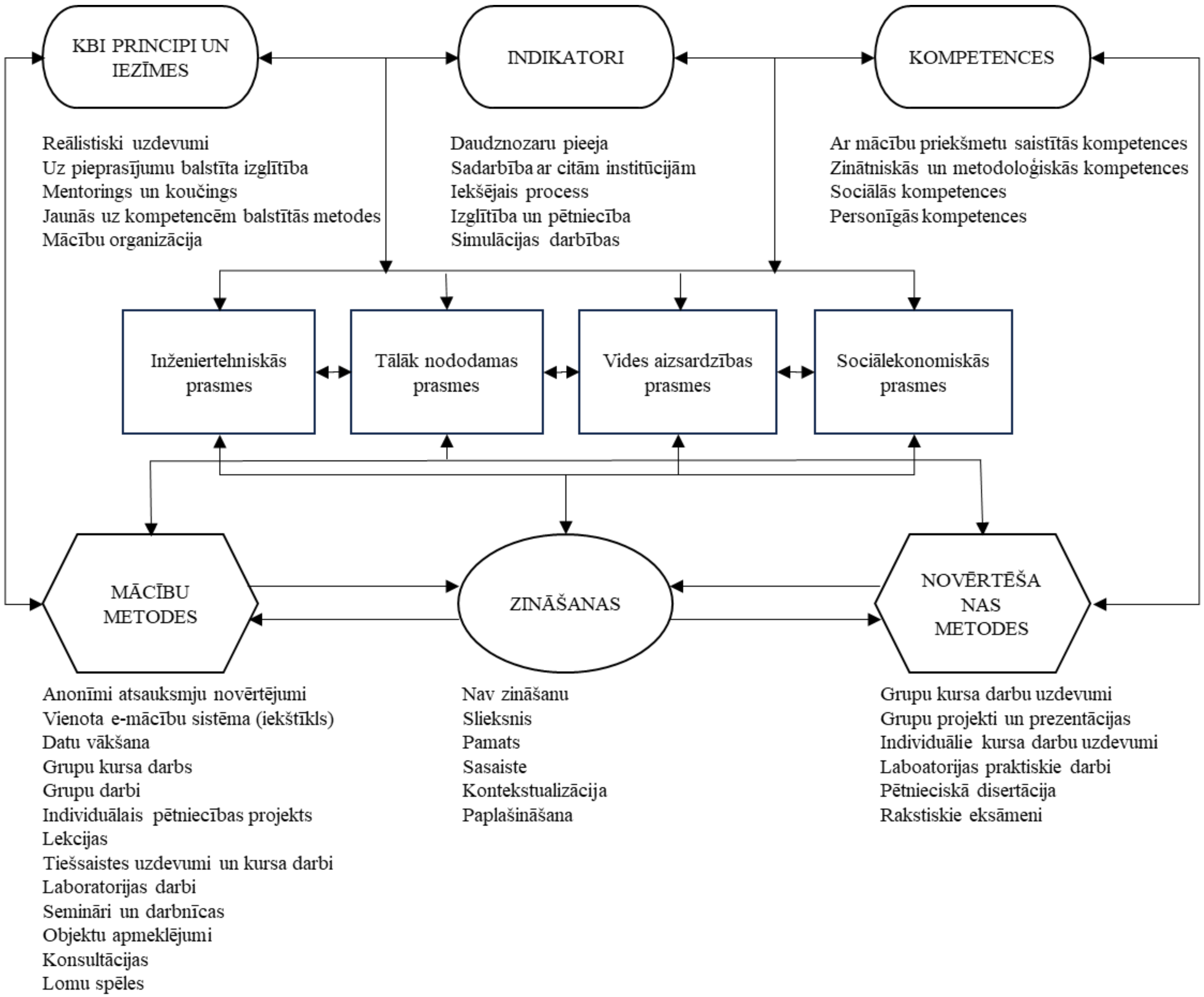


3.9. att. Mācību metožu vērtējumu salīdzinājums.

Kā vērtēšanas metodes grupu uzdevumiem var izmantot grupu darbus un grupu kursa darbus. Atsevišķiem pētniecības projektiem individuālie kursa darbu uzdevumi var dot iespēju novērtēt darbu. Pētnieciskās disertācijas un rakstiskie eksāmeni ir efektīvs līdzeklis individuālā darba novērtēšanā.

Izstrādāta vērtēšanas sistēma vides inženierijas studiju programmas novērtēšanai (3.10.att.).

Piedāvātā vērtēšanas sistēma vides inženierijas studiju programmas novērtēšanai tika pārbaudīta un aprobēta jaunajās Rīgas Tehniskās universitātes maģistra studiju programmās Vides inženierija un Bioekonomika.



3.10. att. Vides inženierijas studiju programmas vērtēšanas sistēma.

Bioekonomikas studiju modulis

Kompetenču integrāciju ilgtspējīgai attīstībai un bioekonomikas kompetencēm var uzskatīt par svarīgu soli augstākajā izglītībā, lai veicinātu bioekonomikas mērķu īstenošanu.

Trūkst informācijas par kompetenču integrācijas faktisko statusu esošajās maģistra studiju programmās par bioekonomiku. Bioekonomikas maģistra studiju programmu analīzē tika izmantotas kompetences, kuras ir parādītas 3.9. tabulā.

3.9. tabula

Analīzē izmantotās bioekonomikas kompetences

Kompetences	Kompetenču diskurss
Sistēmiskās domāšanas kompetence	Spēja kolektīvi analizēt sarežģītas sistēmas dažādās ilgtspējas un bioekonomikas jomās [107].
Prognozēšanas kompetence	Spēja kolektīvi analizēt un novērtēt bioekonomikas un ilgtspējas jautājumus [107].
Normatīvā kompetence	Spēja kopīgi kartēt, konkretizēt, piemērot, saskaņot un vienoties par ilgtspējas vērtībām, principiem, mērķiem un mērķrādītājiem [107].
Stratēģiskā kompetence	Spēja kopīgi izstrādāt un īstenot intervences, pārejas un pārveidojošas pārvaldības stratēģijas, kas vērstas uz bioekonomikas ilgtspēju [107].
Starppersonu kompetence	Padziļinātas prasmes komunikācijā, apspriedēs un sarunās, sadarbībā, vadībā, plurālistiskā un transkulturālā domāšanā un empātijā [107].
Transdisciplinārā kompetence	Uzlabo prasmes transcendences, problēmu risināšanas, inovāciju, starpdisciplinārās pētniecības un pārkāpumu jomā [105].
Mācīšanās kompetence	Spēja uz pašvadītu mācīšanos, uz sadarbību vērstu mācīšanos un uz problēmām orientētu mācīšanos [206].
Starpdisciplinārā kompetence	Spēja integrēt disciplinārās perspektīvas un to atziņas, lai veicinātu izpratni par sarežģītām problēmām, lai piemērotu izpratni reālai problēmai [106]

Pēdējos gados vairākas Eiropas universitātes ir izveidojušas programmas par tēmām, kas saistītas ar bioekonomiku. Analīzei tika atlasītas Eiropas bioekonomikas maģistrantūras programmas. Studiju programmu atlase tika veikta, izmantojot maģistra studiju programmas meklēšanas lapas un meklējot konkrētās mājaslapās par bioekonomiku.

Tika atlasītas tikai pilna laika maģistra studiju programmas. Meklēšanas rezultāti liecina, ka studiju programmas par bioekonomiku Eiropā izplatījušās Ziemeļeiropā (Somijā un Igaunijā), Rietumeiropā (Vācijā, Austrijā, Nīderlandē, Francijā, Beļģijā), Austrumeiropā (Rumānijā), Dienvideiropā (Itālijā, Spānijā) un Apvienotajā Karalistē.

Šobrīd lielākā daļa studiju programmu ir Rietumeiropā. Nīderlande ir līdere ar četrām maģistra studiju programmām par bioekonomiku. Vācijā, Francijā un Apvienotajā Karalistē ir vairāk nekā viena bioekonomikas studiju programma. Septiņas maģistra studiju programmas ir universitātes studiju programmas, divas ir kopīgas maģistra studiju programmas un viena ir *Erasmus Mundus* kopīgā maģistra studiju programma. Studiju programmu kopējais fokuss ir uz bioekonomiku ar specializāciju dažādos bioekonomikas aspektos, piemēram, mežsaimniecībā, biotehnoloģijā, aprites ekonomikā, ķīmijas inženierijā, biobāzētos materiālos, bioinovācijās u. c.

Izlases rezultātā tika izveidotas šādas 10 studiju programmas, kas parādītas 3.10. tabulā.

3.10. tabula

Maģistra studiju programmas bioekonomikā

Universitāte	**Programmas nosaukums**	**Studiju laiks**	**Apraksts**
Māstrihtas Universitāte (Nīderlande)	Biobāzēti materiāli	2 gadi pilna laika	Koncentrēšanās uz jaunu materiālu atklāšanu un ilgtspējīgām bioresursu ražošanas metodēm [207].
Utrehtas Universitāte (Nīderlande)	Bioloģiski iedvesmota inovācija	2 gadi pilna laika	Koncentrēšanās uz aprites uzņēmējdarbības modeļu un bioiedvesmotas pētniecības un inovāciju izstrādi [208].
Vageningenas Universitāte un pētniecība (Nīderlande)	Biobāzētas zinātnes un biosistēmu inženierija (un biotehnoloģija)	2 gadi pilna laika	Koncentrēšanās uz biobāzētu ekonomiku no starpdisciplināras perspektīvas [209].
Edinburgas Universitāte (Apvienotā Karaliste)	Bioekonomikas pārvaldība, Inovācija un pārvaldība	2 gadi pilna laika	Koncentrēšanās uz tādiem bioekonomikas aspektiem kā ilgtspējīga inovācija un jaunu tehnoloģiju ieviešana esošajos un jaunietekmes tirgos [210].
Stratklaida Universitāte (Apvienotā Karaliste)	Rūpnieciskā biotehnoloģija	1 gads pilna laika	Koncentrējieties uz to, lai izprastu pašreizējo rūpnieciskās biotehnoloģijas attīstību [211].
Hohenheimas Universitāte (Vācija)	Bioekonomika	2 gadi pilna laika	Koncentrēšanās uz biobāzētu ekonomiku, izmantojot starpdisciplināru un transdisciplināru pieeju [17].
Helsinku Universitāte (Somija)	Meža zinātnes	2 gadi pilna laika	Koncentrēšanās uz meža bioekonomikas uzņēmējdarbību un politiku [212].
Kopīgā studiju programma: Austrumsomijas Universitāte (Somija), AgroParisTech (Francija), Freiburgas Universitāte (Vācija), Ļeidas Universitāte (Spānija), Dabas resursu un dzīvības zinātņu universitāte (Austrija), Transilvānijas Brašovas Universitāte (Rumānija)	Eiropas mežsaimniecība	2 gadi pilna laika	Koncentrēšanās uz ilgtspējīgu resursu pārvaldību, uzsverot pašreizējos bioekonomikas jautājumus [213].
Kopīgais maģistra grāds: Boloņas Universitāte, Milānas-Bikokas Universitāte, Neapoles Universitāte - Federiko II, Turīnas Universitāte (Itālija)	Eiropas maģistrs bioekonomikā aprites ekonomikā	1 gads pilna laika	Koncentrēšanās uz biobāzētu preču un pakalpojumu nozari, izmantojot bioloģiskos resursus un biotehnoloģiskos procesus [214].
Erasmus Mundus kopīgais maģistra grāds: Parīzes Dzīvības, pārtikas un vides zinātņu tehnoloģiju institūts (Francija), Reimsas Šampaņas-Ardēnu universitāte (Francija), Ālto Universitāte (Somija), Tallinas Tehnoloģiju universitāte (Igaunija), Ljēžas Universitāte (Beļģija)	Eiropas maģistrs bioloģijas un ķīmijas inženierijā ilgtspējīgai bioekonomikai	2 gadi pilna laika	Koncentrējieties uz biotehnoloģiju, bioprocesu izstrādi un paplašināšanu, kā arī biobāzētu produktu inženieriju, papildus koncentrējoties uz vispārīgajām prasmēm, tostarp projektu vadību [215].

Tika izstrādāta analīzes sistēma, izmantojot bioekonomikas kompetences, ko definēja *Wiek et al.* [107], *Repko et al.* [206], *Barth* un *Burandt* [216] un *Tejedor et al.* [61], un katras studiju programmas studiju kursos attaisnotās kompetences. Tika izmantotas bioekonomikas kompetences. Katra kompetence tika interpretēta kompetences sistēmā. Analīzes programmai izmantoti studiju programmu apraksti un studiju kursu apraksti katrai studiju programmai. Mērķis bija izteikt bioekonomikas kompetenču integrāciju katrā studiju programmā: (1) neliela integrācija vai tās neesamība, (2) minimāla integrācija, (3) mērena integrācija, (4) laba integrācija. 3.12. tabula sniedz pārskatu par Edinburgas Universitātes studiju programmas "Bioekonomikas, inovāciju un pārvaldības vadība" analīzes rezultātiem.

3.12. tabula

Studiju programmas individuālās kompetences matricu analīzes piemērs

Bioekonomikas kompetences / Studiju programmas kompetences	Sistēmiskās domāšanas kompetence	Prognozēšanas kompetence	Normatīvā kompetence	Stratēģiskā kompetence	Starppersonu kompetence	Transdisciplinārā kompetence	Mācīšanās kompetence	Starpdisciplinārā kompetence
Tendenču, iespēju un izaicinājumu analīze dabas zinātņu inovāciju ceļā [217]	4	4	3	3	2	4	3	4
Uzņēmējdarbības veicināšana un radoša domāšana par bioekonomikas nākotni [217]	3	3	4	4	4	4	4	4
Biznesa plānu izveide un jaunu tehnoloģiju tirgus maršrutu kartēšana [217]	3	3	2	4	3	3	3	3
Prognozēšana un uz scenārijiem balstītas metodes ar jaunajām tehnoloģijām saistītā riska un nenoteiktības pārvaldībai [217]	4	3	4	3	3	4	2	4
Sarunu un komunikācijas prasmes starpdisciplinārās komandās [217]	4	4	3	4	4	3	4	4

Apzīmējums:

1	neliela integrācija vai tās nav vispār
2	minimāla integrācija
3	mērena integrācija
4	laba integrācija

Tā kā analizētās studiju programmas ir īpaši paredzētas bioekonomikas studijām, vispārējās bioekonomikas un ilgtspējīgas attīstības kompetences ir labi integrētas studiju programmās. Esošajās studiju programmās par bioekonomiku Eiropā transdisciplinārā kompetence, mācīšanās kompetence, starpdisciplinārā kompetence un sistēmiskās domāšanas kompetence ir cieši integrētas studiju programmās. Citu kompetenču, piemēram, prognozēšanas kompetences, normatīvās kompetences, stratēģiskās kompetences un starppersonu kompetences, integrācija var būt spēcīgāka. Tas parādīja, ka ir jāpastiprina šo kompetenču izmantošana ilgtspējīgai attīstībai un bioekonomikai nākotnē.

Analīzes rezultāts par bioekonomikas kompetenču integrēšanu studiju programmā ir parādīts 3.13. tabulā.

3.13. tabula

Bioekonomikas kompetenču integrēšana studiju programmas kompetencēs

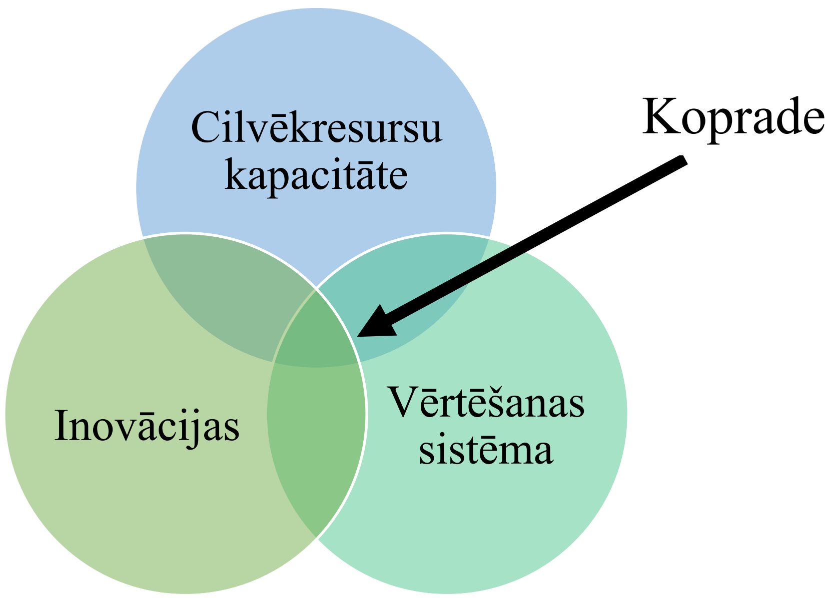
Maģistra studiju programmu kompetences matrica \ Bioekonomikas kompetences	Sistēmiskās domāšanas kompetence	Prognozēšanas kompetence	Normatīvā kompetence	Stratēģiskā kompetence	Starppersonu kompetence	Transdisciplinārā kompetence	Mācīšanās kompetence	Starpdisciplinārā kompetence
Biobāzēti materiāli	3	4	3	3	3	4	4	4
Bioiedvesmota inovācija	4	3	3	3	4	4	4	4
Biobāzētas zinātnes un biosistēmu inženierija (un biotehnoloģija)	4	3	3	4	3	4	4	4
Bioekonomikas, inovācijas un pārvaldības pārvaldība	4	3	3	4	3	4	3	4
Rūpnieciskā biotehnoloģija	3	4	3	4	4	3	4	4
Bioekonomika	4	4	3	4	3	4	4	4
Meža zinātnes	3	4	4	3	3	3	4	3
Eiropas mežsaimniecība	4	3	3	3	4	4	4	4
Eiropas maģistrs bioekonomikā aprites ekonomikā	4	3	4	3	4	4	4	4
Eiropas maģistrs bioloģijas un ķīmijas inženierijā ilgtspējīgai bioekonomikai	4	3	3	3	3	4	4	4

Apzīmējums:

Apzīmējums:	3	mērena integrācija
	4	laba integrācija

3.3.Koprades īstenošanas modulis

Koprades moduli raksturo divas puses (3.11.att.), kur pirmā ir auditorija, ko raksturo tas, cik spēcīgas un labas ir zināšanas, kādi sadarbības moduļi pastāv un var pastāvēt, lai partnerības izjūtas būtu, kādas ir zināšanas par inovācijām. Otra ir vērtēšanas puse, kur tiek novērtēti dalībnieki un rezultāts, uz ko tie tiecas. Koprades īstenošanas modulī tiek izmantota veiktspējas metode kombinācijā ar tehnoloģiju gatavošanas līmeņa metodi.



3.11. att. Koprades moduļa galvenie elementi.

Cilvēkresursu kapacitāte

Sākotnēji tiek definētas zaļās inovācijas vērtības ķēdes dalībnieki un viņu loma. Pētījumā aplūkotie vadošie spēlētāji ir akadēmiskās aprindas (studenti, akadēmiskais personāls), nozare (uzņēmums, mentori, nozares eksperti un citas ieinteresētās puses). Universitāte kā partneris nodrošina motivētus studentus, kas ir viens no moduļa kritiskajiem elementiem. Viņu iesaistīšanās zaļo inovāciju ideju vētrā veicina uz zināšanām balstītu uzņēmējdarbību, stiprina akadēmiskā sektora sadarbību ar industriju, kā arī nodrošina kvalificēta darbaspēka pieejamību ekonomikas attīstībai nākotnē.

Tika noteiktas prasības studentiem – komunikācija un sadarbība, prasmes produktīvai mijiedarbībai komandā, priekšzināšanas par vides tehnoloģijām, izpratne par to, kur un kā meklēt vairāk informācijas ārpus studiju kursa tvēruma, un prasme radīt zinātību.

Studējošo rezultātu nodrošināšanā izšķiroša loma ir universitātes akadēmiskajam personālam, kura izpratne un aktīva līdzdalība studiju procesā motivē studentus risināt problēmas. Mācībspēku iesaistes mērķis ir nodrošināt nepārtrauktu mācību procesu un pārliecināt nozari uzticēties akadēmiskā sektora kompetencēm un studentu spējai radīt un potenciāli komercializēt zinātniskos sasniegumus videi draudzīgu izgudrojumu jomā.

Otrs lielākais moduļa spēlētājs ir nozare, ko uzņēmums pārstāv ar savu problēmu gadījumu. Uzņēmumu var definēt kā “akcionāru”, kuram ir ekonomiska ieinteresētība sadarbības rezultātos un kura aktīva līdzdalība būtiski veicina vides zinātnes izglītības kvalitāti un ekonomikas attīstībai būtiska darbaspēka pieejamību. Nozares ievades formāti – informācijas sagatavošana un augsta līmeņa speciālistu kompetenču apmaiņa – ir viens no dārgākajiem resursiem biznesā un palīdz studentiem radīt praktiskus risinājumus, kas atbilst “akcionāra” vajadzībām. Ja uzņēmums ietaupīs resursus, būs mazāka iespēja iegūt gaidīto rezultātu.

Prasības uzņēmumam – spēja precīzi definēt izaicinājumus, ar kuriem saskaras pats uzņēmums, zināšanas par vides tehnoloģiju komercializācijas un attīstības procesu, ambīcijas, kas vērstas uz starptautisko konkurētspēju, gatavība nodrošināt kompetentus pārstāvjus, t. sk. spēja paskatīties uz sadarbību plašākā kontekstā, ņemot vērā arī nekomerciālas intereses, sniegt biznesa konsultācijas un rast standarta risinājumus problēmas, kas var rasties sadarbībā ar akadēmiskajām aprindām.

Abu galveno partneru – akadēmisko aprindu un industrijas – kopīga atbildība ir piesaistīt šādus kompetenču partnerus, kuru klātbūtne stiprina partneru spējas un iespējas nodrošināt pilnvērtīgu zināšanu apmaiņas procesu zaļo inovāciju izstrādē. Šiem ārējiem mentoriem un sociālajiem partneriem ir sava loma, novērtējot risinājuma pozicionējumu plašākā kontekstā.

Inovācijas

Partneru mijiedarbība ir balstīta uz katras ieinteresētās puses vajadzībām – to mērogs un dziļums nosaka iesaistīšanās pakāpi un ieguldījumu apjomu. Aspekti, kuros pušu vajadzības sakrīt, visbūtiskāk ietekmē pētījumu rezultātus, piemēram, studentam ir nākotnes karjeras iespējas personīgai izaugsmei. Tajā pašā laikā universitāte ir būtiska, lai nostiprinātu savu statusu kā modernu izglītības iestādi, taču uzņēmuma interese ir mijiedarbība.

Lielā mērā akadēmiskā personāla attieksme un entuziasms ietekmē arī studentu motivāciju strādāt, tāpēc universitātes primārais uzdevums ir mācībspēku motivācija iesaistīties – akadēmiskās izcilības stiprināšana:

1) studiju programmas mācību metožu aktualizēšana atbilstoši laikmeta garam;
2) ciešākas saiknes ar rūpniecību, lai veicinātu lietišķos pētījumus;
3) izglītības politikas veidotāju prasību izpilde (akreditācijas procesa prasību izpilde).

Tajā pašā laikā universitāte arī motivē studentus iesaistīties, lai apmierinātu viņu vajadzību pēc personīgās izaugsmes:

1) labi apmaksāta nākotnes profesija;
2) konkurētspējīgu zināšanu apguve;
3) mūsdienīgs studiju process;
4) iespēja pierādīt savas zināšanas un prasmes sev un demonstrēt citiem gan tiešā komunikācijā ar uzņēmuma pārstāvjiem, gan prezentējot komandas sasniegumus.

Lai stiprinātu studentu līdzdalību, viņiem ir jāspēj izvēlēties sev tuvāku tēmu. Studenti norāda savu izvēli prioritārā secībā, lai procesa vadītāji varētu nodrošināt, ka studentam piešķirtais gadījums ir paziņojums par viņu svarīgumu. Šī pieeja motivē studentus un liek viņiem uzņemties atbildību par savām izvēlēm. Tas ļauj izvairīties no studentu pārmetumiem par viņu interešu neievērošanu.

Savukārt uzņēmuma uzdevums ir formulēt savu primāro motivāciju iesaistīties – stiprināt konkurētspēju:

1) jaunu zaļo inovāciju komercializācija;
2) uzņēmējdarbības modeļa optimizācija konkurences priekšrocību iegūšanai;
3) kvalificēta darbaspēka piesaiste, lai radītu produktu ar pievienoto vērtību.

Lai stiprinātu uzņēmuma līdzdalību, universitāte var formulēt “veselīgas ambīcijas” partnerības ieguvumiem, piemēram, zaļo inovāciju izstrādei un ieviešanai ar tehnoloģiju gatavības līmeņiem (TGL) 5–7, lai uzņēmums varētu sasniegt savu akcionāru izvirzītos mērķus.

Kā pievienoto vērtību dalībai pasākumā uzņēmums īsteno korporatīvās sociālās atbildības aktivitātes – atbalstu akadēmiskajai izglītībai studiju procesa kvalitātes uzlabošanai un iesaisti valsts "zaļās politikas" attīstībā, stiprinot nākotnes darbaspēka kvalifikāciju.

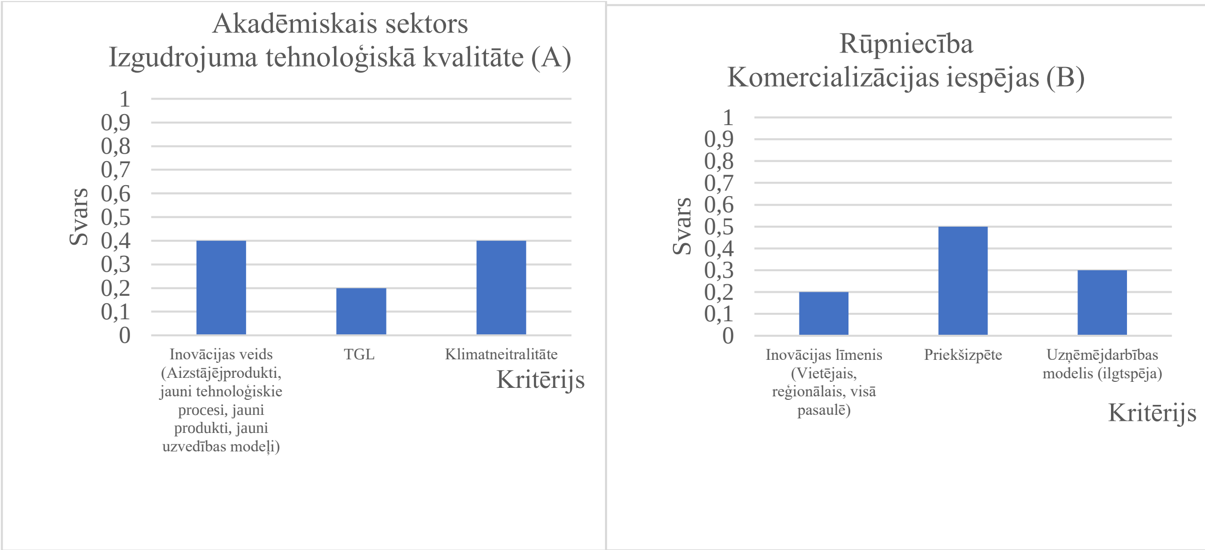
Akadēmiskajam sektoram ir jāvelta vairāk pūļu, lai motivētu ieinteresētās puses, jo studentu gatavība rīkoties ir atkarīga no akadēmiķu iesaistes un uzņēmējdarbības un kompetences partneru iesaistes. Kad akadēmiskais un privātais sektors iesaistās sadarbībā, pirmais solis ir atrast līdzsvaru starp ekonomisko, vides un sociālo ietekmi kā izšķirošiem faktoriem lēmumu pieņemšanā:

a) vides jomā akadēmiskā sektora primārais mērķis ir ilgtspējīga un atbildīga resursu izmantošana, jo risinājumi ir vērsti uz sabiedrības dzīves kvalitātes paaugstināšanu;
b) uzņēmējdarbībā galvenais mērķis ir maksimāli palielināt peļņu - to prasa gan uzņēmumu īpašnieki, gan nepieciešamība nodrošināt stabilu finanšu plūsmu, konkurētspēju un izaugsmi. Peļņas samazināšana ir pieļaujama sabiedrības interesēs, ja to prasa likums, kā tas ir atkritumu apsaimniekošanas gadījumā, kad uzņēmumiem paralēli savai saimnieciskajai darbībai ir jāveic vispārīgas informēšanas un izglītošanas darbības, tādējādi veicinot ilgtspējīgas attīstības mērķu sasniegšanu.

Pamatojoties uz iepriekš minēto, universitātei ir izšķiroša loma notikumu un tehnoloģiju attīstībā kā tādā. Savukārt rūpniecības nozare, ko pārstāv uzņēmumi, balstoties uz tās stratēģiskajām interesēm, pieņem lēmumus par optimālu studentu komandu darbu.

Sadarbojoties universitātei un uzņēmumam, var pienākt laiks, kad abām pusēm ir jāvienojas par mērķiem un metodēm to sasniegšanai. Šajā gadījumā ir iespējama alternatīva pieeja, kas ļauj līdzsvarot intereses tā, lai tās apmierinātu abas puses. Šī pieeja ietver 3–5 kritisko kritēriju noteikšanu un svara piešķiršanu tiem. Tomēr tas var būt ilgstošs process partneru atšķirīgo perspektīvu dēļ.

Autore ierosina izveidot divas sistēmas pušu interešu novērtēšanai, kas atbilstu abu partneru (uzņēmuma un universitātes) vajadzībām. Tiek vērtēti tādi kritēriji kā izdoma, kvalitāte, ietekme uz vidi un idejas komercializācijas potenciāls (inovācija). Katrs kritērijs tiek vērtēts skalā no 1 līdz 10 (kur viens ir zemākais un desmit ir augstākais). Katram kritērijam atkarībā no būtiskuma (kas jāsasniedz notikuma un/vai pētījuma ietvaros) attiecībā uz rezultātu piešķir tā nozīmi (3.12. attēls).



3.12. att. Stratēģisko partneru sadarbības vērtēšanas kritēriju salīdzinājums (A – akadēmiskais sektors; B – rūpniecība).

Vērtēšana

Sacensību gars un spēles elements var būtiski ietekmēt pasākuma galarezultātu. Komandu izveide tieši ietekmē konkurenci un sadarbību vienlaikus. Iespēja pārbaudīt savas zināšanas un pieredzi konkurences disciplīnās veicina labāku, dziļāku un daudzpusīgāku informācijas asimilāciju un izpratni par savu spēju robežām un, kas ir ne mazāk svarīgi, veicina ciešu sadarbību ne tikai komandā, bet arī ar akadēmiskā personāla un uzņēmumu (konsultantu) pārstāvjiem.

Ar vērtēšanas metodi tiek novērtēta komandas lēmuma kvalitāte un gala prezentācijas kvalitāti (3.14. tabula).

3.14. tabula

Galīgās prezentācijas vērtēšanas kritēriji galīgajai prezentācijai

Vērtēšanas kritēriji	**Mēģina sasniegt / nesasniedz**	**Tuvojas**	**Panāk atbilstību**	**Pārsniedz prasības**
	1	*2*	*3*	*4*
	Studentu aktivitātes ir neprecīzas, un aptuveno sniegumu var tikai daļēji attiecināt uz iegūto kompetenci.	Studentu sniegums parasti ir saistīts ar apgūstamo kompetenci.	Studentu sniegums ir precīzs; tas ir balstīts uz spriedumiem par šiem kritērijiem	Studentu sniegums ir precīzs un pārliecinošs; tas parāda kompetences ierobežojumus un sarežģītību.

Autore piedāvā vērtēšanas kritēriju tabulu, ko var pielāgot dažādām izglītības programmām. Katrs kritērijs tiek vērtēts skalā no 1 līdz 4, kur 1 – mēģina sasniegt / nesasniedz un 4 – pārsniedz prasības. Katram tiek piešķirts svars atkarībā no studiju programmas prasībām (3.15. tabula). Idejas attīstības modulis ir elementu kopums, kura lietojums noved pie veiksmīga rezultāta. Moduli var salīdzināt ar sietu, kurā pēc daudzu dažādu informācijas un inovāciju izsijāšanas tiek atdalītas jēgpilnas zināšanas un darbības, lai apmierinātu visu iesaistīto pušu intereses. Modulis sastāv no galvenajiem iepriekš noteiktajiem parametriem: idejas novitātes, ekonomiskās iespējamības un prezentācijas. Pirms pasākuma sākuma studentiem jāsaņem visa iespējamā informācija par dažādiem inovāciju veidiem bioekonomikā (aizstājējprodukti, jauni tehnoloģiskie procesi, jauni produkti, jauni uzvedības modeļi utt.). Šī informācija ļaus studentiem labāk izprast kursa mērķi un labāk veikt uzdevumu [218].

3.15. tabula

Kritēriju novērtēšana

Nr.	Kritēriji	Svars
1.	Virzība uz klimatneitrālu risinājumu	0,20
2.	Tehniski ekonomiskās priekšizpētes kvalitāte	0,20
3.	Identificējams inovācijas veids (*Aizstājējprodukti, jauni tehnoloģiskie procesi, jauni produkti, jauni uzvedības modeļi*)	0,15
4.	Biznesa modeļa kvalitāte (risinājuma ilgtspējas nodrošināšanai)	0,1
5.	Tehnoloģiju gatavības līmenis	0,1
6.	Inovācijas līmenis (vietējais, reģionālais, globālais)	0,1
7.	Ieguldījums viena vai vairāku Apvienoto Nāciju Organizācijas ilgtspējīgas attīstības mērķu sasniegšanā	0,05
8.	Komandas sniegums (prezentācijas kvalitāte)	0,05
9.	Dalībnieki ir formulējuši savu lomu risinājuma ieviešanā	0,05
Kopā		**1,0**

Nākamajā pētījuma solī tika izprasta projekta tehnoloģiskā gatavība. Šī izpratne ļauj izvirzīt mērķi, ko komanda var sasniegt atvēlētajā laikā.

Informācijas apjoms, ko komanda sniedz, ir tieši atkarīgs no mācību programmas prasībām un TGL kritērijiem. Piemēram, TGL1–4 gadījumā tas būs: a) pētniecība; b) jēdziena apraksts; c) analītiskā un eksperimentālā darba rezultāti, d) dokumentēta testa veiktspēja utt. Informācija ietver, piemēram, izmaksu un ieguvumu analīzi, uzņēmējdarbības modeli, tirgus izpēti utt. Pamatojoties uz uzņēmuma apgrozījumu (piemēram, saražoto produktu skaitu), komanda veic projekta ekonomisko analīzi. Lai pierādītu šī projekta panākumus, ir nepieciešama inovatīva risinājuma projekta finanšu analīze. Šīs analīzes papildu priekšrocība ir zināšanu iegūšana par ekonomisko aspektu, kas neapšaubāmi palielina studenta konkurētspēju tirgū. Caurspīdīgas projekta loģistikas ķēdes izveide, sākot ar resursu ražotāju un beidzot ar pircēju, ir otrs nozīmīgais piedāvātā risinājuma rādītājs.

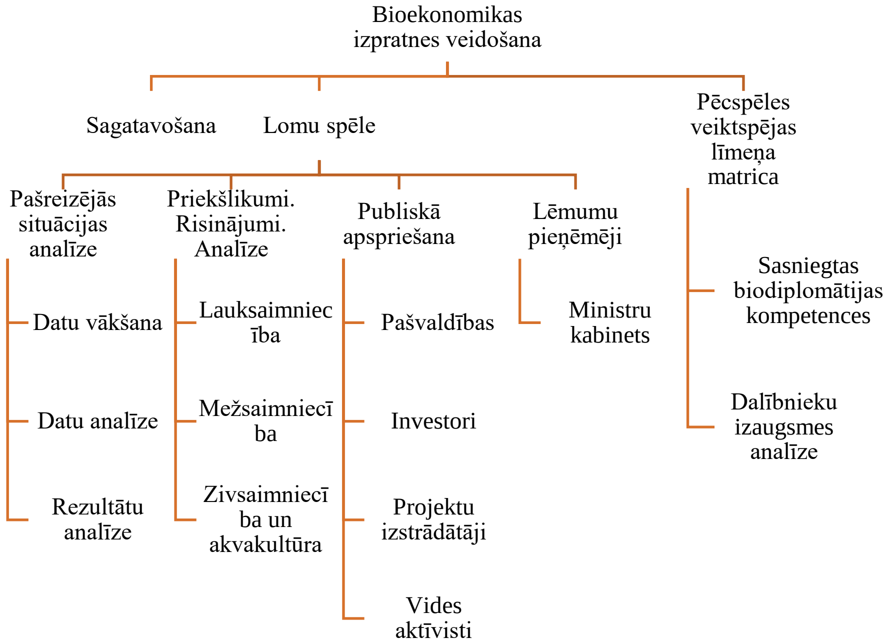
Biznesa modeļa ieviešana ir otrs studentu komandas risinājuma kvalitātes rādītājs no nozares viedokļa. Parasti uzņēmējdarbības modeļus aplūko no vērtību ķēdes perspektīvas apvienojumā ar citām teorijām un uzņēmumu praksi. Uzņēmējdarbības modelis formulē vērtības piedāvājumu klientiem [219] un ņem vērā, kā organizācija rada, piegādā un uztver vērtību [220]. Akadēmiķiem un uzņēmumu vadītājiem ir atšķirīga izpratne par ilgtspējīgu uzņēmējdarbības modeļu jēdzienu, un joprojām notiek debates par to, vai ilgtspējīgi uzņēmējdarbības modeļi nākotnē varētu aizstāt tradicionālos uzņēmējdarbības modeļus [221].

3.4.Uzvedības modulis

Performances jeb veiktspējas metode tiek izmantota, vides inženierijas studentu apmācībā integrējot lomu spēli, jo ir svarīgi veidot uzvedības tipu vai darbību, kas pieprasa daudz uzmanības, lai detalizētu problēmas un izceltu detaļas, kas dažreiz varētu šķist arī nesvarīgas. Lomu spēlei ir jāveido studentu nostāja.

Lomu spēlē dalībnieki iejūtas izdomāta tēla lomā. Dalībnieki nosaka savu personāžu darbību atkarībā no tās uzdevumiem un personalizācijas, un veiksmes faktors ir atkarīgs no spēles sistēmas un dalībnieku uzvedības: gatavības un motivācijas. Svarīgi ir spēles uzstādījumi, un noteikumi, kuru ietvarā, spēlētāji var improvizēt un radoši meklēt risinājumus, pie kam viņu izvēles ietekmē spēles virzienu un iznākumu.

Lomu spēles integrēšana bioekonomikas izpratnes veidošanas modulārajā struktūrā ir parādīta 3.13. attēlā.



3.13. att. Lomu spēles integrēšana bioekonomikas izpratnes veidošanas modulārajā struktūrā

Lomu spēles laikā dalībnieki atbildēja uz galveno jautājumu - kā ieguldīt *Covid-19* ārkārtas atbalsta līdzekļus pandēmijas seku mazināšanai (ilgtspējīga ekonomikas atveseļošana) un saglabāt pāreju uz ilgtspējīgu bioekonomikas attīstību. Katra mērķa grupa – mežsaimniecība, lauksaimniecība, zivsaimniecība un akvakultūra – formulēja, viņuprāt, labākos risinājumus, pamatojoties uz pētījumiem. Bioekonomikas stratēģijā, kas nosaka, ka visnozīmīgākais atbalsts ir lauksaimniekiem un pārtikas ražotājiem, lai garantētu nodrošinātību ar pārtiku. Ir jāņem vērā, ka atlikusī daļa būs jāsadala starp zivsaimniecībām un mežsaimniecību.

Pirmajā sagatavošanas daļā tika izstrādāta lomu spēle Rīgas Tehniskās universitātes bakalaura studiju programmas “Vides inženierija” kursā “Biotehonomika” 2 KP apjomā. Otrajā daļā tika īstenota lomu spēle, kas sastāvēja no pašreizējās situācijas analīzes, priekšlikumu un risinājumu analīzes, sabiedriskās apspriešanas un lēmumu pieņemšanas. Studenti tika iepazīstināti ar problēmsituāciju, spēles mērķi, iesaistītajām pusēm, grupu sadalījumu un vadošo piedāvājumu vērtēšanas kritērijiem pašreizējās situācijas analīzes posmā. Grupā bija četri studenti. Tika apkopoti dažādi kritēriji, lai sagatavotu un izvērtētu nozaru iesniegtos priekšlikumus (sk. 3.16. tabulu). Ar apkopotajiem kritērijiem tika izvērtēti un salīdzināti priekšlikumi, izvēlēti optimālākie un efektīvāk sadalīti finansējumi.

3.16.tabula

Galvenie priekšlikumu vērtēšanas kritēriji grupām

Grupas nosaukums	**Kritēriji**	**Vienības**
Mežsaimniecība Lauksaimniecība Zivsaimniecība un akvakultūra Ministru kabinets Investori Vides aktīvisti Pašvaldību pārstāvji	Laukos un pilsētās nodarbināto personu skaits	Tūkstošiem cilvēku
	Pievienotās vērtības pieaugums	Tūkstotis EUR/gadā
	Pievienotā vērtība uz vienu darbinieku	Tūkstotis
	Ieguldījums IKP	%
	Eksports	Tūkstotis EUR
	No AER saražotās enerģijas īpatsvars rūpniecības un enerģijas patēriņā	%
	Atjaunojamā enerģija un kopējais (gala) rūpnieciskais enerģijas patēriņš	GWh_{AER} $GWh_{kopējais}$

Lomu spēles rezultātā lauksaimniecības grupa saņēma vislielāko finansiālo atbalstu, tāpēc šī grupa tika tālāk analizēta, izmantojot pēcspēles snieguma līmeņa matricu. Lauksaimniecības grupa bija sagatavojusi priekšlikumus, kuri ietvēra nepieciešamību saņemt atbalstu pandēmijas seku novēršanai, bioekonomikas attīstībai un bioekonomikas stratēģijā noteikto mērķu sasniegšanai; iepazīstinājusi ar galvenajām grūtībām, ar kurām lauksaimniecības nozare saskaras pandēmijas dēļ, kādi aspekti kavē bioekonomikas attīstību, kādi ir politikas instrumenti, kas varētu palīdzēt sasniegt mērķus; iesniegusi priekšlikumus par ārkārtas atbalsta finansējuma ieguldīšanu un tā nepieciešamību, ieguvusi rezultātus, ja finansējums tiks piešķirts, un identificējusi sekas, ja ne.

Noslēdzošajā daļā tika īstenota pēcspēles veiktspējas līmeņa matrica, ar kuru tika novērtētas biodiplomātijas kompetences bioekonomikā. Studenti šīs matricas izmantoja kā ceļvežus studiju procesā, gatavojoties lomu spēlei. Spēle ieteicams vērot vairākiem novērotājiem, kuri pirms spēles kalibrē savu izpratni par snieguma līmeni. Spēles laikā vērtētāji identificēja tabulā uzskaitītos biokompetences kritērijus un noteica studentu snieguma līmeni.

Pēcspēles snieguma līmeņa matrica lauksaimniecības grupai biodiplomātisko kompetenču novērtēšanai ir parādīta 3.17. tabulā.

3.17. tabula. Pēcspēles snieguma līmeņa matrica lauksaimniecības grupai.

1. kategorija Produkta / pakalpojuma / procesa atbilstība pārejai no pašreizējās paradigmas par ekonomiskās ražošanas palielināšanu uz ilgtspējīgu bioekonomiku, veicinot zaļā kursa un klimatneitralitātes politikas	***2. kategorija*** Saprātīgs un delikāts dialogs un sadarbība ar mērķa grupām.	***3. kategorija*** Sabiedrības mērķu un uzdevumu kopējā definīcijā, apziņā, ka mēs visi esam viens, sinerģiska pieeja globālu problēmu risināšanā.
1. Nav minēts	1. Nav scenāriju, kā atbildēt uz āķīgiem jautājumiem, daudzi jautājumi netiek izmantoti, lai sāktu dialogu.	1. Priekšlikums par pilsētu lauksaimniecību ir atklāti noraidīts.
2. Nav minēts	2. Solījumi un draudi kā dialoga veicinātāji (kas draud, ja lauksaimniecība netiek atbalstīta?). Virkne jautājumu un atbilžu parāda divvirzienu komunikāciju. Neskaidri argumenti diskusijā ar investoriem.	2. Sadarbība ar mežsaimniecības nozari, izstrādājot kopīgus priekšlikumus zemes izmantošanas maiņai (zemes apmežošana, izmaiņas 1 ha ietvarā).
3. Grupas prezentācija definē lauksaimniecības mērķus bioekonomikas jomā, kas atbilst paradigmas maiņai. Tiek norādīta sagaidāmā pievienotā vērtība, analizēti šķēršļi bioekonomikas attīstībai, sasniegti politikas instrumenti, sniegti precīzi pasākumu priekšlikumi, skaidri priekšlikumi energoefektivitātes uzlabošanai un emisiju samazināšanai, kvantitatīvie argumenti (lauksaimniecības IKP, eksports u. c.) un to analīze, rīcības plāns mērķa grupu iesaistīšanai izglītībā. pasākumi un diskusijas. Investoriem tiek piedāvātas inovatīvas iespējas.	**3. Uzsākts dialogs ar pašvaldībām, lai rastu risinājumu kopējām sociālām un lauksaimniecības problēmām (jauniešu un citu profesiju pārstāvju iesaistīšana sezonas darbā, darbaspēka dinamisma palielināšana).**	**3. Kopīgi mērķi, kas izvirzīti ar vides aktīvistiem, lai apturētu urbanizācijas procesu; kopīga programmas izstrāde jauniešu piesaistīšanai lauku apvidiem.**
4. Nav minēts	**4. Grupas diskusijā plūst pārliecinoša apņēmība, politiķu lēmums piešķirt lielāko finansējuma daļu (uzvara finansējuma piešķiršanas spēlē) norāda uz domāšanas maiņu ilgtermiņa stratēģiju virzienā.**	**4. Nav minēts**

Būtisku lomu ieņem pēc spēles snieguma iztirzājums no vērtētāju puses kopā ar studentiem, lai noskaidrotu un pamatotu sasniegtos līmeņus. Studentiem ir iespēja identificēt savas izpratnes trūkumus.

3.5.Diplomātisko attiecību modulis

Vides inženierijas studentu apmācības uzvedības modulis pamazām tiek papildināts ar sarunu mākslas un zinātnes komponentēm. Faktiski tas lielā mērā ir saistīts ar diplomātiju, kas ir attiecināma ne tikai uz ārpolitiku. Diplomātija ir attiecināma uz dažādu grupu pārstāvjiem, kuri diskutē (dažreiz arī konfliktē) par sabiedrībā aktuāliem jautājumiem. Viens no šādiem jautājumiem, kas nenozūd no dienas kārtības ir vides aizsardzības un klimata pārmaiņu jautājums. Tāpēc vides inženierijas, ieskaitot bioekonomikas, studentiem ir nepieciešams apgūt un veidot diplomātisko attiecību moduli, izprotot dažādas problēmas.

Lai izprastu un izvērtētu, kādas varētu būt svarīgākā tematika, tika atlasītas desmit tēmas un tās izveidotas, kā desmit AHP kritēriji:

C1 kritērijs – ekonomiskie,

C2 kritērijs – sociālais,

C3 kritērijs –klimata un vides,

C4 kritērijs – zinātnes un pētniecības,

C5 kritērijs – inženierzinātnes,

C6 kritērijs – iekšpolitika,

C7 kritērijs – ārpolitika,

C8 kritērijs – piekļuve finansējumam,

C9 kritērijs – citu valstu piemēri,

C10 kritērijs – reģionālā politika.

Šo atbilžu kvantificēšana, sarindošana un analīze ir nākamais solis, lai novērtētu dominējošo kritēriju mežsaimniecības diplomātijas potenciālam, pamatojoties uz vienkāršu svēruma shēmu. Turklāt pirms pārejas uz *TOPSIS* analīzi tiek veiktas arī noturības pārbaudes (t. i., konsekvences pārbaude) attiecībā uz rezultātu stabilitāti.

3.18.tabula

Kritēriju pāra salīdzināšanas matrica

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
C1	1	3	2	2	2	2	2	2	3	2
C2	0,33	1	2	2	2	2	2	2	2	2
C3	0,50	0,50	1	3	3	3	3	3	3	3
C4	0,50	0,50	0,33	1	2	3	2	2	3	3
C5	0,50	0,50	0,33	0,50	1	3	2	3	2	2
C6	0,50	0,50	0,33	0,17	0,33	1	2	3	2	3
C7	0,50	0,50	0,33	0,50	0,50	0,50	1	2	2	2
C8	0,50	0,50	0,33	0,50	0,33	0,33	0,50	1	2	2
C9	0,33	0,50	0,33	0,33	0,50	0,50	0,50	0,50	1	2
C10	0,5	0,50	0,50	0,33	0,50	0,33	0,50	0,50	0,50	1

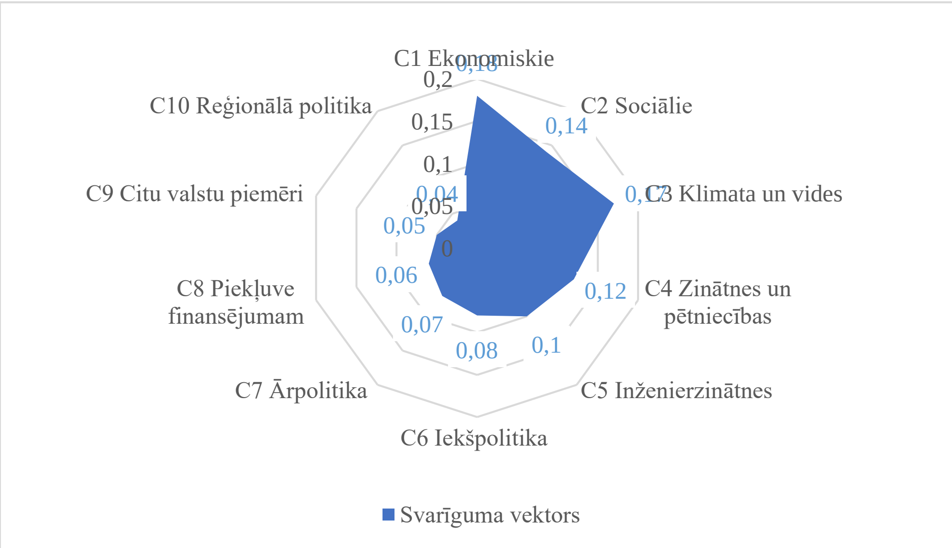
3.18. tabulā redzami Rīgas Tehniskās universitātes Vides aizsardzības un siltuma sistēmu institūta aptaujas rezultāti. Eksperti tabulā izceļ katra kritērija relatīvās atšķirības pret mežsaimniecības nozares potenciālu kļūt par daļu no Latvijas biodiplomātijas. Katrs pāra salīdzināšanas matricas elements atspoguļo to, ka lēmumu pieņēmējs dod priekšroku vienam kritērijam attiecībā pret citiem kritērijiem attiecībā uz potenciālo nozīmi Latvijas biodiplomātijā. Piemēram, ekonomiskie kritēriji ir trīs reizes svarīgāki par sociālajiem kritērijiem, lai meža resursi būtu daļa no potenciālās Latvijas biodiplomātijas. Tāpēc sociālie kritēriji ir viena trešdaļa tikpat svarīgi kā ekonomiskie kritēriji. To atvasināt svarīgumu, vektora-matricas normalizācija jāveic ar kritēriju pāru salīdzināšanas matricu. Rezultāti ir parādīti 3.19. tabulā.

3.19.tabula

Normalizēta pāra kritēriju salīdzināšanas matrica

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*
C1	0,194	0,375	0,273	0,194	0,164	0,128	0,129	0,105	0,146	0,091
C2	0,065	0,125	0,273	0,194	0,164	0,128	0,129	0,105	0,098	0,091
C3	0,097	0,063	0,136	0,290	0,247	0,191	0,194	0,158	0,146	0,136
C4	0,097	0,063	0,045	0,097	0,164	0,191	0,129	0,105	0,146	0,136
C5	0,097	0,063	0,045	0,048	0,082	0,191	0,129	0,158	0,098	0,091
C6	0,097	0,063	0,045	0,016	0,027	0,064	0,129	0,158	0,098	0,136
C7	0,097	0,063	0,045	0,048	0,041	0,032	0,065	0,105	0,098	0,091
C8	0,097	0,063	0,045	0,048	0,027	0,021	0,032	0,053	0,098	0,091
C9	0,065	0,063	0,045	0,032	0,041	0,032	0,032	0,026	0,049	0,091
C10	0,097	0,063	0,045	0,032	0,041	0,021	0,032	0,026	0,024	0,045

Sekojot iepriekš minētajam, lai pabeigtu AHP analīzi, normalizētās kritēriju pāru salīdzināšanas matricas īpašvektors attēlo svarīgāko kritēriju hierarhisko struktūru pret meža nozares potenciālu Latvijas biodiplomātijas iegūšanai, matricas normalizēšanu, un rezultāti ir parādīti 3.14. attēlā.



3.14.att. Svarīguma vektors parāda absolūtās nozīmes svaru klasifikāciju.

No visiem desmit iespējamiem kritērijiem, kas varētu ietekmēt mežsaimniecības nozares potenciālu Latvijas biodiplomātijā, svarīgākais ir ekonomiskais faktors, kam seko sociālie, klimata un vides jautājumi.

Veicot atbilstības pārbaudi 3.20. tabulā, ir iespējams pamatoti secināt, ka šis ranžējums ir noturīgs pret straujām izmaiņām svarīguma skalas definīcijā, kā arī ar milzīgām atšķirībām ekspertu viedokļos, par ko liecina konsekvences koeficients (0,07), kas ir mazāks par plaši atzīto slieksni (0,1).

3.20.tabula

AHP algoritma rezultātu konsekvences pārbaude ar N=10 kritērijiem

Termins	**Vērtība**
Konsistences indekss	0,11
Nejaušās konsistences indekss (N=10)	1,49
Konsistences koeficients	(0,11/1,49) = 0,07 < 0,1

Nākamajam solim, lai labāk saprastu, kuras alternatīvas (apjoms (A1), iegāde (A2), pieejamība (A3), atjaunošana (A4), apglabāšanas iespējas (A5), pieprasījuma (A6) pārvaldība/īpašumtiesības (A7), darbaspēka pieejamība (A8) un speciālistu pieejamība (A9)) ir visnozīmīgākās katra kritērija virzīšanā kopumā lēmumu pieņemšanas procesā, tiek izmantota *TOPSIS* analīze. Tā ir saprātīga pieeja, lai palīdzētu mums izprast mežsaimniecības resursu potenciālu, ja ņem vērā vairāk faktoru, kas nav saistīti ar divpusēju salīdzināšanu. 3.21. tabula parāda lēmuma pieņemšanas matricu, kurā alternatīvas ir izsvērtas attiecībā uz kritērijiem.

3.21.tabula

Svērtā lēmumu matrica

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
C1	2,7	3,6	3,3	3,1	3,2	3,7	2,9	3,1	3,1
C2	3,1	2,6	2,6	2,8	2,4	2,7	3,2	3,4	2,8
C3	3,7	3,2	3,0	3,4	3,1	3,1	2,7	2,2	2,4
C4	3,0	2,7	2,9	3,1	3,6	3,7	2,3	2,0	3,2
C5	3,2	3,2	2,8	3,5	2,9	3,2	2,6	2,6	3,3
C6	3,5	3,1	3,5	3,1	3,6	3,2	3,0	2,9	2,6
C7	3,4	2,4	3,5	2,6	2,6	3,2	2,8	2,6	2,0
C8	3,0	3,1	2,9	2,9	3,1	3,3	2,8	2,3	2,7
C9	2,5	2,7	2,3	2,6	2,9	2,7	2,4	2,1	2,6
C10	3,0	3,0	2,8	3,2	3,1	2,9	2,9	3,1	2,7

Pēc tam matrica ir normalizējama (3.22. tabula). Matricas normalizēšana ļauj mums sistemātiski salīdzināt alternatīvas dažādos kritērijos neatkarīgi no pamatā esošā ģenerēšanas procesa.

Tad nākamais solis ir noteikt labākās un sliktākās alternatīvas šajā alternatīvu diapazonā A1–A9, sākot ar to, ka tiek noteikts, kura alternatīva ir vispiemērotākā un vismazāk piemērota katram kritērijam, līdz minimumam samazinot atšķirību starp katru alternatīvu no sliktākās un labākās alternatīvas attiecībā uz katru kritēriju. Tādējādi, aprēķinot atdalīšanas pasākumus, var kvantificēt, cik tālu katra alternatīva atrodas no ideālās un sliktākās alternatīvas. Atdalīšanas mērījums ir parādīts 3.5.6. tabulā kopā ar tuvuma attiecību (C) pret labāko alternatīvu.

3.22. tabula

Normalizēta svērtā lēmumu pieņemšanas matrica

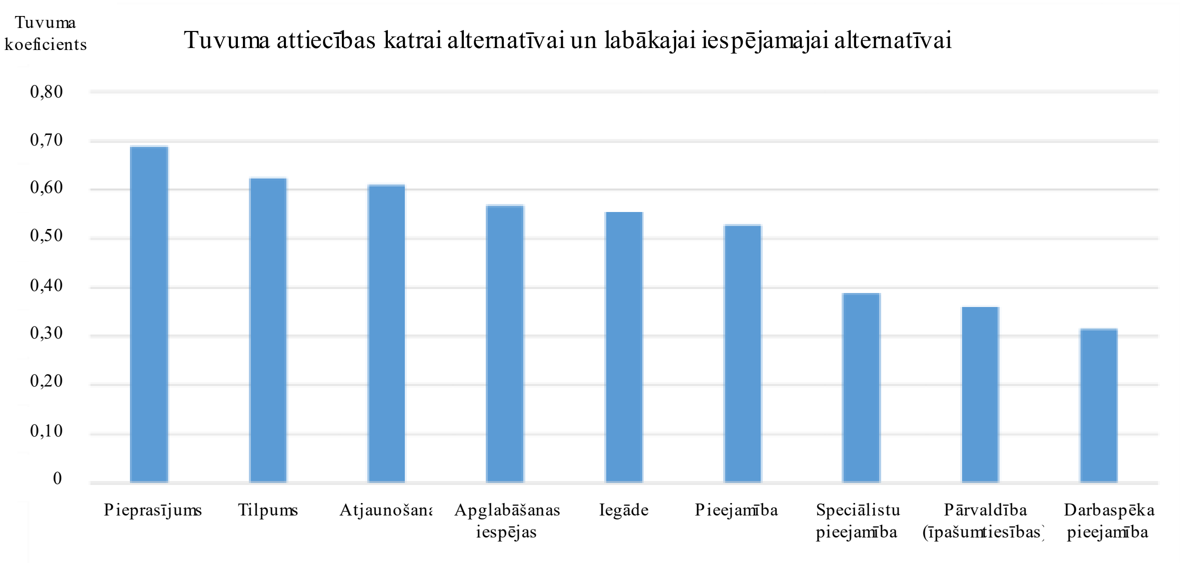
	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
C1	0,05	0,07	0,06	0,06	0,06	0,07	0,05	0,06	0,06
C2	0,05	0,04	0,04	0,04	0,04	0,04	0,05	0,05	0,04
C3	0,07	0,06	0,05	0,06	0,06	0,06	0,05	0,04	0,04
C4	0,04	0,04	0,04	0,04	0,05	0,05	0,03	0,03	0,04
C5	0,04	0,04	0,03	0,04	0,03	0,04	0,03	0,03	0,04
C6	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,02
C7	0,03	0,02	0,03	0,02	0,02	0,03	0,02	0,02	0,02
C8	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
C9	0,02	0,02	0,01	0,02	0,02	0,02	0,01	0,01	0,02
C10	0,01	0,01	0,01	0,02	0,01	0,01	0,01	0,01	0,01

3.23. tabula

Tuvuma attiecība pret labāko alternatīvu

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
d a +	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,04	0,03
d a –	0,04	0,03	0,03	0,03	0,03	0,04	0,02	0,02	0,02
da+ + da–	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,05
C=da-/da+ +da–	0,62	0,55	0,53	0,61	0,57	0,69	0,36	0,31	0,39

Tuvuma attiecības rangs ir apkopots, lai izceltu labāko alternatīvu diapazonā no A1 līdz A9 3.15. attēlā.



3.15. att. Alternatīvu prioritātes noteikšana.

No 3.15. attēla secināms, ka attiecībā uz meža resursiem svarīgākie faktori, kas var palīdzēt noteikt meža resursu potenciālu Latvijas biodiplomātijai, ir to pieprasījums, apjoms, kā arī atjaunošanās, jo tie intuitīvi ir vistuvāk adekvātajai alternatīvai, kad lēmuma pieņēmējs atbilstoši apsver visas alternatīvas. Darbaspēka pieejamība ir pēdējais svarīgais virzītājspēks šajā analīzē.

Pieprasījums, apjoms un atjaunošanās pēc analīzes iet roku rokā, jo, lai izveidotu biodiplomātiju, ir jāsaprot, vai ir pieprasījums, kas tiek uzskatīts par vadošo rādītāju, un vai apjoms apmierinās pieprasījumu un vairāk – procesos tas ir jāuzskata par atjaunošanu. Šie rezultāti nozīmē, ka nākamais solis biodiplomātijas veicināšanā ir izpratne par to, kāda veida mežsaimniecības produkts ir jāattīsta, lai palielinātu pieprasījumu. Šajā produktā jāņem vērā ekodizaina principi, jo apjoms ir nākamais svarīgais virzītājspēks. Atjaunošana ir trešais svarīgais faktors. Protams, nedrīkst aizmirst arī citus virzītājspēkus, kas ir otrā prioritātes daļā kā speciālistu pieejamība, vadība (īpašumtiesības) un darbaspēka pieejamība, pat tos, kas netiek uzskatīti par galvenajiem jautājumiem biodiplomātijas attīstībā.

3.6.Tālmācības modulis

Tālmācības modulī tiek izmantota sistēmdinamikas metode, kura tiek lietota kā apmācības rīks masīvu tiešsaistes atvērtu kursa (*MOOC*) "Enerģijas pāreja un klimata pārmaiņas" ietvarā.

MOOC tika ievietots *Moodle* platformā, ko atbalstīa Rīgas Tehniskās universitātes studentu kursu portāls ORTUS [222]. Tika izveidota jauna kursa lapa, kas darbojas kā izstrādātā *MOOC* un ietver visus resursus, kas nepieciešami abām daļām – teorētiskajam un praktiskajam. *Moodle* platforma ļauj veidot kursa struktūru, pievienojot galvenās tēmas sadaļas un apakšnodaļas, kas ietver teorijas lapas un interaktīvu saturu, piemēram, interaktīvus video, jautājumu kopas, '*drag and drop"* jautājumus, jautājumus ar atbildēm, prezentācijas u. c. Studiju kursā "Enerģijas pāreja un klimata pārmaiņas" izmantotie praktiskie uzdevumi atšķiras – daži tiek veikti, lai virzītu studenta zināšanas par aprakstīto teoriju daudzizvēļu jeb "patiess/nepatiess" anketu veidā, bet daži ietver praktisku darbu ar saskarni, pēc kuras lietotājam jāatbild uz viktorīnas jautājumiem par rezultātiem, kas sasniegti, manipulējot ar dažādiem mainīgajiem.

MOOC tika nodots testēšanai pieciem studentiem ar padziļinātām zināšanām par sistēmdinamiku un energosistēmām, pēc tam rezultāti tika iegūti strukturētās intervijās. Studenti tika izvēlēti no Rīgas Tehniskās universitātes, un kritērijs bija, lai testa lietotāji būtu bakalaura studiju laikā pabeiguši sistēmdinamikas kursu.

MOOC "Enerģētikas pārkārtošana un klimata pārmaiņas" ir izstrādāts angļu valodā un paredzēts 100 % apmeklēšanai tiešsaistē. Tas ļauj studentiem mācīties savā ātrumā un aplūko trīs svarīgus un savstarpēji saistītus mūsdienu enerģētikas politikas aspektus: energoefektivitāti, atjaunojamo enerģiju un klimata pārmaiņas. Tajā aprakstīta pašreizējās energosistēmas sociāli tehniskā pārkārtošanās, tostarp inovatīvi risinājumi enerģētikas un klimata tehnoloģiju jomā, aplūkotas mācīšanās līknes un ekonomika, cilvēku uzvedība kā viens no galvenajiem pārmaiņu virzītājspēkiem, kā arī dažādu tehnoloģiju izplatīšana, lai sasniegtu klimata un enerģētikas politikas mērķus. Šīs zināšanas lietotājam tiek sniegtas caur sistēmdinamikas prizmu, izskaidrojot, kā darbojas enerģētikas nozares piedāvājuma un pieprasījuma puse. Kurss sastāv no piecām sadaļām, no kurām trīs tika iekļautas pilotversijas izstrādē. Katrā nodaļā ir iekļauti praktiski uzdevumi, lai pārbaudītu lietotāju zināšanas pirms studijām, to laikā un pēc tām.

Apmācības uzdevums notiek katras kursa daļas sākumā, un tā novērtējums nav iekļauts galīgajā vērtējumā. Praktiskie uzdevumi tiek novērtēti un iekļauti studenta noslēguma piezīmē.

Kursa ievaddaļā ir paskaidrots, kas ir klimata pārmaiņas un kā ar tām ir saistīta enerģētikas nozare. Šīs daļas rezultāti ietver zināšanas par galvenajiem klimata pārmaiņu cēloņiem un ietekmi, oglekļa cikla dinamiku atmosfērā un globālo klimata pārmaiņu politikas pasākumu pamatiem. Otrajā nodaļā ir dziļāk aplūkota enerģētikas nozares piedāvājuma un pieprasījuma puse. Ir iekļauts īss ievads ar piemēriem par dažādiem kurināmajiem, ko izmanto enerģijas ražošanā, kam seko energoefektivitātes nozīme un pieaugošais ražojošo patērētāju skaits enerģētikas nozares pieprasījuma pusē. Šī kursa daļa ietver ievadu piedāvājuma un pieprasījuma puses attiecībās caur sistēmdinamikas prizmu. Nākamajā nodaļā ir aprakstītas enerģijas lietotāju galveno nozaru (dzīvojamo, rūpniecisko, sabiedrisko u. c.) galvenās iezīmes attiecībā uz elektroenerģijas un apkures/dzesēšanas sistēmu izmantošanu. Visbeidzot, kursa ievada daļas pēdējā nodaļā ir izskaidrota enerģijas pārejas procesa nozīme, iespējas un sarežģījumi [223], [224]. Tas ietver pārejas teoriju, arhetipu "Sloga novirzīšana", iespējamos šķēršļus enerģētikas pārkārtošanas procesā uz ilgtspējīgākām tehnoloģijām un to, kā notiek fosilo energoresursu sistēmu savienošana ar atjaunojamās enerģijas sistēmām. Tiek apspriesta arī decentralizēta enerģijas pārvaldība, kas ir būtisks dalīšanās ekonomikas, kā arī agregatoru aspekts.

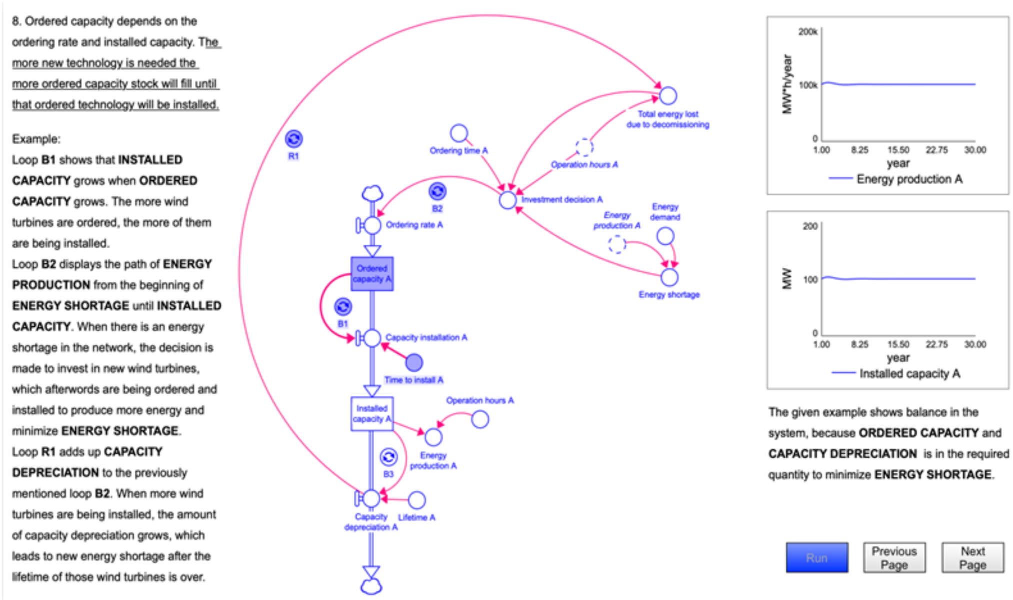
Sadaļas "Piedāvājuma puse" un "Pieprasījuma puse" ir veidotas, izmantojot līdzīgu pieeju – vispirms tiek sniegta informācija no publikācijām, kas aptver galvenos interesējošos tematus, kam seko piemēri no enerģijas piedāvājuma un pieprasījuma nozaru krājumu un plūsmu struktūrām. Lietotāji var noteikt, aprakstīt un novērtēt galvenos enerģijas pārejas virzītājspēkus abās pusēs no sistēmdinamikas viedokļa. Piedāvājuma puse ietver dažādus pašreizējos un nākotnes enerģijas avotus, savukārt pieprasījuma puses apakšmodeļi ietver enerģijas patēriņa nozares, piemēram, mājsaimniecības, terciāro nozari, rūpniecību, sabiedrisko un transporta nozari. Ir iekļauti praktiski uzdevumi, izmantojot saskarnes, kur lietotāji var plānot dažādus scenārijus, kā attīstīt enerģētikas pārkārtošanu uz CO_2 neitrālām energosistēmām, galvenos sviras punktus energosistēmās, īstermiņa un ilgtermiņa ietekmi, kā arī kavējumu, nelinearitātes un atgriezeniskās saites ietekmi enerģētikas pārkārtošanas procesā.

Kursa piedāvājuma puses sadaļā aplūkotās tēmas ietver galveno enerģijas ražošanā izmantoto tehnoloģiju definīcijas un to cenu diapazona datus, kam seko saskarne, kurā izskaidrots, kā tiek veidota energoapgādes nozares krājumu un plūsmu struktūra (sk. 3.16. att.). Pēc tam lietotājiem ir jāizstrādā dažādi scenāriji, lai izpētītu, kuriem struktūras mainīgajiem lielumiem ir vislielākā ietekme uz enerģijas tarifu, enerģijas daudzumu, kas saražots, izmantojot fosilā kurināmā un uz atjaunojamiem energoresursiem balstītas tehnoloģijas, kā arī uzstādīto jaudu elektrostacijās dažādām tehnoloģijām. Ir paskaidrots, kā tiek veidota jauda starp konkurējošām tehnoloģijām, kurās izmanto fosilo kurināmo un atjaunojamos energoresursus (AER), kā arī iekļauti teorētiskie piemēri no divām elektrostacijām, kas darbojas ar dabasgāzi un vēja enerģiju. Tādi faktori kā jaudas uzstādīšanas aizkavēšanās, sabiedrības atbalsts un resursu pieejamība izskaidro, cik svarīga ir zemes platība un cik lielu zemes pēdas nospiedumu rada elektrostacijas, kas izmanto dažāda veida kurināmo.

Pieprasījuma puses sadaļā ir aprakstīti iekšējie un ārējie šķēršļi energoefektivitātes pasākumu īstenošanai, kas bieži vien izpaužas kā nekvalitatīvi būvdarbi renovācijas projektu laikā [225].

Tiek apspriesta arī iedzīvotāju uzvedība laikā, kad tiek lemts par to, vai atbalstīt vai neatbalstīt ēkas renovāciju tās energoefektivitātes paaugstināšanai, un šī lēmuma ietekme ir iekļauta enerģijas pieprasījuma sektora krājumu un plūsmu struktūrā. Pārvietojoties pa saskarni, lietotāji tiek iepazīstināti ar katru struktūras elementu ar teoriju un piemēriem. Līdzīgi, kā tas bija piedāvājuma puses sadaļā, saskarne ietver simulācijas moduli, kurā studenti veido vairākus scenārijus un nākamajā nodaļā atbild uz viktorīnas anketu par savu pieredzi. Tiek apspriesta arī energoefektivitāte dažādās galapatēriņa nozarēs (sabiedriskajā, dzīvojamajā, rūpniecības, terciārajā).

Katrā kursa sadaļā ir iekļauti praktiski uzdevumi, lai pārbaudītu lietotāju zināšanas pirms studijām, to laikā un pēc tām. Apmācības uzdevums notiek katras kursa daļas sākumā, un tā novērtējums nav iekļauts galīgajā vērtējumā. Praktiskie uzdevumi tiek novērtēti un iekļauti studenta noslēguma vērtējumā.



3.16. att. Saskarne, kurā paskaidrots, kā tiek veidota energoapgādes nozares krājumu un plūsmu struktūra.

Likerta vērtēšanas skala no 1 (Pilnībā nepiekrītu) līdz 5 (Pilnībā piekrītu) tika piemērota, lai novērtētu kursu astoņās jautājumu grupās. Vidējais vērtējums saturā bija 3,65, mācīšanās un atbalsts – 3,45, vizuālais noformējums – 3,15, navigācija – 3,36, pieejamība – 3,27, interaktivitāte – 3,80, pašvērtējums un mācīšanās spēja – 3,35, motivācija mācīties – 3,71. Zemākais rādītājs (3,15) kursu vērtēšanā ir piešķirts *MOOC* vizuālajam noformējumam. *MOOC* prototips vēl nav izstrādāts līdz stadijai, kad tiek veidots kursa vizuālais noformējums. Lietotāji sniedza vērtīgus komentārus un ieskatus, kas tiks tālāk izmantoti, lai uzlabotu *MOOC*.

3.7. Zinātniskās pētniecības modulis

Vides inženierijas studentiem studiju kursu darbu un noslēguma darbu izstrādē tiek piedāvāta iespēja izvēlēties gan kvalitatīvo, gan kvantitatīvo zinātniskās izpētes metodi. Ilggadīgie studiju procesa apkopotie dati liecina, ka 80–85 % studējošo izvēlas kvalitatīvo metodi, tādēļ promocijas darbā pētniecības jomu piemēri izvēlēti, lai ilustrētu kvalitatīvo zinātnisko metožu izmantošanas iespējas.

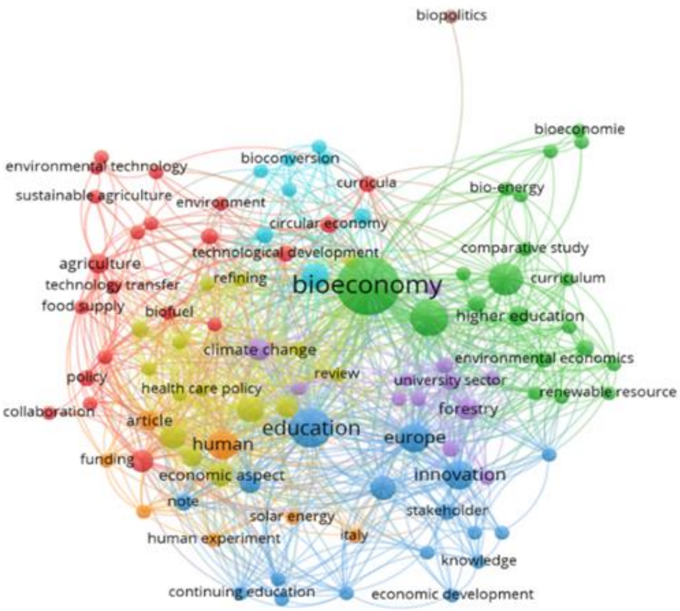
Autore zinātniskās izpētes demonstrāciju īsteno ar četru gadījuma rakstura zinātniskās izpētes piemēriem.

1. modulis. Bibliometriskās analīzes modulis. Meklēta un analizēta bioekonomikas nozares zinātniskās izpētes jomas svarīgums, kā arī Eiropas Savienības klimata politikas Zaļā kursa ietvaros saite ar bioekonomikas izglītību.
2. modulis. Bezatlikumu produktu ranžēšanas modulis. Meklēti un analizēti bioproduktu (kliju pārkraušanas atkritumu) ražotnes blakusproduktu izmantošanas iespējas produktu ražošanai ar augstu pievienotu vērtību.
3. modulis. Bezatlikumu tehnoloģiju ranžēšanas modulis. Meklētas un analizētas ražotnes blakusproduktu pārstrādes tehnoloģisko procesu izmantošanas iespējas.
4. modulis. Energoresursu lietotāja pārvaldības modulis. Meklētas un analizētas agregatoru iespējas un potenciāls.

Bibliometriskās analīzes modulis

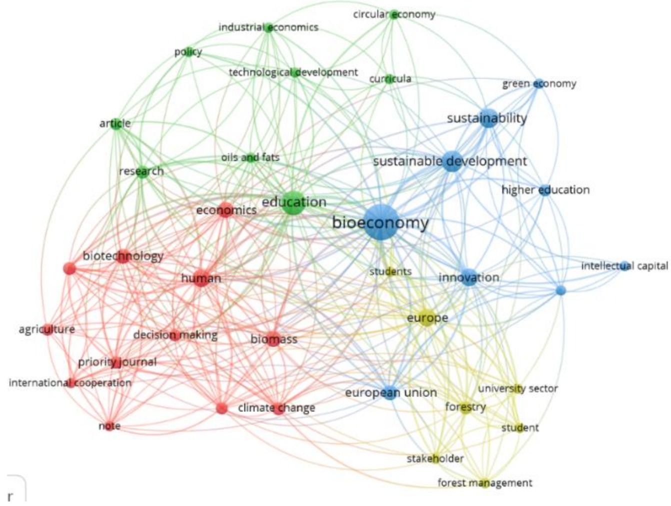
Bibliometriskās analīzes modulī galvenā uzmanība tika pievērsta pētījumiem zinātniskajā literatūrā, kas saistīta ar bioekonomikas nozares izpētes jomas svarīgumu, kā arī sasaitē ar Eiropas Savienības klimata politikas *Zaļo kursu* un bioekonomikas izglītību. Šajā modulī tika izmantota bibliometriskā metode (programmatūra *VOSViewer*).

3.17. un 3.18. att. ir redzama saikne starp zinātniskajiem rakstiem, kuros tiek izmantoti vārdi “izglītība” un “bioekonomika” (atlasīti raksti, sākot ar 2012. gadu). *Scopus* datubāzē tika indeksēti sešdesmit pieci raksti. Šie skaitļi parāda būtiskas atšķirības vārdu atkārtošanas minimālajā biežumā. 3.17. attēlā, šis minimālais vārdu atkārtošanās biežums ir divas reizes, bet 3.18. attēlā – trīs reizes. Minimālais vārdu atkārtošanas biežums tika mainīts, jo autore uzskatīja, ka vārdu savienojumi ir jāvizualizē ar atbilstošāk saistītiem vārdiem. Kā parādīts attēlos (3.17. att. un 3.18.att.), šo vārdu attiecības veido kopas. 3.20. attēlā tika uzģenerēts 101 atslēgvārds, kas veido astoņas kopas. Kopas sastāv no atbilstošiem atslēgvārdiem un to saitēm.



3.17. att. Bibliogrāfijas vizualizācija ar vārdu salikumu "izglītība" UN "bioekonomika" kopš 2012. gada (minimālais vārdu atkārtošanas biežums – divas reizes).

3.18. attēlā parādīti 37 atslēgvārdi, kas tiek iedalīti četrās kopās. Tālāk tiek analizēti bibliogrāfiskie dati ar vārdu salikumu ‘izglītība” un “bioekonomika” kopš 2012. gada (minimālais vārdu atkārtošanas biežums – trīs reizes), atslēgvārdus identificējot četrās kopās.



3.18. att. Bibliogrāfijas vizualizācija ar vārdu salikumu ‘izglītība” un ‘bioekonomika” kopš 2012.gada (minimālais vārdu atkārtošanas biežums – trīs reizes).

3.17. attēlā tiek parādīts korelācijas saišu tīkls starp šiem 37 atslēgvārdiem, kas sastāv no 319 saitēm un kopējā saišu stipruma 564. 3.18. attēlā redzams, ka publikācijās visbiežāk sastopamais atslēgvārds ir ‘bioekonomika’. Protams, to varētu uzskatīt par visatbilstošāko vārdu, jo raksti tika atlasīti, izmantojot atslēgvārdu "bioekonomika", kas parādās 36 zinātniskās publikācijās un attiecas uz 36 citiem atslēgvārdiem, kas aprakstīti kā saites. Otrs atbilstošākais atslēgvārds ir “izglītība” (32 saites) 16 zinātniskos rakstos. Trešais izplatītākais vārds 13 zinātniskajos rakstos ir “ilgtspējīga attīstība” (23 saites), “ilgtspēja” (14 saites) 11 zinātniskos rakstos un “cilvēks” (28 saites), “inovācija” (22 saites), “Eiropa” (30 saites) deviņos zinātniskos rakstos. Visvairāk tiek izmantoti jēdzieni “bioekonomika” un “izglītība”, un tie parādās lielākajā daļā publikāciju. Vārdi “cilvēks”, “inovācija” un “Eiropa” parādās mazāk pētījumos nekā vārdi “ilgtspējīga attīstība” un “ilgtspēja”, taču tiem ir lielāka saikne ar citiem tīkla atslēgvārdiem, kas nozīmē, ka autori rakstos izmanto biežāk lietotu valodu un vārdus, lai atspoguļotu turpmāko zinātnisko tēmu attīstību un to nozīmi zinātnē.

3.19. tabulā ir atainotas četras kopas ar dalītiem atslēgvārdiem bibliogrāfiskajā tīklā, kur tika izmantoti vārdu salikumi “izglītība” un “bioekonomika”, atlasot zinātniskos rakstus *Scopus* datubāzē no 2012. gada. Atslēgvārds tiek parādīts vienu reizi vienā no kopām.

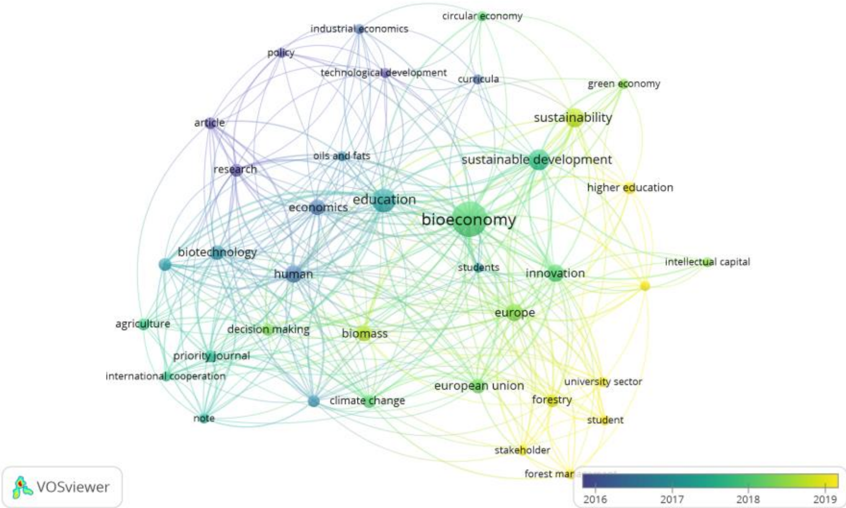
3.19. tabula

Kopš 2012. gada atainotās kopas bibliogrāfiskajā tīklā ar vārdu salikumu “izglītība” un “bioekonomika” (minimālais vārdu atkārtošanas biežums – trīs reizes)

1. kopa	**2. kopa**	**3. kopa**	**4. kopa**
lauksaimniecība biomasa biotehnoloģija klimata pārmaiņas lēmumu pieņemšana ekonomiskais aspekts ekonomika cilvēks cilvēki starptautiskā sadarbība piezīme prioritārais žurnāls	raksts aprites ekonomika mācību programmas izglītība rūpniecības ekonomika eļļas un tauki politika pētniecība tehnoloģiju attīstība	bioekonomika vides ekonomika Eiropas Savienība zaļā ekonomika, augstākā izglītība inovācijas intelektuālais kapitāls ilgtspēja ilgtspējīga attīstība	Eiropa meža apsaimniekošana mežsaimniecība ieinteresētās personas students studenti augstskolu sektors

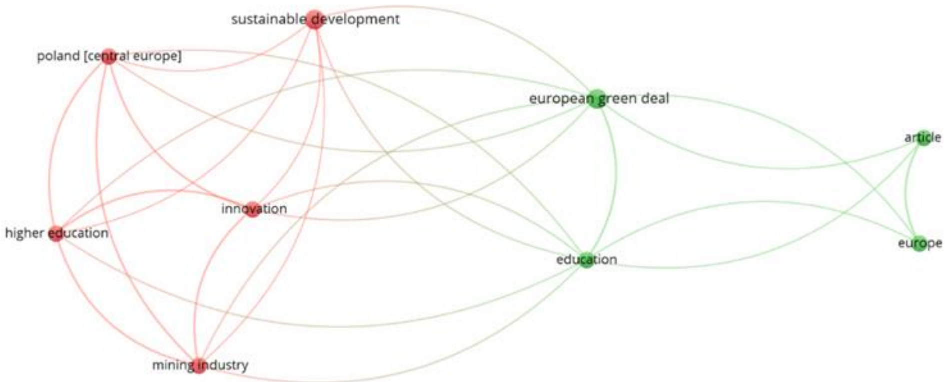
Pēc iegūtajiem rezultātiem tika identificēta studiju joma katrā kopā, kurā izglītība ir saistīta ar bioekonomiku.

1. kopa ir atslēgvārdi, kas saistīti ar cilvēku iesaistīšanos lauksaimniecībā un bioekonomikas attīstību, izmantojot biotehnoloģijas, kur zināšanas ir būtiskas. Izglītības nepieciešamība industriālajā ekonomikā ir parādīta 2. kopā, kur būtu jāapsver tehnoloģiju attīstība un pētniecība. 3. kopas atslēgvārdi ir saistīti ar inovāciju nepieciešamību bioekonomikā, kas būtu jādara, iesaistot augstāko izglītību ilgtspējīgai attīstībai. 4. kopa pārstāv mežsaimniecības nozares un studentu izglītības nepieciešamību bioekonomikas attīstībai.



3.19.att. Bibliogrāfijas (hronoloģiskā) vizualizācija ar vārdu salikumu “izglītība" un “bioekonomika” kopš 2012. gada (minimālais vārdu atkārtošanas biežums – trīs reizes).

3.19. attēlā ir parādīts atslēgvārdu hronoloģiskais attēlojums pētījumos, kur atslēgvārdi dzeltenā krāsā, piemēram, “meža apsaimniekošana”, “mežsaimniecība”, “ieinteresētā persona”, “students” u. c., vairāk parādās aktuālajās publikācijās, piemēram, 2019. gadā. Iepriekšminētais ir izskaidrojams, ka nozīmīgāki pētījumi tiek izmantoti oglekļneitrālākiem lietojumiem, piemēram, meža resursiem. Atslēgvārdi tumši zilā krāsā, piemēram, “tehnoloģiju attīstība”, “politika”, “industriālā ekonomika”, tika lietoti jau 2016. gadā. Atslēgvārdi dzeltenā krāsā parāda jaunākos sasniegumus pētniecībā, kuri tiek aplūkoti mežsaimniecības nozarē. Tiek veicināti inovatīvāki pielietojumi mežsaimniecības nozarē bioekonomikas attīstībai ar izglītības palīdzību.



3.20. att.. Bibliogrāfijas vizualizācija ar vārdu salikumu “izglītība” un “zaļais kurss” kopš 2019. gada (minimālais vārdu atkārtošanas biežums – divas reizes).

3.20.attēlā ir parādīta zinātnisko rakstu saistība ar vārdiem “izglītība” un “zaļais kurss”. Pētījumi tika atlasīti no 2019. gada, jo *Zaļā kursa* dokuments tika publicēts attiecīgajā gadā. Kopumā ir deviņi raksti. Jāatzīmē, ka rakstu skaits ir daudz mazāks, salīdzinot ar iepriekš minētajām vārdu kombinācijām.

Bezatlikumu produktu ranžēšanas modulis

Bezatlikumu produktu ranžēšanas modulī ir meklēti un analizēti bioproduktu (kliju pārkraušanas atkritumu) ražotnes blakusproduktu izmantošanas iespējas produktu ražošanai ar augstu pievienotu vērtību, izmantojot kvalitatīvās pētniecības metodi.

Tika identificēti 30 produkti, kuri tika iegūti no četriem kviešu blakusproduktiem – klijām, salmiem, miziņām un putekļiem. Visplašāk tiek izmantotas klijas, savukārt putekļus izmanto, lai ražotu tikai vienu produktu – biobāzētu iepakojumu [226]. Šajā modulī tika sadalīti produkti sešās grupās: iepakojuma materiāli, būvmateriāli, adsorbenti, kurināmais, siltumizolācijas materiāli un ķīmiskās vielas.

No pārskatītajiem produktiem *MCDA* vajadzībām tika atlasīti septiņi produkti. Analīzes mērķis ir atrast produktu ar visnozīmīgāko komercializācijas potenciālu, ņemot vērā vides, sociālos, ekonomiskos un tehniskos aspektus. No visām produktu grupām kurināmais un būvmateriāli netika tālāk apsvērti, jo šiem produktiem nav salīdzinoši augstas pievienotās vērtības. Tika konstatēts, ka kviešu klijas ir visplašāk izmantotā izejviela, tāpēc to produkti tika pārbaudīti *MCDA*. Attiecībā uz klijām tika pārskatītas deviņas publikācijas, apkopojot informāciju par trīspadsmit produktiem. Novērtējot par šiem produktiem pieejamos datus, 3.20. tabulā norādītie produkti tika atlasīti *MCDA*.

3.20. tabula parāda *MCDA* ievaddatus. Izņemot produktu cenu salīdzinājumu, visi kritēriji tika novērtēti piecu punktu skalā, pamatojoties uz apkopotiem datiem un ekspertu novērtējumiem. Tā kā produkti ir jauni, tie vēl nav plaši pētīti, un daudzos gadījumos dati tika ņemti no līdzīgiem produktiem.

Produkta TGL tika novērtēta tehnoloģijas pieejamība. TGL tika novērtēts, pamatojoties uz ekspertu atzinumu. Ja TGL bija četri vai mazāk, tam tika piešķirts rezultāts no 1 līdz 2; ja TGL bija 5 vai 6, tam bija 3 punkti; un, ja TGL bija 7 vai 8, produkts saņēma 4 punktus [227].

3.20.tabula

MCDA ievades dati

Kritērijs	Alternatīva						
	Micēlija bāzes kompozīts	Adsorbents	Biobāzēts PP kompozīts	Biobāzēta filma	Fermenti	Pienskābe	Viensūnu eļļa
Tehnoloģiju pieejamība	3	4	3	3	4	4	3
Ilgtspēja	5	4	4	4	5	5	5
Produktu cenu salīdzinājums, %	92,5	92,6	14,2	0,01	50	32,6	37,9
Tirgus pieprasījums	4	2	4	2	2	3	5
Ietekme uz vidi	4	5	3	2	3	4	5
Sociālie aspekti	5	4	5	5	3	3	4

Tika novērtēta produkta ilgtspējas atbilstība ANO ilgtspējīgas attīstības mērķiem [228]. Lauksaimniecības atlikumu izmantošana produktos ar augstāku pievienoto vērtību atbilst vismaz trim no septiņpadsmit mērķiem. Ja produkts sasniedza visus trīs mērķus, tika piešķirti 5 punkti; ja būtu mazāk mērķu, tad attiecīgi mazāk punktu.

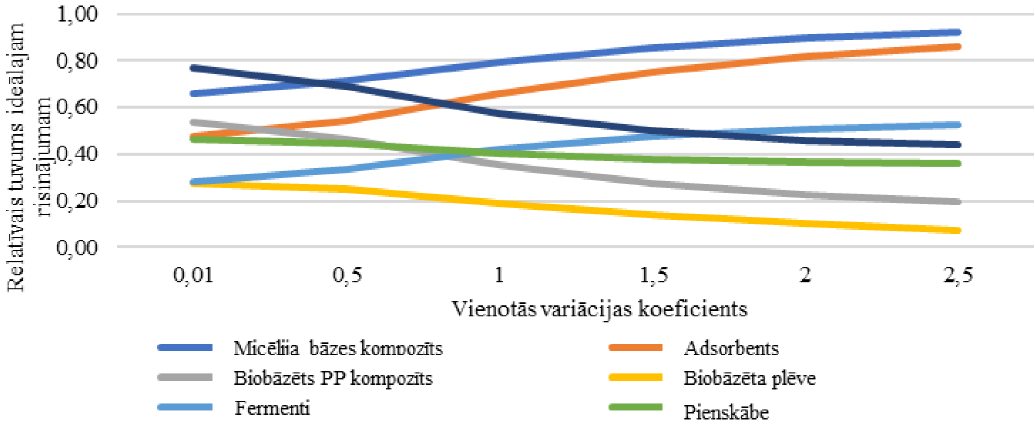
Produktu iespējamās cenas salīdzināja ar tradicionāli izmantotajiem produktiem un izteica procentos no cenu starpības. Izmantojot lauksaimniecības un rūpniecības blakusproduktus, micēliju saturoša biokompozīta izejvielu izmaksas ir 0,06–0,15 EUR/kg [229]. Nav datu par kopējām ražošanas izmaksām, bet uzskatāms, ka izejvielas veido lielāko daļu. Šāds materiāls tika salīdzināts ar polistirolu, kas maksā no 1,85–2,02 EUR/kg [229]. Komerciālās aktīvās ogles izmaksas ir 5,85 EUR/kg, kas tiek izmantots kā adsorbents, savukārt bioadsorbenta izmaksas ir 0,05–0,43 EUR/kg, kas ir ievērojami lētāk [157]. Biokompozītu ar PP salīdzināja ar pētījumu, kurā kviešu kliju vietā tika izmantotas koriandra šķiedras. PP granulām, pievienojot 40 % koriandra šķiedru, cena samazinājās no 1,27 EUR/kg līdz 1,09 EUR/kg [230]. Pārtikas plēve ar antioksidantu īpašībām, salīdzinot ar PLA, dabisku materiālu, kas izgatavots no raudzētas augu cietes. 2016. gadā PLA plēve maksāja 2 EUR/kg, savukārt zema blīvuma polietēns (*LDPE*), fosilā plastmasa, maksāja 1,25–1,45 EUR/kg [231]. Konkrētajā gadījumā produkta cena, iespējams, būtu zemāka, jo to iegūtu, izmantojot zemu izmaksu atlikumus. Aptuvens fermentu ražošanas cenu salīdzinājums parādīja, ka kviešu kliju izmantošana par izejvielu samazinātu cenu par līdz pat 50 % [160]. No alus darītavas izlietotajiem graudiem iegūtās pienskābes cena ir 0,76–1,11 EUR/kg, bet pienskābe parasti ir 1,64 EUR/kg [232]. Tā varētu būt līdzīga mūsu pienskābes cenai, jo pētījumā kā izejvielas izmantoti arī blakusprodukti. Ja vienšūnas eļļa tiktu ražota, izmantojot glikozi bez maksas, pieņemot atkritumu vai blakusproduktu plūsmas, tā izmaksātu 2,99 EUR/kg ar 10 000 tonnām gadā. Ja pieņem, ka glikozes cena ir 351,68 EUR/t, vienšūnu eļļas ražošanas izmaksas būtu 4,82 EUR/kg [233]. Šajā gadījumā dati ir balstīti arī uz pieņēmumiem, jo patiesībā kviešu klijām ir ekonomiska vērtība.

Tirgus pieprasījums tika mērīts pēc pasaules produktu tirgus lieluma. Globālais biokompozītu tirgus 2020. gadā bija 18,44 miljardi EUR [234]. 2020. gadā globālais adsorbentu tirgus bija 3,43 miljardi EUR [235]. Tika lēsts, ka globālais bioplastmasas tirgus 2020. gadā bija 5,1 miljards EUR [236]. Pasaules fermentu tirgus vērtība 2019. gadā bija 7,6 miljardi EUR [237]. Organisko skābju tirgus 2021. gadā bija 9,69 miljardi EUR [238]. Šajā pētījumā [169], autori uzskata, ka vienšūnas eļļu varētu pievienot tirgos, kas nav biodegvielas tirgi, piemēram, ražojot augstākas kvalitātes taukskābju bāzes oleoķīmiskas vielas. 2020. gadā pasaules tauku pārstrādes produktu tirgus bija 27,62 miljardi EUR [239]. Tā kā datubāzes gadi atšķiras, tika ņemti vērā arī ekspertu viedokļi. Pieprasījums tirgū tika izteikts piecu punktu sistēmā, salīdzinot produktu tirgus apjomus.

Ietekme uz vidi tika novērtēta piecu punktu līmenī, ņemot vērā ražojuma emisijas ražošanas laikā salīdzinājumā ar pašlaik izmantotajiem ražojumiem. Jo lielāks ir emisiju ietaupījums, jo augstāks ir produkta vērtējums. Savāktie dati bija nepilnīgi, tāpēc šajā kritērijā tika iesaistīti arī eksperti. Micēlija bāzes kompozīts tika salīdzināts ar *MycoBamboo*, materiālu ar bambusa daļiņām un micēliju. Šāda parauga ražošana izdala 86 g CO_2ekv. uz plati, bet 27 g CO_2/ekv. uz plati, ja dabasgāzes vietā izmanto atjaunojamo enerģiju. Katrs *MycoBamboo* paraugs svēra aptuveni 33 g [240]. Materiālu varētu salīdzināt ar ekstrudētu putupolistirolu, kura globālais sasilšanas potenciāls ir no 13,22 kgCO_2ekv. līdz 1,75 kg putām [241]. Izmantojot kviešu kliju šķiedru, lai iegūtu biokompozītu ar PP, var samazināt emisijas par 1470 kgCO_2ekv./t un radīt enerģijas ietaupījumu 2130 MJ/t salīdzinājumā ar tīru PP materiālu [145]. Pārtikas plēve tika salīdzināta ar PLA plēvi, kuras izmeši ir 0,27 kgCO_2ekv./m^2. Plēves svars ir 0,6 kg uz 10 m^2 [242]. PLA tika salīdzināta ar LDPE plēvi ar emisijām 0,11 kgCO_2ekv./m^2 un svaru 0,5 kg uz 10 m^2 [242]. Pārskatītajos pētījumos ir aplūkotas arī emisijas no izejvielu ieguves, kas varētu būt zemākas mūsu pētījumā iekļautajiem produktiem, jo izejvielas ir lauksaimniecības blakusprodukti.

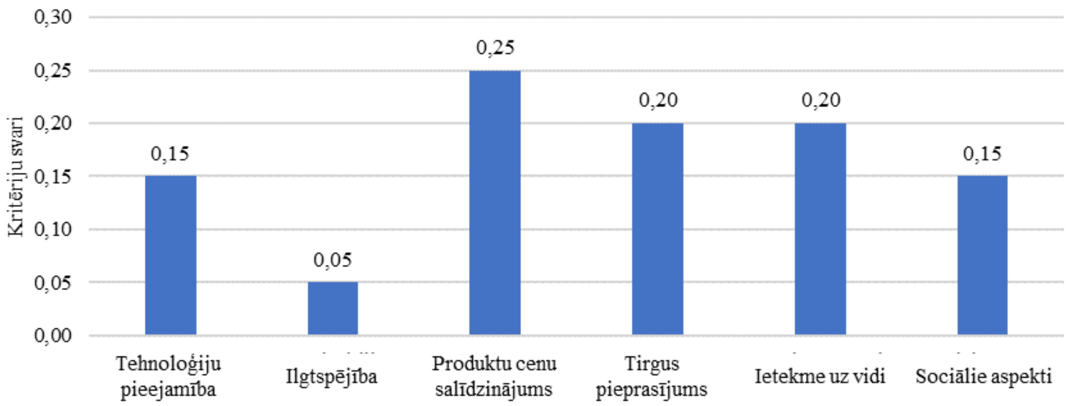
No sociālā viedokļa eksperti novērtēja produkta ražošanas procesā iesaistītā darbaspēka daudzumu. Ja produkta ražošana ir automatizēta un neprasa daudz darba, tad tai tika piešķirti 1–3 punkti, jo tādā gadījumā rūpnīca neradīs salīdzinoši lielu darba vietu skaitu. Bet, ja ražošanas process nav diezgan automatizēts, tad tika piešķirti 4–5 punkti, jo rūpnīca radītu jaunas darba vietas, kas uzlabotu sociālo situāciju valstī.

Kritēriju svari tika noteikti, izmantojot jutīguma analīzi. Jutīguma analīze parādīja, ka ilgtspējas aspektam ir viszemākā jutība pret svara izmaiņām, ko var noteikt arī, aplūkojot ievades datus, jo visas alternatīvas ieguva 4 līdz 5 punktus. Tāpēc šim kritērijam tika piešķirts zemākais svars (0,05). Arī tehniskajiem un sociālajiem aspektiem bija nelielas svara izmaiņas salīdzinājumā ar citiem kritērijiem, tāpēc tiem tika piešķirts svars 0,15. Ietekme uz vidi un tirgus pieprasījums kļuva jutīgāki pret svara izmaiņām, kad vienotais mainīgais koeficients svārstījās no 0,5 līdz 1,5, tāpēc šiem kritērijiem piešķirtā nozīme ir 0,2. Produkta cenu salīdzinājums visvairāk reaģēja uz svara izmaiņām, visticamāk, tāpēc, ka ievades dati atšķīrās vairāk. Galu galā, tie netika izteikti piecu punktu skalā. Šī kritērija jutīguma analīzes rezultāti grafiski parādīti 3.21. attēlā.



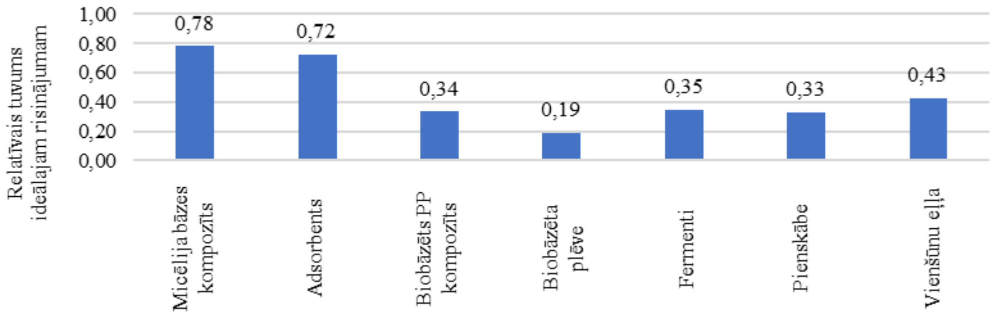
3.21. att. Jutīguma analīzes rezultāti produktu cenu salīdzināšanai.

Visu kritēriju svari ir parādīti 3.22.attēlā.



3.22.. att. Kritēriju svars (*TOPSIS*).

TOPSIS aprēķini tika veikti, izmantojot ievades datus un iegūtos kritēriju svarus. Iegūtie rezultāti grafiski atainoti 3.23. attēlā. Rezultāti parādīja, ka vislielākais relatīvais tuvums analizēto produktu ideālajam gadījumam ir biokompozīta materiālam uz micēlija bāzes. Tas galvenokārt ir saistīts ar salīdzinoši augsto produktu cenu atšķirību. Ja šis kritērijs nebūtu ņemts vērā, vienšūnas eļļa būtu ieguvusi visaugstāko rezultātu, ko var novērtēt arī, aplūkojot ievades datus. Adsorbentam ir arī salīdzinoši labi rezultāti, jo tā cena un ietekme uz vidi ir daudz zemāka nekā pašlaik izmantotajiem adsorbentiem. Sliktāko rezultātu ieguva pārtikas plēve ar antioksidantu īpašībām. Tas ir tāpēc, ka dati par šo produktu tika izmantoti no PLA parametriem, un PLA tika salīdzināts ar *LDPE*, kam pašlaik ir zemākas ražošanas emisijas un cenas nekā bioplastmasai. Arī bioplastmasai ir mazāks tirgus pieprasījums, kas ir jāuzlabo. Arī bioplastmasai ir mazāks tirgus pieprasījums, kas ir jāuzlabo. Tomēr dati netika ņemti tieši par izvēlēto produktu. Produkta parametri ir labāki, jo tos iegūst no klijām, nevis kukurūzas, ar atšķirīgām ekstrakcijas īpašībām, piemēram, ūdens patēriņu un ražu [242].



3.23. att. *TOPSIS* rezultāti.

Bezatlikumu tehnoloģiju ranžēšanas modulis

Bezatlikumu tehnoloģiju ranžēšanas modulī ir meklētas un analizētas ražotnes blakusproduktu pārstrādes tehnoloģisko procesu izmantošanas iespējas, izmantojot kvalitatīvās pētniecības metodes. Kā gadījumizpētes piemērā tika salīdzinātas ekstrakcijas metodes, ar kurām iegūt ēteriskās eļļas.

Pieaugot iedzīvotāju skaitam visā pasaulē, pieaug arī augļu un dārzeņu ražošana un audzēšana. Turklāt pārtikas atkritumiem ir ilgstoša ietekme uz atkritumu poligoniem un sociālekonomisko ietekmi, jo tiem ir lielāks mitrums un bioloģiskā noārdīšanās spēja [243]. Tāpēc pārtikas atkritumu apsaimniekošana kļūst par galveno problēmu visā pasaulē, bet, izmantojot progresīvas tehnoloģijas, pārtikas atkritumi var būt daudzpusīgs vides bioresurss, ko var pārvērst biodegvielā, produktos ar pievienoto vērtību un biomateriālā [244]

Šis pētījums īpaši koncentrējas uz augļu atkritumu valorizācijas ceļiem, jo ir veikti milzīgi pētījumi par augļu atkritumu nonākšanu poligonos, anaerobo pārstrādi, kompostēšanu utt. [245]. *Pfaltzgraff et al.* apgalvo, ka augļu atkritumi ir ne tikai plašs enerģijas avots, bet tiem ir arī neticama spēja ražot rūpnieciskus produktus, piemēram, ēterisko eļļu, zāles, kosmētiku, organiskos produktus utt. [246]. Katrai augļa daļai, piemēram, mizai, mīkstumam un sēklām, ir unikāls atlikušais un ķīmiskais sastāvs, ko var izmantot dažādu bioloģisko produktu ražošanai.

Tradicionāli augļu mizas ir visizplatītākie atkritumi, kurus var viegli atrast vidē. Augļu mizām piemīt vislabākās ārstnieciskās īpašības, piemēram, pretmikrobu, antioksidants, pretiekaisuma, pretinfekcijas, antimutagēns un hepatoprotektīvs. Ēteriskā eļļa ir viena no būtiskākajām augļu mizām, pētnieki pēc vairākiem eksperimentiem ir atklājuši, ka ēteriskajai eļļai ir aktivitāte pret baktērijām, pelējuma sēnītēm, raugiem un patogēniem un fitopatogēniem mikroorganismiem. Tā rezultātā ir pierādīts, ka ēterisko eļļu var izmantot, lai mikroorganismus ar antibiotikām nonāvētu [247]. Daži piemēri ir minēti 3.21. tabulā.

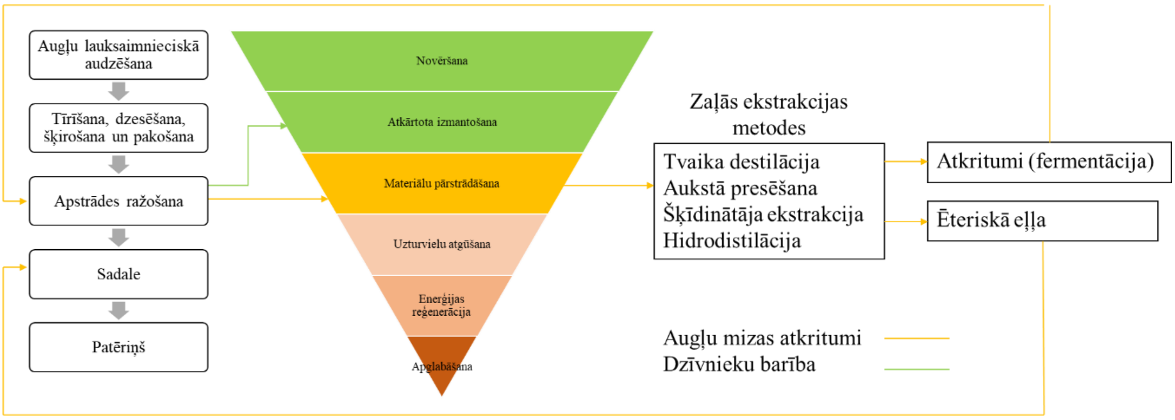
3.21. tabula

Augļu atkritumi medicīniskai lietošanai

Augļu atkritumi	Produkts ar pievienoto vērtību	Medicīniskā pielietošana	Metodes	Atsauce
Banānu miza	Ēteriskā eļļa	Antioksidanta īpašība	Ekstrakcija	[247]
Citrusaugļu miza	Ēteriskā eļļa	Mazina sāpes Mazina iekaisumu Izšķīdina žultsakmeņus	Ekstrakcija	[248]
Apelsīna miza	Ēteriskā eļļa	Antimikrobiālā iedarbība Zāļu aromatizētājs	Destilācija ar tvaiku Aukstā presēšana Šķīdinātāja ekstrakcija Tvaiku absorbēšana	[247], [249]
Mango miza	Pektīns	Ieguvumi veselībai	Ekstrakcija	[250]
Greipfrūtu miza	Ēteriskā eļļa	Antibakteriālas un antioksidantu īpašības Biopesticīds pret moskītu kāpuriem	Papīra disku difūzija	[251]

Viena no būtiskākajām sastāvdaļām, ko var iegūt no augļu mizas (ābolu izspaidas, citrusaugļi, cukurbiešu mīkstums), ir pektīns. Agrākie pētījumi liecina, ka pektīns ir efektīvs komponents rūpnieciskā līmenī un noderīgs arī vēža, šūnu apoptozes ārstēšanā un holesterīna novēršanai [252]. Vairākos pētījumos atklāts, ka augļu mizas atkritumi var lietot medikamentos.

Ēteriskā eļļa ir koncentrēts hidrofobs šķidrums, kas dabiski iegūts no augiem [253]. Nesenā sistemātiskā pārskatā tika pētīta ēterisko eļļu plašā izmantošana kosmētikas rūpniecībā un ikdienas dzīvē smaržu [254], un farmācijas industrijas dēļ [255], kas liecina par pieaugošo pieprasījumu pēc ēteriskās eļļas tirgū. Ekstrakcijai var droši izmantot dažādas metodes. 3.24. attēls parāda skaidru vīziju par ēteriskās eļļas ieguves ceļu no augļu atkritumiem. Autore iepazīstina ar ēteriskās eļļas ekstrakciju no augļu mizas atkritumiem.



3.24. att. Ēterisko eļļu ieguves ceļš.

Sākotnēji tika salīdzināti tehnoloģiskie, ekonomiskie, vides un sociālie kritēriji. AHP kritēriju pāra salīdzinājuma rezultāti ir parādīti 3.22. tabulā.

3.22. tabula

AHP kritēriju pāru salīdzināšanas matrica

Kritēriji	**Tehnoloģiskie**	**Ekonomiskie**	**Vides**	**Sociālie**
Tehnoloģiskie	1	3	2	4
Ekonomiskie	0,33	1	2	3
Vides	0,5	0,5	1	4
Sociālie	0,25	0,33	0,25	1

Tika aprēķināti kritēriju svari pēc matricas normalizācijas. Rezultāti rāda, ka tehnoloģiskā kritērija svars ir vissvarīgākais – 0,45, tad kā otrs būtiskākais svars ir ekonomiskais – 0,25, tad trešais un ceturtais kritērijs ir vides un sociālais, kas ir – attiecīgi – 0,22 un 0,08.

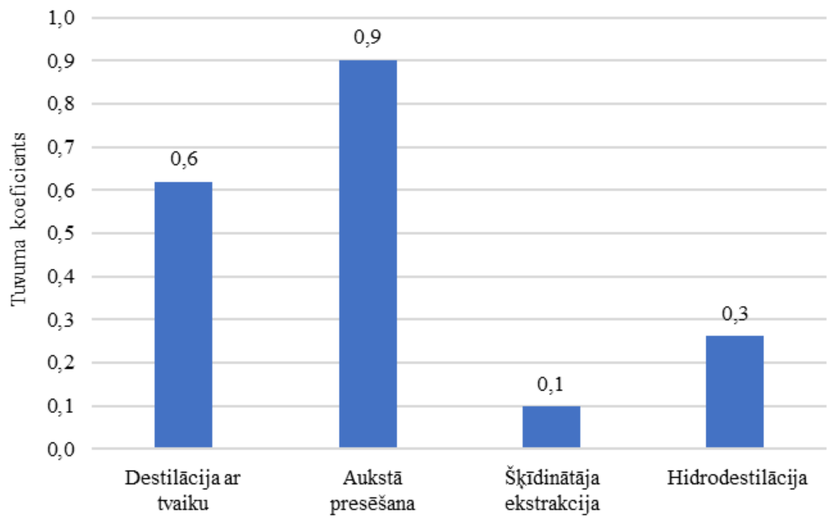
Salīdzinājumi ir konsekventi un tiek izmantoti šādos aprēķinos, ņemot vērā, ka konsekvences koeficienta vērtība ir CR=0,079. Ja CR ir mazāks vai vienāds ar 0,1, tad neatbilstība ir pieņemama, bet subjektīvais novērtējums ir jāpārskata, ja tas ir lielāks par 0,1.

3.23. tabula

TOPSIS Lēmumu pieņemšanas matrica

Alternatīvas tehnoloģijas	Kritērijs			
	Tehnoloģiskais	Ekonomiskais	Vides	Sociālais
Destilācija ar tvaiku	4	4	3	4
Aukstā presēšana	4	5	4	3
Šķīdinātāja ekstrakcija	3	3	3	4
Hidrodestilācija	3	3	4	4

Četru tehnoloģiju izmantošanas potenciāls tika novērtēts skalā no 1, kas atbilst zemākajam vērtējumam, līdz 5, kas atbilst augstākajam vērtējumam. 3.23. tabulā tiek parādītas novērtēšanas vērtības lēmumu pieņemšanas matricā.



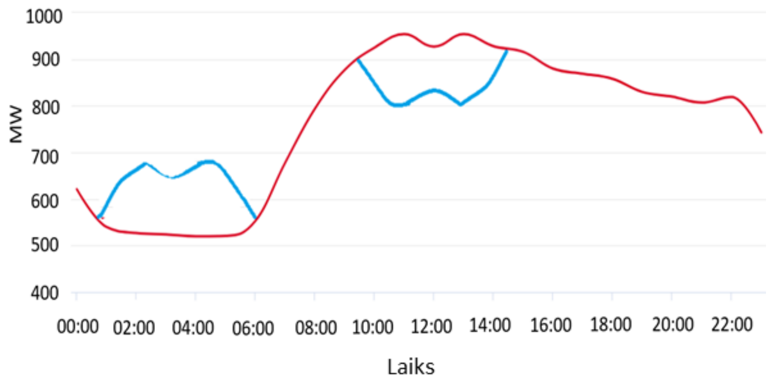
3.25. att. *TOPSIS* sarindošanas tehnoloģiju rezultāti.

TOPSIS analīzes rezultāti ir parādīti 3.25. attēlā. Aukstā presēšana (0,9) ir tuvākā alternatīva vislabākajam risinājumam, ne tikai tehnoloģiskajam kritērijam, kuram ir vislielākais svars no visiem kritērijiem (0,45) un laba veiktspēja ekonomiskajā kritērijā ar otro lielāko ietekmi uz rezultātiem. Tvaika destilācija ierindojas kā otrā tehnoloģija, novērtējot 0,6, un trešais iespējamais tehnoloģiskais risinājums ir hidrodestilācija ar 0,3 un šķīdinātāja ekstrakcija – 0,1.

Energoresursu lietotāja pārvaldības modulis

Energoresursu lietotāja pārvaldības modulī, izmantojot kvalitatīvās pētniecības metodes, tika meklētas un analizētas agregatoru iespējas un potenciāls.

Tiek izšķirtas divas dažādas pieejas agregatoru apkopošanai – mājsaimniecību agregācijai un agregācijai apstrādes rūpniecībā. Mājsaimniecību sektors nozīmē, ka kopējais elektroenerģijas apjoms ir daudz mazāks. Agregatoram, kas strādā ar mājsaimniecībām, būtu nepieciešams liels mājsaimniecību portfelis, lai radītu ietekmi un veiktu rentablu uzņēmējdarbību. Kā autorei neformālā intervijā skaidroja uzņēmējs no Francijas, kurš strādā agregācijas jomā un kuram ir pilotprojekts Igaunijā, mājsaimniecību agregatori koncentrējas uz tādām sadzīves ierīcēm kā elektriskie sildītāji, katli, siltumsūkņi, gaisa kondicionieri un termostati. Tos var viegli kontrolēt attālināti, netraucējot patērētāju ikdienas dzīvi, kuri nejustu diskomfortu elektroenerģijas patēriņa ierobežojumu dēļ. Tomēr, kā paskaidroja iepriekš minētais uzņēmējs, agregatoram ir jābūt vismaz 10 000 patērētājiem, kuri ietaupa 5 kWh dienā, lai padarītu to par rentablu biznesu. Piemēram, vispārīgs pārskats par elektroierīču tiešsaistes piedāvājumiem paredz, ka vidēji centrālais gaisa kondicionieris vai siltumsūknis patērē ap 5–15 kW stundā, tāpēc elektroenerģijas patēriņa samazinājums par 5 kWh dienā nav tik liels, ņemot vērā, ka daļa no elektroenerģijas daudzuma vēl tiktu patērēta, bet citā diennakts laikā, kad elektrības cenas ir zemākas. Piemēram, 3.26. attēls rāda elektroenerģijas pieprasījumu Latvijā 2020. gada 3. augustā. Sarkanā līnija ir faktiskais pieprasījums, bet autore ir novilkusi zilo līniju, lai parādītu, kā agregators varētu izlīdzināt pieprasījumu pīķa stundās, novirzot to uz citu diennakts laiku.



3.26. att. Elektroenerģijas patēriņš MWh/stundā Latvijā 2020. gada 3. augustā [256].

Piemēram, valstij piederošajam elektroenerģijas piegādātājam AS “Latvenergo” kā elektroenerģijas klienti ir ap 700 000 mājsaimniecību [257], līdz ar to 10 000 patērētāju portfeļa izveide, kas būtu gatava iesaistīties pieprasījuma reaģēšanas aktivitātēs, nebūtu neiespējama. Turklāt kombinētam agregatoram pat nav vajadzīgs tik daudz patērētāju, jo starp agregatoru un elektroenerģijas piegādātāju pastāvētu cilpa, kurā agregatora radītie ienākumi pēc būtības paliktu tam pašam uzņēmumam (piegādātājam) un tādējādi piegādātājam nerastos faktiskas izmaksas. Otrajam lielākajam elektroenerģijas piegādātājam Latvijā AS “Enefit” kā elektroenerģijas klienti ir gandrīz 6000 mājsaimniecību elektroenerģijas klientu [258], tādējādi nodrošinot arī jau esošu lielo klientu bāzi, kur daļa no tiem varētu nodarboties ar pieprasījuma reakciju.

Ja agregatoram ir agregācijas līgumi ar 10 000 patērētāju, kas dienā patēriņu samazina par vismaz 1 kWh (nevis 5 kWh, jo lielākā daļa no kopējā apjoma tiek pārvietota uz citu atskaites periodu un netiek samazināta), tie ir 10 MWh dienā jeb 3650 MWh gadā pēc aptuveniem aprēķiniem. Latvijas elektroenerģijas patēriņš gadā ir ap 7 TWh. Tas nozīmē, ka agregators varētu samazināt gada elektroenerģijas patēriņu Latvijā vismaz par 0,05 %. Tas var nešķist daudz, bet vienam agregatoram tas nav slikts rezultāts un kalpotu arī kā līdzeklis nacionālo enerģētikas un klimata mērķu sasniegšanai [259].

Tomēr, ņemot vērā nepieciešamo klientu skaitu, kas vajadzīgs, lai agregatoru uzņēmējdarbība būtu rentabla, pagaidām nešķiet reāli, ka tirgū ienāk neatkarīgs agregators, ja vien tas nav starptautisks ieguldītājs, kas nāk ar savu uzņēmējdarbību no citas ES valsts, kurai jau ir liels tirgus portfelis. Pašreiz valstī spēkā esošie tiesību akti neļauj neatkarīgam agregatoram ienākt tirgū, jo pastāv prasība, ka agregatoram jābūt saistītam ar to pašu balansēšanas pakalpojumu sniedzēju, ar kuru ir saistīts patērētāja objekts, ko paredzēts izmantot pieprasījumreakcijas pakalpojumā. Šim balansēšanas pakalpojumu sniedzējam būtu jādod atļauja agregēšanai [260]. Tas nozīmē, ka agregatoram ir jāsaskaņo savas darbības ar patērētāja elektroenerģijas piegādātāju, kas ir arī balansatbildīgā puse. Tādējādi, ja patērētāja piegādātājs nepiekrīt, agregators nevar piedalīties agregēšanā. Tomēr tas neattiecas uz Direktīvu 2019/944, kurā paredzēts, ka ne patērētājam, ne neatkarīgajam agregatoram nav jākoordinē savstarpējā vienošanās un pieprasījumreakcijas izmantošana ar elektroenerģijas piegādātāju un/vai tā balansēšanas pakalpojumu sniedzēju. Direktīvas 2019/944 noteikumi ir jāievieš līdz 2020. gada 31. decembrim, tāpēc tuvākajā laikā tie ir jāmaina.

Grozītais valsts regulējums dotu iespēju agregatoriem piedalīties ne tikai balansēšanas tirgū, bet arī esošās dienas un nākamās dienas tirgos, un ES tiesiskais regulējums ļauj dalībvalstīm ieviest kompensācijas mehānismu piegādātājiem. Jautājums ir par to, kā noteikt taisnīgu atlīdzību, lai agregatori nenostumtu piegādātāju neizdevīgā stāvoklī.

3.24. tabula

Apkopošanas ekonomiskie aspekti

A. Nav pieprasījuma reakcijas	**B. Pieprasījuma reakcija bez kompensācijas**
1. Piegādātājs prognozē patēriņu 20 MWh	1. Piegādātājs prognozē patēriņu 20 MWh
2. Piegādātājs iepērk *NordPool* 20 MWh elektroenerģiju x 50 EUR/MWh = 1000 EUR	2. Piegādātājs iepērk *NordPool* 20 MWh elektroenerģiju x 50 EUR/MWh = 1000 EUR
3. Piegādātājs pārdod patērētājiem 20 MWh elektroenerģiju par 50 EUR/MWh = 1000 EUR	3. Agregators aktivizē pieprasījumreakciju un samazina patērētāju patēriņu par 2 MWh
	4. Piegādātājs pārdod patērētājiem 18 MWh elektroenerģiju par 50 EUR/MWh = 900 EUR
	5. Piegādātājs pieprasījuma reakcijas dēļ zaudē 100 EUR (2 MWh x 50 EUR/MWh)

3.24. tabulā parādīts hipotētisks piemērs par apkopošanas ekonomiskajiem aspektiem. Scenārijs A ir parastie apstākļi – piegādātājs iepērk prognozēto elektroenerģijas daudzumu no *NordPool* elektroenerģijas biržas un piegādā to patērētājiem. Tomēr B scenārijs ievieš pieprasījuma reakciju. Piegādātājs prognozē tādu pašu patēriņa apjomu un *NordPool* elektroenerģijas biržā pērk elektroenerģijas daudzumu, kas parasti būtu nepieciešams patērētājiem. Tomēr, pateicoties līgumam ar agregatoru, patērētāji galu galā patērē mazāk, nekā tika prognozēts. Tātad piegādātājs ir nopircis 20 MWh, bet tas var pārdot tikai 18 MWh, kā rezultātā piegādātājs ir zaudējis 100 EUR. Tā ir aptuveni tāda pati summa, kādu iegūs agregators (pieņemot, ka agregators ir pārdevis arī savus apkopošanas pakalpojumus par 50 EUR/MWh x 2

MWh = 100 EUR). Izprotot piegādātāja situāciju, ja lūgtu agregatoru kompensēt zaudējumus, agregatoram nebūtu ekonomiska pamatojuma.

Tomēr šeit ir vēl viena iespēja, ko var uzskatīt par godīgu. Dažos pētījumos ir novērots, ka tad, kad agregators sniedz savus pakalpojumus elektroenerģijas tirgum, kopējā elektroenerģijas cena *Nordpool* elektroenerģijas biržā samazinās, jo dārgākās ražošanas vienības tiek izslēgtas no solīšanas [184]. Tā rezultātā piegādātājs gūst labumu, jo viņš par 20 MWh ir samaksājis mazāk, nekā viņš būtu samaksājis, ja nebūtu pieprasījuma reakcijas.

Piemēram, *NordPool* cena bez pieprasījuma reakcijas varētu būt 55 EUR/MWh. Tādējādi piegādātājs būtu nopircis tās pašas 20 MWh par 1100 EUR (par 100 EUR vairāk). Šajā gadījumā piegādātājs neko nezaudē – viņš samaksājis *NordPool* par 100 EUR mazāk, kas ir tā pati summa, ko viņš zaudējis pieprasījuma reakcijas dēļ, nepārdodot 2 MWh (B scenārijs). Tā rezultātā piegādātājam nav neto zaudējumu, un agregatoram nebūtu jāmaksā nekāda kompensācija piegādātājam.

Vēl viens piemērs varētu būt, kur *NordPool* cena bez pieprasījuma reakcijas ir 52 EUR/MWh. Šajā gadījumā piegādātājs būtu samaksājis 1040 EUR par 20 MWh (par 40 EUR vairāk). Šeit piegādātājs ir ieguvis 40 EUR *NordPool*, bet zaudējis 100 EUR, nepārdodot 2 MWh. Tātad piegādātāja neto zaudējumi ir 60 EUR. Tā ir summa, kas agregatoram būtu jākompensē piegādātājam.

Ņemot vērā iepriekš minēto, būtu taisnīgi, ja gan piegādātājs, gan agregators ieviestu šādu kompensācijas mehānismu. Tomēr šajā gadījumā izaicinājums ir noteikt, kāda būtu bijusi *NordPool* cena bez apkopošanas. Iespējamais risinājums būtu, ja *NoordPool* sniegtu šādus datus un pārvades sistēmas operators aprēķinātu norēķinu summu. Tas novestu pie centrālā norēķinu modeļa, kurā kompensācijas mehānismu pārvalda pārvades sistēmas operators [261].

Tikmēr jāņem vērā vēl viena detaļa, ka ne visi elektroenerģijas patērētāji šobrīd varētu vienoties ar agregatoru, jo ne visi elektroenerģijas patērētāji ir aprīkoti ar viedajiem elektroenerģijas skaitītājiem, kas ievaddaļā tika minēti kā priekšnoteikums pieprasījuma reakcijas pakalpojumu saņemšanai. Šobrīd Latvijā aptuveni 60 % no visiem elektroenerģijas skaitītājiem ir viedie skaitītāji, taču plānots, ka līdz 2022. gadam visi elektroenerģijas skaitītāji tiks atjaunināti uz viedajiem skaitītājiem [262].

SECINĀJUMI

- Ar daudzpusīgu metožu izmantošanu var novērtēt pastāvīgu uz zināšanām un kompetencēm balstītu ilgtspējīgu vides inženierijas izglītību un analizēt trijos līmeņos: akadēmiskās augstākās izglītības, mūžizglītības un zinātniskās jaunrades.
- Klimatneitralitātes un *Zaļā kursa* mērķus var iespējams sasniegt, ja tiek īstenota uz zināšanām un kompetencēm balstīta vides inženierijas izglītība akadēmiskās augstākās, mūžizglītības un zinātniskās jaunrades līmeņos.
- Ar biblimetrisko metodi bibliometriskās analīzes modulī var meklēt un analizēt bioekonomikas nozares zinātniskās izpētes jomas svarīgums, kā arī Eiropas Savienības klimata politikas Zaļā kursa ietvaros saiknis ar bioekonomikas izglītību.
- Ilgtspējīgas inovācijas un bioekonomikas rādītāji un ilgtspējīgas attīstības kompetences bioekonomikas izglītībā ietver starpdisciplināro kompetenci, mācīšanās kompetenci, transdisciplināro kompetenci un sistēmiskās domāšanas kompetenci, prognozēšanas kompetenci, normatīvo kompetenci, stratēģisko kompetenci un starppersonu kompetenci. Visas šīs kompetences ir izrādījušās vissvarīgākās bioekonomikas mērķu īstenošanai un pārejai uz zināšanām balstītu ilgtspējīgu bioekonomiku.
- Daudzfaktoriālās analīzes rezultāti nosaka, ka lekcijas, objektu apmeklējumus, grupu kursa darbus un laboratorijas darbus kopā ar lomu spēļu simulācijām ir jāiesaista lielākajā daļā studiju procesā. Ar izstrādāto vērtēšanas sistēmu var novērtēt vides inženierijas studiju programmu. Piedāvātā sistēma vides inženierijas studiju programmas novērtēšanai tika pārbaudīta un aprobēta jaunajās Rīgas Tehniskās universitātes maģistra studiju programmās vides inženierijā un bioekonomikā.
- Koprades īstenošanas modulī, analizējot uzņēmuma pārstāvju atsauksmes, pētījuma autore var secināt, ka uzņēmums noteiktas vajadzības sāk apzināties tikai pasākuma beigās. Cieša sadarbība ar akadēmisko personālu ļauj identificēt slēptos mērķus. Aptaujas rezultāti liecina, ka kopumā dalībnieki ir apmierināti ar pašu notikumu un tā sekām. Komandas locekļi augstu novērtē savu ieguldījumu komandas kopējā rezultātā un pieņem, ka gūtā pieredze palīdzēs viņiem veiksmīgāk sasniegt rezultātus nākotnē.
- Kā liecina daudzfaktoriālās analīzes rezultāti, augstākās akadēmiskās izglītības attīstība realizējama, izmantojot inovatīvas metodes, līdzekļus un rīkus.
- Meža resursiem ir potenciāls kļūt par būtisku Latvijas biodiplomātijas sastāvdaļu. Rezultātu nozīme ir tāda, ka politikas veidotājiem būtu jāveido biodiplomātija, jāņem vērā galvenie virzītājspēki kā pieprasījums, apjoms un atjaunošana, kur jābūt uzsvariem.
- Uzvedības simulācijā tika sasniegts (1) lomu spēles mērķis – sadalīt *Covid-19* ārkārtas atveseļošanas atbalsta finansējumu, ņemot vērā ES bioekonomikas stratēģijas mērķus un *Covid-19* ietekmi uz primāro resursu ražošanu un izmantošanu starp trim galvenajām bioresursu grupām: mežsaimniecība, lauksaimniecība; zivsaimniecība un akvakultūras; (2) ņemot vērā gūtās atziņas, idejas jāiesniedz Ministru kabinetam, pašvaldībām, dažādām atbildīgajām institūcijām u. c.; (3) lauksaimniecības grupas dalībnieki ir apguvuši biodiplomātijas kompetences bioekonomikas kontekstā, kas raksturo

biodiplomātus. Jo augstāks ir kategorijas kritēriju novērtējums attiecīgajai kompetencei, jo lielāka iespēja, ka tiks sasniegti *Zaļā kursa* izvirzītie mērķi.

- Izveidotais mūžizglītības studiju ietvars rāda pieeju *Zaļā kursa* un klimatneitralitātes mērķu sasniegšanai, izmantojot kopradi, veiktspēju un politisko instrumentu integrēšanu.
- Pētījuma laikā var ar izstrādāto mērķauditorijai piemēroto bezmaksas masīva atvērtā tiešsaistes kursa izmēģinājuma versiju iegūt atbilstošas kompetences, lai risinātu pašreizējās un nākotnes enerģijas un klimata problēmas, izmantojot sistēmas domāšanas teoriju un prizmu.
- Kā liecina kvalitatīvie un daudzfaktoriālās analīzes rezultāti, zinātnē balstīta izglītība un zinātniskā jaunrade ļauj attīstīt komercializāciju un jaunu ideju attīstību.
- Ar kvalitatīvās pētniecības metodi bezatlikumu tehnoloģiju ranžēšanas modulī var meklēt un analizēt ražotnes blakusprodukτu pārstrādes tehnoloģisko procesu izmantošanas iespējas.

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Multi-Criteria Decision Analysis Methods Comparison

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***Abstract* – Multi-criteria decision analysis (MCDA) is widely used to solve various decision problems through alternative evaluation. MCDA methods can be used in every field that can define a problem, alternatives and criteria. However, finding the appropriate method can influence the results, in this research five MCDA methods have been tested on the renewable energy sector in Latvia to find the best alternative. The main results showed that TOPSIS, VIKOR and PROMETHEE-GAIA have similar priority selection and the highest ranking was selected for hydropower plant, but MULTIMOORA and COPRAS results were beneficial to Solar PV.**

***Keywords* – COPRAS; MCDA; MULTIMOORA; PROMETHEE-GAIA; renewable energy; TOPSIS; VIKOR.**

1. INTRODUCTION

Multi-criteria decision analysis (MCDA) is a multi-step process consisting of a set of methods to structure and formalise decision-making processes in a transparent and consistent manner [1]. Over the years, MCDA has developed many methods and software to resolve the defined problems. To use the methods, it is important to define the problem, alternatives, and criteria that may be different types of costs, environmental impact indicators, social indicators, energy efficiency, quality and other specific criteria that are relevant to the problem. When there are many alternatives for one problem, it is important to find the most suitable alternative with the best cost criteria, lowest impact on environment, and good energy efficiency. This can be achieved by using the MCDA method as a tool for comparing alternatives.

There are many methods that can be used for solving problems and they can be arranged according to different parameters. Each MCDA method has its own calculation method by which alternatives are queued and it is not possible to claim that using specific methods with the same input data will lead to the same final result. Methods can be selected by the type of result [2]. If the result is required as a comparison of values, AHP, MULTIMOORA, MAUT, Weighted Sum Method, Weighted Product Method and other methods can be used. Using AHP, TOPSIS, and VIKOR, COPRAS, STEP and other methods can be used to reach the defined goal and to find the best alternative from the provided options. PROMETHEE and ELECTRE methods are based on pairwise comparison and conformity assessment for the desired purpose.

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There is a possibility to get the same results using different methods: TOPSIS and VIKOR [3], VIKOR and PROMETHEE [4] methods lead to quite similar results, TOPSIS and COPRAS results are practically the same except for two alternatives [5], MULTIMOORA, TOPSIS and VIKOR [6], VIKOR, COPRAS and PROMETHEE [7], COPRAS and VIKOR [8] method lead to the same results. But there might be results that do not match, for example, VIKOR, COPRAS and TOPSIS results [9] and MULTIMOORA and PROMETHEE [10] ranking results.

There are many MCDA methods and each method has its own definition of best alternative and it is not determined if using same input data in different MCDA methods will give the same results. To see how similar or different results might evolve from five MCDA methods – a comparison of TOPSIS, VIKOR, COPRAS, MULTIMOORA, and PROMETHEE-GAIA methods are made, using data about renewable energy technologies alternatives in Latvia. The alternatives applied are solar photovoltaic (Solar PV), wind power plants (WPP), hydropower plants (HPP) and biomass, and biogas combined heat and power (CHP) (Bio-energy CHP). To compare the methods, seven criteria are used about cost, CO_2 emissions and electrical capacity. After this comparison, it will be possible to see what results the MCDA methods provide, similar or different, and which renewable energy technologies are best for Latvia.

2. METHODS

MCDA methods can be selected by their properties and requirements. A summary of properties applies through the TOPSIS, VIKOR, COPRAS, MULTIMOORA, PROMETHEE-GAIA and AHP methods to select the most appropriate method by data and ranking type, software, input and output data are provided in Table 1. This comparison was done to see similarities and differences between methods.

In the Analytical Hierarchy Process (AHP) method, alternatives are listed and then compared pairwise according to their contribution to reaching each objective or criterion [1]. This method was developed by Thomas L. Saaty and is one of the popular methods to find weight of criteria.

For all selected methods subjective data are criteria weights. The TOPSIS method requires minimal input data and results are easy to understand and it is with shortest geometrical distance to ideal result [2]. The VIKOR method focuses on alternative ranking by closeness to best solution and the maximum and minimum values of the criteria give impact to result [3]. COPRAS method takes into account performance of the alternatives with best and worst values which affect the result [4]. With MULTIMOORA method it is possible to determine the objectives of conflicting criteria and it has a ratio system and reference point calculation method [5]. PROMETHEE-GAIA method is based on the computation of preference degrees and it shows which alternative would be more appropriate to solve the problem and how criteria weight impact alternative position [2].

TABLE 1. SUMMARY OF MCDA METHODS

	TOPSIS	**VIKOR**	**COPRAS**	**MULTIMOORA**	**PROMETHEE-GAIA**	**AHP**
Type of normalization	Vector normalisation (square root of sum (L2 normalization)	Linear normalization (L1 normalization)	Vector normalization (sum)	Vector normalization (square root of sum)	Normalization is performed automatically	Vector normalisation (sum)
Suitability	Choice problems, ranking problems	Choice problems, ranking problems	Choice problems, ranking problems	Choice problems, ranking problems	Choice problems, ranking problems, description problems (GAIA)	Choice problems, ranking problems, sorting problems (AHPsort)
Inputs	Ideal and anti-ideal option weights	Best and worst option weights	Best and worst option weights	Best and worst option weights	Indifference and preference thresholds weights	Pairwise comparison on ratio scale (1–9)
Outputs	Complete ranking with closeness score to ideal and distance to anti-ideal	Complete ranking with closeness score to best option	Complete ranking	Complete ranking	Partial and complete ranking (pairwise outranking degrees)	Complete ranking with scores
Preference function	Distance metric (Euclidean distance, Manhattan distance, Tchebycheff distance)	Distance metric (Manhattan distance)	Min Max	Min Max	Usual, Linear, U-shape, V-shape, Level, Gaussian	
Approach	Qualitative and/or quantitative	Quantitative	Quantitative	Quantitative	Qualitative and/or quantitative	Qualitative
Ranking scale	0 to 1	Positive values	Positive values	Positive values	−1 to 1	0 to 1
Best alternative	Max value	Min value	Max value	Max value	Max value	Max value
Consistency levels	no restrictions	no restrictions	no restrictions	no restrictions	7±2	9
Software	MS Excel, Matlab, Decerns	MS Excel	MS Excel	MS Excel	Visual Promethee, Decision Lab, D-Sight, Smart Picker Pro	MS Excel, MakeItRational, ExpertChoice, Decision Lens, HIPRE 3+, RightChoiceDSS, Criterium, EasyMind, Questfox, ChoiceResults, 123AHP, DECERNS

2.1. INPUT DATA

Input data – criteria with values and alternatives – have been taken from 'Progress in renewable energy technologies: innovation potential in Latvia' [6] and are presented in Table 2. These data are used to find the best alternative for renewable energy production. In each method, data are the most important element to rank alternatives because these values are used in the calculation process.

TABLE 2. INPUT DATA

Criteria		**Alternatives**			
		Solar PV	**WPP**	**HPP**	**Bio-energy CHP**
C1	Installed electrical capacity, MW	1	77	1565	155
C2	Investment cost, €/kW	1238	3565	1388	1113.5
C3	Operation and maintenance cost, €/kW	12.37	26.7	2.67	0.00446
C4	RES equipment prices by manufacturer, €/kW	430	1380	1290	3787.5
C5	Levelled cost of electricity, €/kW	0.08	0.06	0.09	0.075
C6	Life-cycle CO_2 emissions, gCO_2eq/kWh	200	150	150	200
C7	Job creation, thousands	3095	1155	865	528

Data about installed electrical capacity (C1) shows maximum net production capacity of power plants in Latvia and are taken from the IRENA report on Renewable Capacity Statistics [7]. From Data for investment cost (C2) are from IRENA report on Renewable Power Generation Costs [8] and depend on alternative capacity and criteria levelled cost of electricity (C5) data which are average values for each alternative in Europe. The criteria operation and maintenance cost (C3) and RES equipment prices by manufacturer (C4) data are from the IRENA report on Renewable Power Generation Costs [8] and from Energy Outlook [9] and concern Europe. Life-cycle CO_2 emissions (C6) data are on Europe and are from the European Environment Agency (EEA) report on Renewable energy in Europe-2017 [10] and World Nuclear Association report data [11]. Job creation (C7) criteria data are from the IRENA review on Renewable Energy and Jobs [12] and pertain to alternatives in Europe.

For some MCDA methods it is important to know if it is better for the value of the criteria to be maximizing or minimizing. In this study, most criteria values are better to be minimizing and only electrical capacity and job possibilities are better to be maximising.

2.2. AHP

In the AHP method an important indicator is the number of criteria and it affects result consistency because more than seven criteria lead to an increase in inconsistency [22].

The AHP model facilitates the organization of the various variables in levels of hierarchy and it helps experts to evaluate criterion against criterion [23].

The AHP method equations (1) and (2) are [22]:

- Define and value criteria (scale 1–9).
- Calculate normalized matrix using Eq. (1):

$$X_{ij} = \frac{C_{ij}}{\sum C_{ij}} \ , \tag{1}$$

where

C_{ij} criteria value;

$\sum C_{ij}$ column sum.

Calculate priority vector from Eq. (2):

$$W_{ij} = \frac{\sum X_{ij}}{n} , \tag{2}$$

where

$\sum X_{ij}$ normalized matrix column sum;

n number of criteria.

In application of this AHP method to calculate weight it is important to use experts to evaluate criteria because this affects the alternative's values in the future when MCDA methods are using criteria weight.

When weights are calculated using the AHP method, these values can be used in every MCDA method. Also, after the AHP method, results can make conclusions about the indicated values and which indicator can solve the problem.

2.3. TOPSIS

The full name of the method is Technique for Order Preference by Similarity to Ideal Solutions. This method evaluates the distance of alternatives to ideal and anti-ideal point and alternative with shortest distance to ideal point is the best alternative. There are three distances in the TOPSIS method – Manhattan distance, Tchebycheff distance and Euclidean distance, which were all used in this study Eq. (1).

TOPSIS method Eq. (3), (4), (5), (6) and (7) are from [3]. Method described:

– Calculate normalized matrix using Eq. (3):

$$R = \frac{X}{\sqrt{\sum X^2}} , \tag{3}$$

where

X criteria value;

$\sum X$ sum of criteria value.

– Calculate normalized weight matrix from Eq. (4):

$$V = R \times W , \tag{4}$$

where

R normalized matrix value;

W criteria weight.

– Define the best and worst values of criteria: best values V^+= max and worst values V^-= min; best values V^+= min and worst values V^-= max.

– Use of formulas as shown in Eq. (5) and (6) to difference value from best or worst value:

$$d_a^+ = \sqrt{\Sigma(V^+ - v_{a)}^{\ 2}}\ , \tag{5}$$

where

V^+	ideal or best value;
v_a	normalized weighted matrix value,

$$d_a^- = \sqrt{\Sigma(V^- - v_{a)}^{\ 2}}\ , \tag{6}$$

where

V^-	non-ideal or worst value;
v_a	normalized weighted matrix value.

– Find the relative closeness and rank the alternatives using Eq. (7):

$$C_a = \frac{d_a^-}{d_a^+ - d_a^-}\ , \tag{7}$$

where

d^-_a	non-ideal or worst value;
d^+_a	ideal or best value.

The main difference between this and other methods is that TOPSIS uses best and worst value for each criterion and calculates the value of alternatives using gap between best and worst criteria. The smallest difference between best and worst values are the closer values for results of alternatives will be.

2.4. VIKOR

The full name of the method in Serbian is VlseKriterijumskaOptimizacija I KompromisnoResenj. In this method, an important factor is alternative closeness to the ideal solution and after that alternatives are ranked [13]. The Euclidean distance[14] is used in this method.

Eq. (8) and Eq. (9) are from [26]. Method described:

– Define best and worst value of criteria.
– Find values for best and worst values matrix using Eq. (8):

$$S = w\frac{f^* - f}{f^* - f^-}\ , \tag{8}$$

where

w	criteria weight;
f	criteria value;
f^*	best value of criteria (max or min);
f^-	worst value of criteria (min or max).

– Find values *S*, *R* and *Q* for each alternative:

$$Q = v\frac{S_j - S^*}{S^- - S^*} + (1-v)\frac{R_j - R^*}{R^- - R^*}, \quad (9)$$

where v is decision making factor (if major agreement than $v \geq 0.5$, if consensual agreement than $v = 0.5$, if agreement with veto than $v \leq 0.5$), in this case $v = 0.5$;

$S_j = \sum w\frac{f^* - f_i}{f^* - f^-}$, $S^* = \min S_j$, $S^- = \max S_j$; $Rj = \max\left[w\frac{f^* - f_i}{f^* - f^-}\right]$, $R^* = \min R_j$, $R^- = \max R_j$.

In this method, there is not a normalized and normalized weights matrix as in the TOPSIS, COPRAS and MULTIMOORA methods.

2.5. COPRAS

The full name of the method is Complex Proportional Assessment. This method applies stepwise sorting and utility degree calculation which helps when there are conflicting criteria [4]. In order to achieve alternative sequencing after utility degree, the alternatives needs to be sorted in descending order [5].

The COPRAS method equations (10), (11), (12), (13), (14) and (15) are from [15].

Method described:

– Find normalized matrix from Eq. (10):

$$\overline{x_{ij}} = \frac{x_{ij}}{\sum x_{ij}}, \quad (10)$$

where

x_{ij} criteria values;

$\sum x_{ij}$ sum of criteria values.

– Find normalized weighted matrix from Eq. (11):

$$\widehat{x_{ij}} = \overline{x_{ij}} \times w, \quad (11)$$

where

$\overline{x_{ij}}$ normalized matrix values;

w criteria weight.

– Determination of the maximizing index Eq. (12) and minimizing index Eq. (13):

$$P_j = \sum \widehat{x_{ij}}, \quad (12)$$

$$R_j = \sum \widehat{x_{ij}}, \quad (13)$$

where

P_j maximizing index;

R_j minimizing index;

$\widehat{x_{ij}}$ weighted normalized matrix.

– Using Eq. (14) find relative weights for every alternative:

$$Q_j = P_j + \frac{\sum R_j}{R_j \sum \frac{1}{R_j}}, \quad (14)$$

where
P_j maximizing index;
R_j minimizing index.

– Calculate utility degree using Eq. (15):

$$N = \frac{Qi}{Q\text{max}} \times 100\%. \quad (15)$$

In this method criteria value and all alternative sums are used to find values of normalized matrix, but in other methods, like TOPSIS, the criteria value and square root from sum of square is used to calculate values of alternatives.

2.6. MULTIMOORA

Full name of method is Multi-Objective Optimization on the basis of Ratio Analysis. MULTIMOORA is a system that optimizes conflicting alternatives to find the best result and is easy to apply to solve various problems [5].This method has an extended version where it is possible to work with a value interval [16].

Equations (16), (17), (18) and (19) for MULTIMOORA method are from [17]. Method described:

– Normalized matrix in Eq. (16):

$$X^* = \frac{x_i}{\sqrt{\sum x_i^2}}, \quad (16)$$

where x_i is criteria value.

– Calculate normalized weight matrix using Eq. (17):

$$Y = x_i \times w, \quad (17)$$

where:
x_i normalized matric value;
w criteria weight.

– Difference between max and min values for each alternative using Eq. (18):

$$y_i = \sum \max x_{ij}^* - \sum \min x_{ij}^*. \quad (18)$$

– Find alternatives values from Eq. (19):

$$U_i = \frac{\sum \max X_{ij}^*}{\sum \min X_{ij}^*}. \quad (19)$$

In this method, it is possible to use inverse formula of Eq. (19) and use the minimum value as the best alternative, if it is needed to compare with other methods where minimum values are the best alternatives as in case of the VIKOR method.

In this method it is quite important to calculate the difference between minimum and maximum values of criteria and the value of alternative

2.7. *PROMETHEE-GAIA*

PROMETHEE stands for Preference Ranking Organization Method for the Enrichment of Evaluations and GAIA stands for Graphical Analysis for Interactive Aid [30].

In the PROMETHEE method, criteria weight gives more impact than the values of the preference function threshold [30]. It is possible to choose preference functions and software can be used to arrange the criteria and their weights [30]. Calculations are made in the program Visual PROMETHEE academic.

3. RESULTS AND DISCUSSION

The AHP method pairwise comparison is made by assessing the importance of the criterion over the other criterion and the results are illustrated in Table 3. In pair comparison value 1 represents that both criteria are equally important, value 5 represents that one criterion is very important compared to other criteria and value 9 represents that one criterion is absolutely most important than other criteria. And for opposed criteria comparison values are proportionally opposed. This pairwise comparison was made by three experts from the field of environmental science.

After calculation criteria weight very important is to verify if $\sum W_{ij} = 1$ and consistency values, for this AHP consistency index (CI) is 0.127 and consistency ratio (CR) is 0.097. If CR > 10% then pairwise comparisons are inconsistent [2].

Table 4 contains all criteria and their weights. The most important criteria are installed electrical capacity with a weight 27 % and the next is job creation criteria with 22 % weight. The lowest impact on alternatives is from the criteria about levelled cost of electricity and on life-cycle CO_2 emissions.

Important value in the TOPSIS method is alternative closeness indicator which are final value for alternative and are in Table 5. Based on the results of the TOPSIS method, the best alternative is the hydroelectric power plant (HPP) followed by biomass and biogas CHP (Bio-energy CHP).

In accordance with the VIKOR method, the best alternative is that with the minimal value. Results of this method are in Table 6 and the best alternative is hydroelectric power plant (HPP) then solar PV. To compare VIKOR and other methods it is important to remember that in this method an important step is to minimize all criteria to make comparisons.

The COPRAS method is simple and most impact for best alternative is from criteria weight and index values. Based on this method, the best alternative is solar photovoltaic (Solar PV) and hydroelectric power plant (HPP). The values of alternatives are presented in Table 7. Best alternative in this method is Solar PV and worst alternative is wind power plants (WPP) and both alternatives have large difference in their final values and this might be because of these alternative values for each criterion.

TABLE 3. CRITERIA PAIRWISE COMPARISON

		C1	C2	C3	C4	C5	C6	C7
		Installed electrical capacity, MW	Investment cost, €/kW	Operation and maintenance cost, €/kW	RES equipment prices by manufacturer, €/kW	Levelled cost of electricity, €/kW	Life-cycle CO_2 emissions, gCO_2eq/kWh	Job creation, thousands
C1	Installed electrical capacity, MW	1	6	5	2	3	2	0.5
C2	Investment cost, €/kW	0.17	1	1	1	2	2	0,.5
C3	Operation and maintenance cost, €/kW	0.2	0.5	1	2	2	3	0.5
C4	RES equipment prices by manufacturer, €/kW	0.5	1	0.5	1	2	2	0.5
C5	Levelled cost of electricity, €/kW	0.33	0.5	0.5	0.5	1	2	0.5
C6	Life-cycle CO_2 emissions, gCO_2eq/kWh	0.5	0.5	0.33	0.5	0.5	1	0.5
C7	Job creation, thousands	2	2	2	2	2	2	1

TABLE 4. CRITERIA VALUES AND WEIGHTS

Installed electrical capacity, MW	27 %
Investment cost, €/kW	12 %
Operation and maintenance cost, €/kW	13 %
RES equipment prices by manufacturer, €/kW	11 %
Levelled cost of electricity, €/kW	8 %
Life-cycle CO_2 emissions, gCO_2eq/kWh	7 %
Job creation, thousands	22 %

TABLE 5. TOPSIS RESULT AND RANK

A1	A2	A3	A4
Solar PV	WPP	HPP	Bio-energy CHP
0.33	0.16	0.77	0.28
2	4	1	3

TABLE 6. VIKOR RESULTS AND RANK

A1	A2	A3	A4
Solar PV	WPP	HPP	Bio-energy CHP
0.67	0.92	0	0.81
2	3	1	4

TABLE 7. COPRAS RESULTS AND RANK

A1	A2	A3	A4
Solar PV	WPP	HPP	Bio-energy CHP
1.94	0.86	1.47	0.93
1	4	2	3

Results from the MULTIMOORA method is in Table 8 and the best alternative is solar photovoltaic (Solar PV) and hydroelectric power plant (HPP). Final values have large range and it's because final values are calculated from difference between the minimum and maximum values

TABLE 8. MULTIMOORA RESULTS AND RANK

A1	A2	A3	A4
Solar PV	WPP	HPP	Bio-energy CHP
3.25	0.47	1.93	0.28
1	3	2	4

Table 9 contains results from the PROMETHEE-GAIA method and the complete ranking is based on net preference flow (Phi) which is a balance between positive preference flow (Phi+) which measures strength and negative preference flow (Phi−) that represents weakness. In this case, the preference function is linear and thresholds are absolute. In accordance with this method, the best alternative is the hydroelectric power plant (HPP) and solar photovoltaic (Solar PV).

TABLE 9. COMPLETE RANKING

	A1	A2	A3	A4
	Solar PV	WPP	HPP	Bio-energy CHP
Phi	0.0100	−0.2567	0.2833	−0.0367
Phi+	0.4533	0.3200	0.5900	0.4300
Phi−	0.4433	0.5767	0.3067	0.4667

PROMETHEE rankings results can be displayed as PROMETHEE Diamond in Fig. 1. In the PROMETHEE Diamond, each alternative has point on the (Phi+, Phi−) plane and the vertical dimension (green-red axis) corresponds to the Phi net flow which is a balance point [18].

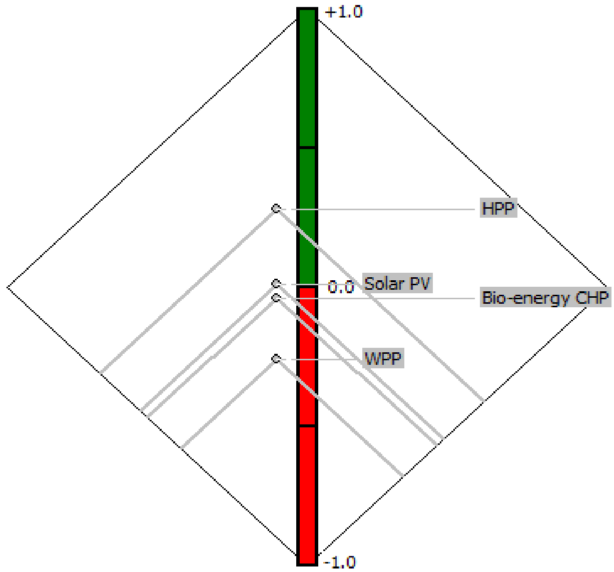

Fig. 1. PROMETHEE Diamond.

Fig. 2 illustrates the PROMETHEE Network and shows which alternative is better and helps to compare alternatives. The network representation is like a close-up of the Diamond view where the distances between the alternatives are displayed [30].

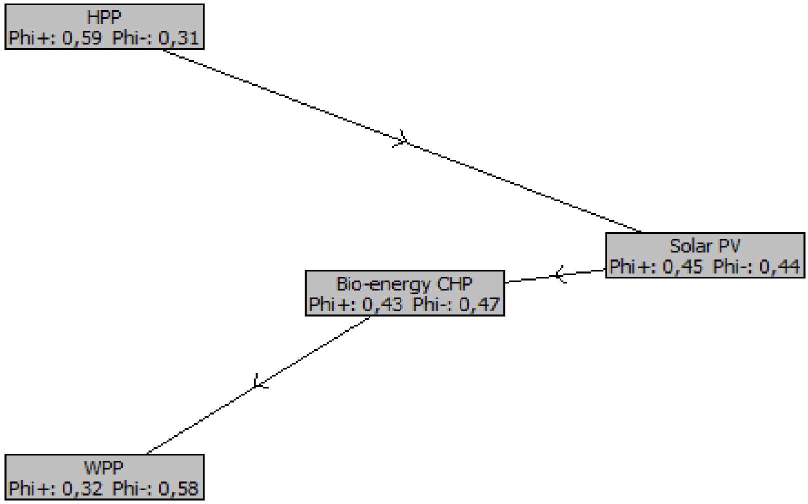

Fig. 2. PROMETHEE Network.

The PROMETHEE Rainbow is shown in Fig. 3 where every alternative's strong and weak criterion is depicted. Positive (upward) slices represents criteria that positively affects the alternative and negative (downward) slices represent criteria that give a negative effect to the alternative [18].

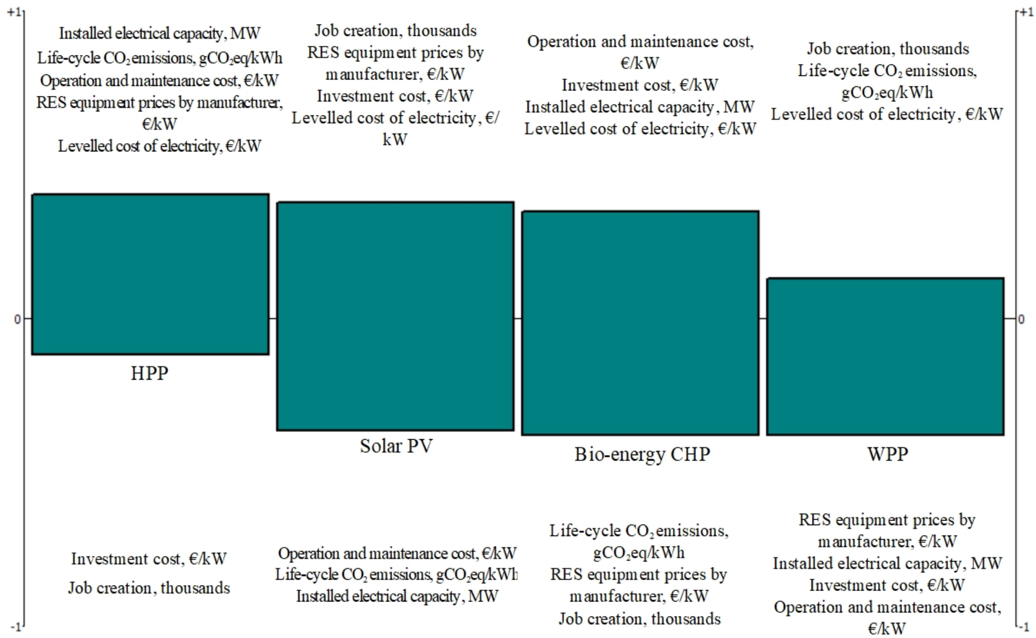

Fig. 3. PROMETHEE Rainbow.

For the hydroelectric power plant (HPP) alternative, weakness stems from investment cost and job creation and after this method it is the best alternative. For wind power plants (WPP) which are the worst alternative, there are only three good criteria – job creation, life-cycle CO_2 emissions and levelled cost of electricity.

After five Multi-criteria decision analyses – TOPSIS, VIKOR, MULTIMOORA, COPRAS and PROMETHEE-GAIA, Table 10 provides a summary of all final values for each alternative. For TOPSIS, VIKOR and PROMETHEE-GAIA methods the best alternative is hydroelectric power plant (HPP) and in accordance with the other 2 methods, HPP is ranked second. But in COPRAS and MULTIMOORA methods, the best alternative is solar photovoltaic (Solar PV). The most impact for the final results is from criteria weights and methods definition of best alternative - closeness indicator to ideal distance, closeness score to best option, pairwise outranking or ranking with scores. The best value of the criteria – minimum or maximum – is also an important indicator.

TABLE 10. ALTERNATIVE VALUES AND RANKING

	Solar PV	WPP	HPP	Bio-energy CHP
TOPSIS	**0.33**	**0.16**	**0.77**	**0.28**
	2	4	1	3
VIKOR	**0.67**	**0.92**	**0**	**0.81**
	2	3	1	4
COPRAS	**1.94**	**0.86**	**1.47**	**0.93**
	1	4	2	3
MULTIMOORA	**3.25**	**0.47**	**1.93**	**0.28**
	1	3	2	4
PROMETHEE-GAIA	**0.01**	**–0.26**	**0.28**	**–0.04**
	2	4	1	3

The results from MCDA methods are reflected in Fig. 4 and they are ranked from best to worst alternative. After this result is displayed in the diagram, it is easier to see the trend in terms of which alternatives are ranked higher than others. The best alternative would be hydroelectric power plant (HPP) and then solar photovoltaic (Solar PV) because these alternatives are in first or second position in comparison with most of the other alternatives.

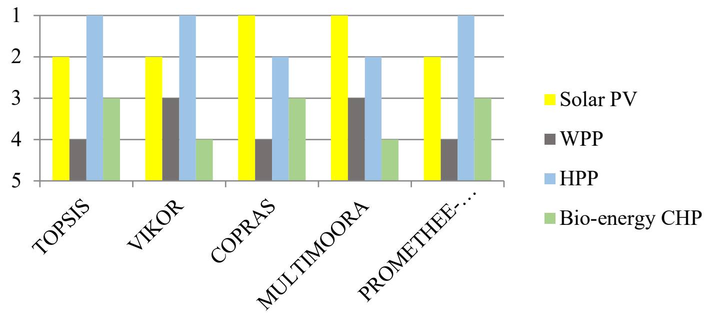

Fig. 4. Result rank of MCDA methods.

The lowest rank is for the wind power plants (WPP) alternative because in 3 out of 5 methods it is in the last place. For this alternative minimal and maximal criterion values are lowest rates which impact final ranking.

4. Conclusion

The aim of this paper was to use same input data for five MCDA methods and to see if alternatives ranking would be the same or different for each method and of course to see which is the best renewable energy technology for Latvia. Five MCDA methods – TOPSIS, VIKOR, COPRAS, MULTIMOORA and PROMETHEE GAIA have been chosen because they have different approaches on how to calculate alternatives values and there it was possible to use criteria which can be definite minimum or maximum as best value.

The same results were not obtained for all methods but in all methods two alternatives were in the first two places as best alternatives - hydroelectric power plant (HPP) and solar photovoltaic (Solar PV). On the basis of seven criteria, the best renewable energy technology for Latvia is hydroelectric power plant (HPP) and it is because in the most valuable criteria installed electrical capacity (27 %) in this alternative had best results from all energy alternatives.

The results of five MCDA methods have produced different results, but with a similar trend to best alternative. It's not really objective to compare the results obtained by different methods because results are similar but not the same. To get more reliable results and for comparison use one methodology for problem and sub-problem. MCDA methods are developing with new modules and software's which are more specific and helpful to solve problems. Methods can be chosen after goal of result, method approach, input and output type, used software and suitability for the problem.

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Evaluation of the Environmental Engineering Study Programme at University

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***Abstract* – The European Union has placed competence-based teaching and competence-based education as one of its highly relevant goals. Due to mass higher education, the assessment of effectiveness and relevance evaluation of environmental engineering study programmes should become an important issue. Presently the focus of the evaluation on multi-disciplinary study programmes varies from the evaluation of attitudes, impacts or effectiveness of utilisation-focused evaluation, summative evaluation and participatory evaluation approaches. The objective of this study was to propose an effective framework to evaluate the Environmental Engineering Master study programmes. During the research, the evaluation of existing study programmes on environmental engineering in Europe was conducted, information about the study courses, teaching methods, assessment methods and competences was used for the analysis. The results obtained showed that lectures, site visits, group coursework, practical laboratories and role-plays allows to reach the necessary knowledge, skills and competences and to provide an effective and relevant education to the Environmental Engineering Master programme students. The proposed evaluation framework was tested and approbated on new Riga Technical University Master study programmes on Environmental Engineering and Bioeconomy.**

***Keywords* – Assessment; bioeconomy; competence-based higher education; environmental engineering; indicators; internal quality management; MCA**

Nomenclature	
MCA	Multi-Criteria Analysis
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
EE	Environmental Education
CBE	Competence-based education

1. INTRODUCTION

Environmental studies are becoming more and more popular in the last years; the evidence of this is, for example, a big number of articles in high-impact journals, a lot of project calls and projects, etc. [1]. New study programmes on bio-based circular economy, bioenergy, biofuels and bioproducts [2], clean energy [3], bioeconomy [4], [5] have been established and implemented recently.

Due to mass higher education, the assessment of effectiveness and relevance evaluation of EE study programmes should become an important issue. Scientists in different regions have

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been looking for ways to evaluate EE study programs in universities [1], [6]–[15]. The focus of evaluations on EE vary from the evaluation of attitudes, impacts or effectiveness to utilisation-focused evaluation, summative evaluations and participatory evaluation approaches [16], [17].

Higher education is one of the main indicators of global competitiveness and in the future due to globalization and knowledge transfer, modern masters programmes should have a multidisciplinary and interdisciplinary approach and be able to answer the demand of environmental engineering knowledge on a regional scale [18].

The European Union places competence-based teaching and competence-based education as one of its highly relevant goals. European Higher Education Area focused on the assuredness of comparability and compatibility of qualifications between graduates from different countries in the European Union. The "shift from teaching to learning" has been an influential factor in the development of new study programmes which include a shift from content-centred curricula to competence-centred curricula [19]–[21], putting employability as one of the main priorities. According to Oversberg et al. the current evaluation is based on quality measures focused on academic personnel, teaching methods and student satisfaction, instead of concentrating on the learning outcomes of the educational programmes.

In general, a competence-based education can help a student to deal with the challenges of the modern world: analyse data, be responsible, learn to learn and to make an appraisal based on a careful analytical evaluation. The main features and principles of a competence-based education (CBE) in higher education [21] are shown in Fig. 1. Based on the main features and principles, competence-based teaching involves working with knowledge, skills and attitudes.

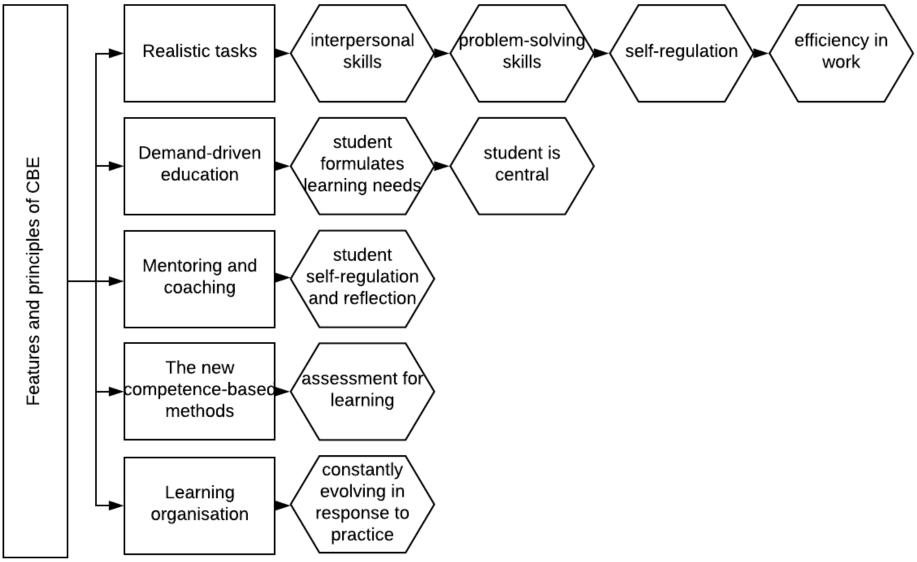

Fig. 1. Features and principles of CBE.

At the same time, there is no one single evaluation instrument for the evaluation of CBE in general and specifically in the evaluation of Environmental Engineering study programmes.

In accordance with Bergsmann et al. [20], there are some main limitations of existing evaluation methods:

1. Main focus is laid on the competencies of the individual student;
2. Evaluation focus is on specific aspects of the teaching process;
3. Methods are based on status assessments, where the needs of stakeholders are not considered.

MCA is a well-known tool which has been used for the identification of different alternatives for solving complex questions, since this method allows selecting the best of different options. Mustafa [22] was the first scientist who described applying the multiple criteria decision-making method in higher education administration. Decades later, Ho et al. [23], used MCA to solve higher education decision problems, such as resource allocation, performance measurement, budgeting, and scheduling. Skordoulis et al. [24], used MCA for the analysis of student satisfaction. Basaran [25], analysed selecting and evaluating digital learning materials through multi criteria decision analysis approaches. Salomon et al. [26], described analysis of classrooms standardisation in higher education using MCA.

The proposed literature review highlights the lack of clear vision on evaluation methods for the assessment of the study programmes and the integration of MCA into the evaluation of competences.

Considering the results of the literature review, the main goal of this study is to propose a framework to evaluate the EE study programmes based on the use of MCA. This article consists of six parts. Part 2 observes the utility of MCA for the evaluation of EE study programmes and shows the pathway of the research step-by-step. Part 3 looks at EE programmes analysis in Europe. The results of the integration of MCA into evaluation and implementation of two new master study programmes on environmental engineering and bioeconomy are interpreted in Section 4. The results of MCA are analysed in Section 5 and overall conclusions are displayed and argued in Section 6.

2. METHODS AND METHODOLOGY

The interest from students, stakeholders and society on the multidisciplinary master´s programmes led to the decision to implement new master study programmes on Environmental Engineering and Bioeconomy in the Riga Technical University, Institute of Energy Systems and the Environment. To reach the objective of this study and to propose an effective framework to evaluate EE study programmes, the use of the MCA framework for the evaluation of study programme and assessment of effectiveness and relevance evaluation of environmental engineering study programmes has been developed.

The first part of the methodological algorithm is focused on identification and analysis of the existing situation and is based on literature review on teaching methods, assessment methods, competences and indicators used in evaluation and assessment of environmental engineering study programmes. In this stage the analysis of regulations and legislative framework, as well as analysis of results of survey on EE education in Europe have been conducted. The second step is definition of the issue, objective and scope of the study programme, which follows by identification and selection of the most significant indicators and definition of key factors influencing the shift to CBE. Taken into account key factors, the definition of teaching methods, skills, knowledge, assessment methods and competences are defined.

To find and evaluate the optimal teaching methods combination, TOPSIS (the Technique for Order of Preference by Similarity to Ideal Solution) was applied. The MCA method dwells mostly on a weighted set of criteria.

During the MCA process, the multi-objective matrix has been optimized. The criteria identified within are reduced into a single-score measure using a weighting procedure that determines relative importance by multiplying each criterion with a weighing factor.

Qualitative and quantitative analysis of Environmental Engineering study programmes: core competences, indicators, skills, knowledge, desirable outcomes, teaching methods and assessment methods using CBE concepts and features have been conducted.

The basic approach is established within the scheme presented as Fig. 2.

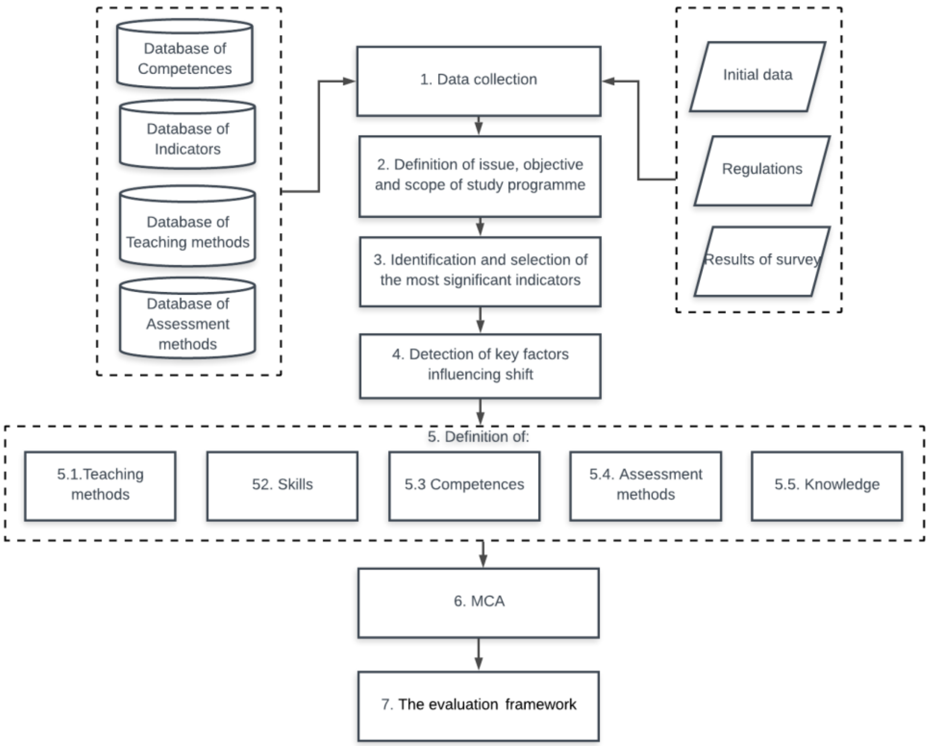

Fig. 2. Overall methodological scheme.

3. EE Programme Analysis in Europe

The work started with the survey on EE Master study programmes conducted by European Universities. Geographical location – Europe was chosen because of similar education systems between different universities in the region. The focus of this study was to analyse good practice in EE, therefore academic institutions with excellent performance were investigated. Ranking websites [27], [28] were used for the selection of study programmes for the study. In total 110 study programmes were analysed. As the objective of the research was the evaluation of existing masters programmes in environmental engineering, 35 study programmes were selected for the evaluation. The selected multi-disciplinary masters study programmes comprise of masters programmes from the fields of Environmental Engineering (22 study programmes), Water and Waste Management (3 study programmes), Environmental Technologies (2 study programmes), Environmental Science (2 study programmes), Land Planning Engineering, Project Management, Biological Engineering, Energy Engineering and Bioeconomy (see Table 1). To be able to use the best practices, masters programmes performing highly in the QS Global World Ranking by QS Quacquarelli Symonds were examined. Ten of the analyzed study programmes are ranked in the top-100, twelve between 100 and 200, three between 200 and 300, six between 300 and 400, two between 400 and 500 and two between 500 and 600. The study length degree is one (13 of 35 study programmes), one and a half (2 study programmes) or two (20 study programmes) full time years.

TABLE 1. MULTI-DISCIPLINARY STUDY PROGRAMMES ON ENVIRONMENTAL ENGINEERING

University	Master programme	Ranking	Years
ETH Zurich	Environmental Engineering	3	2
Delft University of Technology	Environmental Engineering	16	2
Technical University of Denmark	Environmental Engineering	45	2
TUM – Technical University of Munich	Environmental Engineering	61	2
University of Nottingham	Environmental Engineering	82	1
Trinity College Dublin	Environmental Engineering	104	1
Aalto University	Environmental Engineering	140	2
Newcastle University	Environmental Engineering	141	2
Universitat de Barcelona	Environmental Engineering	166	1
University of Bologna	Environmental Engineering	180	2
Queen’s University Belfast	Environmental Engineering	180	1
Cranfield University	Environmental Engineering	251–300	1
Universität Stuttgart	Environmental Engineering	260	2
Universitat Politècnica de Catalunya	Environmental Engineering	275	2
Universitat Politècnica de València	Environmental Engineering	310	1
Czech Technical University in Prague	Environmental Engineering	317	2
University of Porto	Environmental Engineering	328	1
University of Lisbon	Environmental Engineering	355	2
Norwegian University of Science And Technology	Environmental Engineering	363	2
Universidad Politécnica de Madrid	Environmental Engineering	470	1
Universität Bremen	Environmental Engineering	511–520	1.5
Universidade de Santiago de Compostela	Environmental Engineering	581–590	1.5
KTH Royal Institute of Technology	Environmental Engineering and Sustainable Infrastructure	104	2
Ghent University	Environmental Technology and Engineering	138	2
University of Natural Resources and Applied Life Sciences Vienna	Water Management and Environmental Engineering	151–200	2
Politecnico di Milano	Environmental and Land Planning Engineering	156	2

University	Master programme	Ranking	Years
Universitat Autònoma de Barcelona	Biological and Environmental Engineering	193	1
University College Dublin	Water, Waste & Environmental Engineering	193	1
Aalborg University	Water and Environmental Engineering	343	2
University of Hohenheim	Bioeconomy	495	2

For the evaluation of existing study programmes, information about study courses, teaching methods, assessment methods and competences were used. Based on this information, the set of competences, indicators, skills, assessment methods, knowledge, teaching methods for the evaluation of Environmental engineering masters study programmes was elected.

4. USE OF MCA FOR IMPLEMENTATION AND EVALUATION OF STUDY PROGRAMMES

4.1. Environmental Engineering Study Programmes' Evaluation Indicators

For the definition of Environmental Engineering Programme indicators, the indicators from existing research published in scientific journals for the mapping of environmental education programmes in higher education were analysed.

During the research, five indicators were found to be suitable for the evaluation of environmental engineering study programmes:

1. Multidisciplinary approach;
2. Cooperation with other institutions;
3. Internal process;
4. Education and research;
5. Simulation activities [7].

Multidisciplinary approach has a very important role in environmental engineering, since students need to solve complex problems within study programme with different stakeholders' interests and by interacting among various interests. An interdisciplinary research is highly valuated in leading universities, helps students to develop critical thinking and creativity [29], [30]. At the same time, the balance between multi- and interdisciplinarity and in deep knowledge of different courses must be taken into consideration [31].

Cooperation with other institutions can be organized through research projects, common (joint or double) study programmes. Cooperation allows the sharing of knowledge, experiences and capacities [32], [33]. A lot of universities offer common study programmes for EE, for example, Nordic masters in environmental engineering, in cooperation with Aalto University, KTH Royal Institute of Technology, Technical University of Denmark, Norwegian University of Science and Technology and Chalmers University of Technology, whereby 5 universities from one region are cooperating with each other. Another example is cooperation between University of Valencia and Universitat Politècnica de València, where a joint masters in environmental engineering is offered.

An internal process through adoption of environmental management strategies, providing and understanding of environmental issues and sustainable development in universities can be introduced [34].

Education and research are the basic of higher educational institutions, therefore the research outcomes should be analysed.

Simulation activities and practical learning allows to reach the best outcomes in study programmes, allowing for the introduction of competence-based education into the agenda.

These five indicators (multidisciplinary approach, cooperation with other institutions, internal process, education and research and simulation activities) can help to evaluate if the knowledge triangle: education-innovation-research, as well as competence-based education have been achieved.

European Network for Accreditation of Engineering Education (EUR-ACE) is a framework and accreditation system that provides a set of standards for engineering degree programmes in Europe and beyond. The sets of learning outcomes for environmental engineering masters programmes are shown in Table 2.

TABLE 2. LEARNING OUTCOMES WITHIN EUR-ACE [35]

Areas	**Learning outcomes**
Knowledge and understanding	Knowledge and understanding of the scientific and mathematical principles underlying their branch of engineering
	Systematic understanding of the key aspects and concepts of their branch of engineering
	Coherent knowledge of their branch of engineering including some at the forefront of the branch
	Awareness of the wider multidisciplinary context of engineering
Engineering analysis	Ability to apply their knowledge and understanding to identify, formulate and solve engineering problems using established methods
	Ability to apply their knowledge and understanding to analyse engineering products, processes and methods
	Ability to select and apply relevant analytic and modelling methods
Engineering design	Ability to apply their knowledge and understanding to develop and realise designs to meet defined and specified requirements
	Understanding of design methodologies, and ability to use them
Investigations	Ability to conduct searches of literature, and to use data bases and other sources of information
	Ability to design and conduct appropriate experiments, interpret the data and draw learning skills workshop and laboratory skills
	Workshop and laboratory skills
Engineering practice	Ability to select and use appropriate equipment, tools and methods
	Ability to combine theory and practice to solve engineering problems
	Understanding of applicable techniques and methods, and of their limitations
	Awareness of the non-technical implications of engineering practice
Transferable skills	Function effectively as an individual and as a member of a team
	Use diverse methods to communicate effectively with the engineering community and with society at large
	Demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice
	Demonstrate an awareness of project management and business practices, such as risk and change management, and understand their limitations

4.2. Competences

The main competences which should be reached at the end of the studies can be divided into 4 categories. These are:

1. Subject-related competences;
2. Scientific and methodological competences;
3. Social competences;
4. Personal competences [19].

The degree to which students need to reach the respective knowledge at the end of the study programme should correspond to expansion level, see Table 3. At the end of the study programme students should reach certain cognitive aspects, as a) test specific research questions and b) make contribution to research, and practical aspects, as well as a) develop certain techniques and b) test certain techniques.

TABLE 3. COMPETENCE LEVELS [19]

Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
No knowledge	Threshold	Foundation	Interconnection	Contextualization	Expansion	Generation

To reach these competences and knowledge degree different teaching methods can be used. To evaluate which teaching methods are more suitable for environmental engineering studies, MCA was applied.

5. RESULTS

During the research, the experience in the organization of study programmes of the previously mentioned universities were analysed. As a result of the research, thirteen teaching methods were found to be suitable to reach the best results in the study process and to provide a competence-based environmental engineering education for the masters study level: anonymous feedback evaluations, united e-learning system (intranet), field data collection, group coursework, group exercises, individual research project, lectures, online assignments and coursework, practical laboratories, seminars and workshops, site visits, tutorials and role-plays.

These teaching methods have been used in undergraduate and postgraduate study programmes during the study process at the Riga Technical University, Institute of Energy Systems and Environment (RTU IESE).

The teaching methods selected for the educational purposes have a significant impact on effectiveness of the study process [36]–[41] and obtained skills.

Anonymous feedback evaluation, as well as direct feedback [42] from students can be a useful and effective method for the improvement of the study process, especially in CBE, where students can formulate their study needs and lead to better results in the study process.

United e-learning system (intranet), in the case of the Riga Technical University it is ORTUS multifunctional higher education establishment website, is essential in CBE, since if used comprehensively, can lead to strongest improvements in student’s flexibility and can help to develop creative thinking [43], [44].

Group work organized in the form of coursework or group exercises, develop personal and social competences, understanding of team work, stimulate a multidisciplinary concept, etc. [45].

Use of site visits and field data collection, seminars and workshops and practical laboratories allows to introduce CBE features [45] and concepts in the teaching process. Lectures and tutorials together with individual research projects are an indispensable part of any higher education process, but not the only one. Lectures and tutorials form just a part of the teaching methods which should be used in the study process.

Role-play simulations develop core competences for environmental engineering study programme students and in general have been considered to be rich and authentic learning environments [45]. The combination of these teaching methods can help to change the pathway from teaching to learning and provide CBE principles in study process.

5.1. Indicators

In MCA four indicators were developed to analyse the following competences: engineering skills, transferable skills, environmental protection skills and socio-economic skills. The aim of MCA was to evaluate which teaching methods are more suitable and in which proportions to enhance core competences for the environmental engineering masters programme graduates. The indicated indicators were elaborated by evaluating the literature and assembling the assessment of academic staff in the sector. The indicators used in MCA for the assessment of teaching methods appraisal are shown in Table 4.

TABLE 4. INDICATORS USED FOR THE ASSESSMENT OF TEACHING METHODS APPRAISAL

Indicator	Unit	Preferable outcome
Engineering skills	Competence level	Max
Transferable skills	Competence level	Max
Environmental protection skills	Competence level	Max
Socioeconomical skills	Competence level	Max

During the research, thirteen teaching methods were appraised and compared for the sake of finding the most effective methods for the achievement of the best results in the study process (Table 5).

TABLE 5. DESIGNATION OF TEACHING METHODS

Designation	Environmental engineering teaching methods
A_1	Anonymous feedback evaluations
A_2	United e-learning system (intranet)
A_3	Field data collection
A_4	Group coursework
A_5	Group exercises
A_6	Individual research project
A_7	Lectures
A_8	Online assignments and coursework
A_9	Practical laboratories
A_{10}	Seminars and Workshops
A_{11}	Site Visits
A_{12}	Tutorials
A_{13}	Role-plays

Criteria weights ($w_1b_{i1}, w_2b_{i2}, w_3b_{i3}, w_3b_{i3}$) were evaluated by RTU IESE experts. Normalized and weighted values from the decision-making matrix for the evaluation of teaching methods are displayed in Table 6.

TABLE 6. NORMALIZED AND WEIGHTED DECISION-MAKING MATRIX

Criterion / Teaching method	**Engineering skills**	**Transferable skills**	**Environmental protection skills**	**Socio-economic skills**
	w_1b_{i1}	w_2b_{i2}	w_3b_{i3}	w_3b_{i3}
A_1	0.0015625	0.005625	0.003125	0.00375
A_2	0.0046875	0.00375	0.003125	0.00375
A_3	0.0078125	0.001875	0.00625	0.00125
A_4	0.00625	0.0075	0.00625	0.005
A_5	0.0046875	0.0075	0.0046875	0.005
A_6	0.00625	0.005625	0.0046875	0.00375
A_7	0.0078125	0.0075	0.0078125	0.00625
A_8	0.003125	0.00375	0.0015625	0.0025
A_9	0.0078125	0.005625	0.0078125	0.005
A_{10}	0.003125	0.009375	0.0046875	0.00625
A_{11}	0.00625	0.009375	0.00625	0.0025
A_{12}	0.0015625	0.009375	0.0078125	0.00625
A_{13}	0.0046875	0.001875	0.0015625	0.00125

The teaching methods evaluation using TOPSIS were completed for masters study programme on Environmental Engineering.

The results obtained showed that lectures (A_7), site visits (A_{11}), group coursework (A_4) and practical laboratories (A_9) together with role-plays (A_{13}) allows to reach necessary knowledge, skills and competences (Fig. 3).

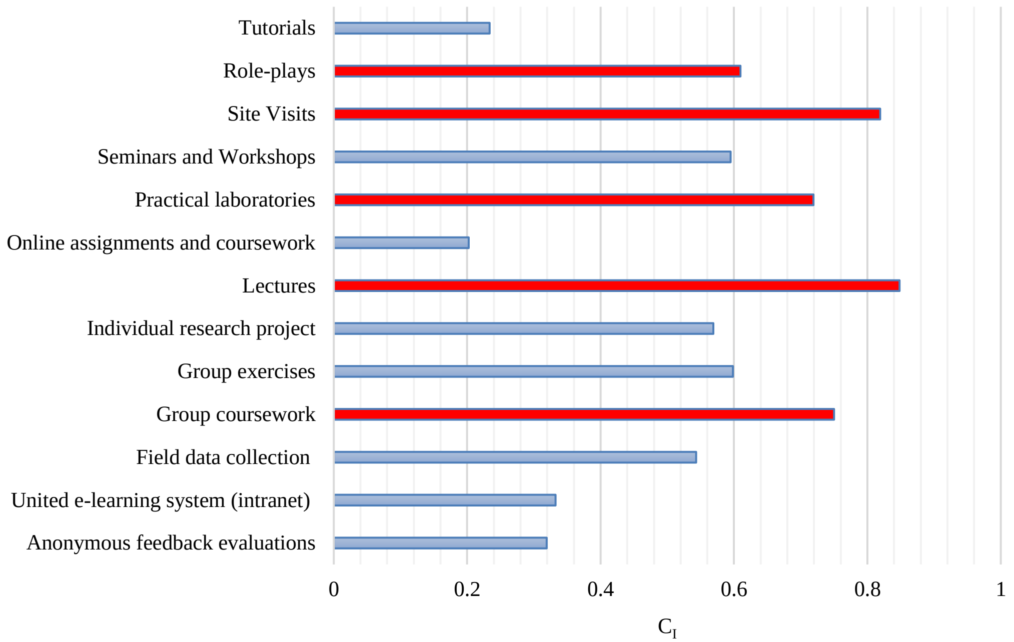

Fig. 3. Comparison of teaching methods ratings.

As assessment methods for group exercises, group course assignments can be used, for group coursework group projects and presentations, individual coursework assignments for the individual research projects should be used. For the individual research projects, individual coursework assignment can allow to evaluate the work. Research dissertations and written examinations are an effective tool in the assessment of individual work.

The assessment framework for the evaluation of environmental engineering study programme was developed (Fig. 4).

The proposed assessment framework for the evaluation of environmental engineering study programme was tested and approbated on new Riga Technical University masters study programmes on Environmental Engineering and Bioeconomy.

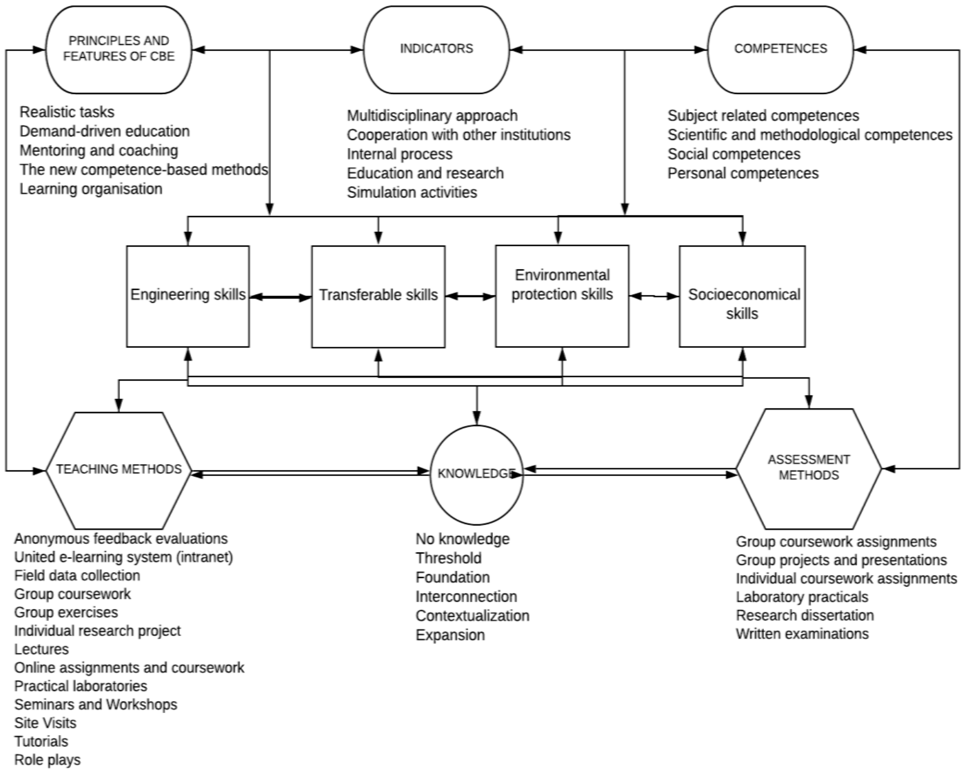

Fig. 4. Assessment framework for the evaluation of environmental engineering study programme.

6. Conclusions

The overall objective of this study was to propose a compelling scheme of the evaluation of the environmental engineering masters study programme.

During the research, the evaluation of existing study programmes on environmental engineering in Europe were analysed, information about study courses, teaching methods, assessment methods and competences were used for the analysis. The results obtained showed that lectures, site visits, group coursework, practical laboratory work and role play allows to reach necessary knowledge, skills and competences and provide effective and relevant education to Environmental Engineering Masters programme students.

The core competences (subject-related competences, scientific and methodological competences, social competences and personal competences) were determined to assure quality measures of study process. This process is related with the use of five evaluation indicators (multidisciplinary approach, cooperation with other institutions, internal process, education and research and simulation activities), which allows to evaluate programme learning outcomes.

Thirteen learning methods (anonymous feedback evaluations, united e-learning system (intranet), field data collection, group coursework, group exercises, individual research projects, lectures, online assignments and coursework, practical laboratory work, seminars and workshops, site visits, tutorials and role-plays) suitable for the environmental engineering studies were selected, evaluated and compared in order to find the most effective methods for the achievement of the best results in the study process. The results of MCA defined that that lectures, site visits, group coursework and practical laboratories together with role-plays simulations should engage the major part of study process.

Developed assessment framework can be used during the development process of new environmental engineering study programmes and for the evaluation of the existing study programmes with a similar profile. Future research based on the results of this study should include sensitivity analysis and deeper investigation on CBE outcomes, as well as determination of bottlenecks for the effective transfer of given information to competence-based knowledge.

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Education for Advancing the Implementation of the Bioeconomy Goals: An Analysis of Master Study Programmes in Bioeconomy

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Abstract **– Bioeconomy in Europe has become one of the leading courses for sustainable and resource-efficient development. Main aspects of bioeconomy: development of new technologies and processes, development of markets and competitiveness for bioeconomy can be implemented through higher education and transformative knowledge for building a sustainable bioeconomy. Over the past year, new bioeconomy-related Master study programmes have been created and have integrated bioeconomy goals into their research, programme aims and learning outcomes. During the research the set of competences based on sustainable development competences and bioeconomy competences have been created. The integration of competences for bioeconomy development in higher education can be seen as an important step in transformation towards knowledge-based bioeconomy. On this basis, 10 Master study programmes across Europe were analysed in order to find out the actual integration of competences in different study programmes for bioeconomy. Results of the analysis show that transdisciplinary competence, learning competence, interdisciplinary competence and system-thinking competence are strongly integrated into the study programmes. The analysis also shows that the integration of other competences, like anticipatory competence, normative competence, strategic competence and interpersonal competence can be improved in the future.**

Keywords **– Sustainable higher education; competences; green innovation; bioeconomy integration assessment**

1. INTRODUCTION

Bioeconomy in Europe has become one of the leading courses for sustainable and resource-efficient development. Main aspects of bioeconomy: development of new technologies and processes and development of markets and competitiveness for bioeconomy [1] can be implemented through higher education and transformative knowledge for building a sustainable bioeconomy. Intellectual capital gained through the knowledge-based bioeconomy became crucial for the development agenda of the European Union [2]. Therefore, the implementation of bioeconomy in Europe will be in a short loop with education and research [3]–[6]. The successful

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development of bioeconomy requires new skills from graduates of higher education based on revised model of intellectual improvement and knowledge-based technology innovation [7], [8].

The Green deal [9] set ambitious targets for European Member states to strive for with the goal to reach the climate neutrality by 2050, with a special attention to a number of sectors crucial to fulfil its ambitious aims: clean energy, sustainable industry, building and renovating, sustainable mobility, biodiversity, farm to fork and eliminating pollution. As bioeconomy instead of fossil fuels rely on renewable biomass for the production of value-added products and these products will be produced in accordance with a cascade principle, the development of bioeconomy can help to reach The Green deal goals and targets.

Golembiewski *et al*. [10] identified three main bioeconomy challenges: knowledge base, converging technologies and commercialization issues. The role of higher education in crucial for all three of these challenges, cause innovation and intellectual capital development can be achieved only with adequate skills and knowledges. In accordance with Val Lancker *et al*. [11] five factors impacting implementation of innovation development in bioeconomy:

1. Radical innovation.
2. Complex knowledge base.
3. Intense cooperation.
4. Commercialization and adoption.
5. Complex and fragmented policy schemes [11].

The implementation of bioeconomy goals should be absorbed from the systematic perspective, considering different stakeholder's groups. Working on overcoming of bioeconomy challenges special attention should be paid to environmentally sustainable economy development, because ecologically correct business practices [12], [13] can reduce the impact on environment and speed up the achievement of Green Deal goals. Montalvo *et al*. [14], [15] pointed out that the creation of greener technologies includes technological capabilities through well prepared high-quality human resources, equipment and laboratories. Different authors have carried out studies, according to which development of environmentally sustainable innovation and green innovation requires innovation-oriented learning and acquisition of specific skills [16]–[19]. Considering the above mentioned, the best practices for teaching bioeconomy, environmental responsibility and green innovations in Europe should be discussed and analysed.

2. METHODOLOGY

A research was conducted to propose an effective framework to evaluate the effectiveness of Master study on Bioeconomy with a focus on competence-based education and development of sustainable innovations.

During the first and second step of the research the research definition, objectives and research questions were defined. Conduction of the research started with data collection and analysis. During this step the systematic review of scientific literature on teaching bioeconomy in higher education, competences for sustainable development and bioeconomy, innovation indicators was conducted.

During the next step of the research most significant innovation indicators for bioeconomy were identified and selected.

The integration of competences for bioeconomy development in higher education can be seen as an important step in transformation towards knowledge-based bioeconomy. During the next step key competences for bioeconomy have been defined. During the research the set of competences based on sustainable development competences and bioeconomy competences have been created.

Over the past year, new bioeconomy-related Master study programmes have been created and have integrated bioeconomy goals into their research, programme aims and learning outcomes.

A systematic review [20]–[22] of existed Master study programmes on Bioeconomy was required. For identification and selection of the most significant indicators in teaching of bioeconomy in higher education, study programmes in Europe, including joint programmes and Erasmus Mundus joint programmes were investigated.

Based on this examination, ten Master study programmes across Europe were analysed in order to find out the actual integration of competences in different study programmes for bioeconomy.

The methodological algorithm of the research is shown in Fig. 1.

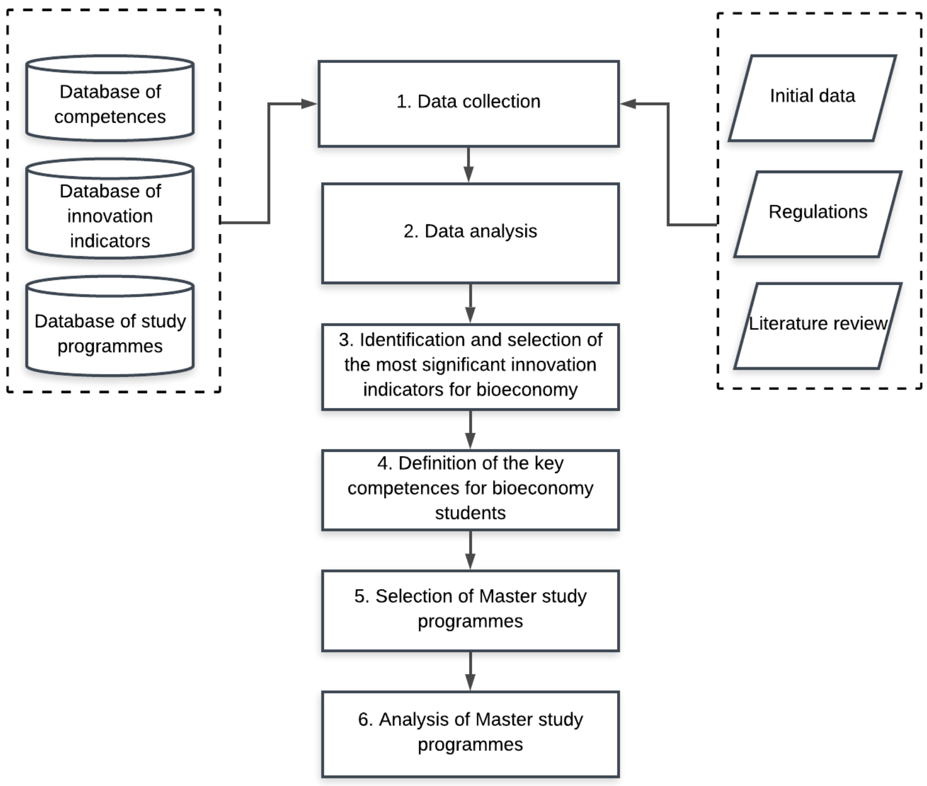

Fig. 1. Methodological algorithm.

3. Results and Discussion

3.1. The Role of Higher Education in Innovation Development in the Bioeconomy

The development of the bioeconomy is related with the promotion of innovation. The interaction of innovation with the bioeconomy context should be defined. Through innovation and use of knowledge-based technologies bioeconomy provide entirely new products, at the same time adapting the existing technologies and products to reach the demands of sustainable economy [23].

How to measure innovation in the bioeconomy? Wydra [24] had analysed innovation indicators in bioeconomy, including research and development activities, bibliometrics and patents, human resources and commercialization and the impact of innovation. Ribeiro and Cherobim [25] described stages of the innovation process and Van Lancker *et al.* [11] analysed the role of universities in innovation in the bioeconomy. Fig. 2 shows the innovation process in bioeconomy, including innovation process, stages, involvement of university and innovation indicators. Universities play the core role in the innovation process.

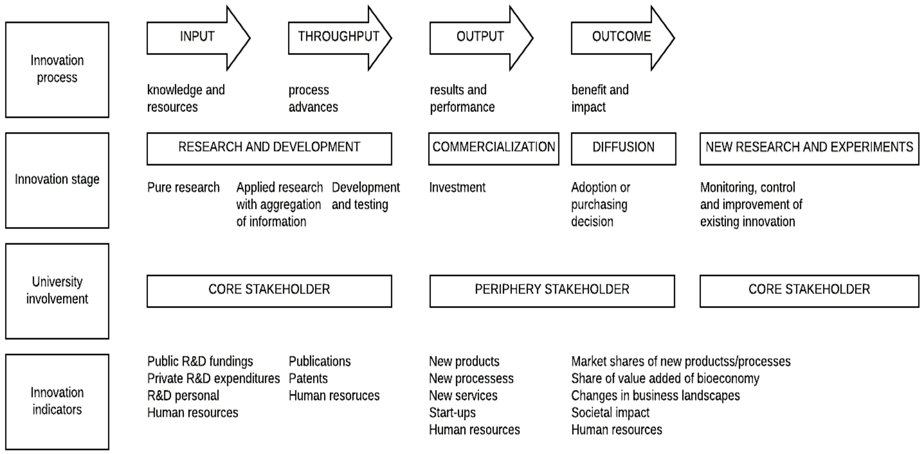

Fig. 2. Innovation process and indicators in bioeconomy.

3.2. The Integration of Competences for Bioeconomy Development in Higher Education

European Commission has defined the theoretical concept of Knowledge-Based-Bioeconomy (KBBE) as life science knowledge transformation process into eco-efficient, new and sustainable products [26]. The transformation process of the existing production system towards KBBE will increase demand for the high-skilled and highly qualified workers. To analyse the qualification needed, the competences and knowledge for building a sustainable bioeconomy were analysed. Due to the global changes and transition to bioeconomy and circular economy, new ways of knowledge production and decision-making at university level should be developed [27].

In accordance with Segalas *et al.* [28], education, although an important condition, does not guarantee a change to sustainability. Engineering students upon graduating should have systems thinking and transdisciplinary competence. The same statement can be addressed to bioeconomy. Transdisciplinary in contest of engineering education is considered a competence for sustainability [29]. Lambrechts *et al.* [30] analysed the integration of competences for sustainable development in higher education via a holistic, interdisciplinary and transdisciplinary approach and competence-based education. Authors analysed how competences for sustainable development, such as responsibility, emotional intelligence, system orientation, future orientation, personal involvement and action skills were integrated into bachelor study programmes in management. Weak *et al.* [31] defined system-thinking competence, anticipatory competence, normative competence, strategic competence and interpersonal competence as main competences for sustainability.

The transition towards a bioeconomy requires well prepared bioeconomy professionals with basic and key competences acquitted through interdisciplinary educational process and new learning environments. Sustainability is considered to be a basic principle of bioeconomy; therefore, the competences for sustainability can be used as the basis for the competences for bioeconomy [32].

The programmes on bioeconomy are trying to integrate innovative learning and facilitate the development of interdisciplinary competence acquiring the ability to integrate and collaborate [33]. Learning competence include self-directed learning, collaborative learning and problem-oriented learning [34].

The integration of competences for sustainable development and bioeconomy competences can be seen as an important step in higher education for advancing the implementation of the bioeconomy goals.

There is a lack of information on the actual status of the integration of competences in existing Master study programmes on bioeconomy. The competences used for the analysis of Master study programmes on bioeconomy are shown in Table 1.

TABLE 1. COMPETENCES FOR BIOECONOMY USED FOR THE ANALYSIS

Competence	Discourse of Competence
System-thinking competence	The ability to collectively analyse complex systems across different domains of sustainability and bioeconomy [31].
Anticipatory competence	The ability to collectively analyse and evaluation in bioeconomy and sustainability issues [31].
Normative competence	The ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets [31].
Strategic competence	The ability to collectively design and implement interventions, transitions, and transformative governance strategies towards bioeconomy sustainability [31].
Interpersonal competence	Advanced skills in communicating, deliberating and negotiating, collaborating, leadership, pluralistic and trans-cultural thinking, and empathy [31].
Transdisciplinary competence	Advances skills in transcendence, problem solving, innovation, interdisciplinary research, transgression [28].
Learning competence	The ability to self-directed learning, collaborative learning and problem-oriented learning [33].
Interdisciplinary competence	The ability to integrate disciplinary perspectives and their insights to advance understanding of complex problems with the goal of applying the understanding to a real-world problem [30].

3.3. Analysis of Master study programmes on bioeconomy

In the last years several universities in Europe have established programmes on topics related with bioeconomy. For the analysis from European master programmes on bioeconomy were selected. The study programme selection was done through the master study programmes search pages and through the search on specific home pages about bioeconomy.

Only full time Master Study programmes were selected. Search results have shown that study programmes on bioeconomy spread around Europe from North Europe (Finland and

Estonia), Western Europe (Germany, Austria, Netherlands, France Belgium), Eastern Europe (Rumania), Southern Europe (Italy, Spain) and the United Kingdom.

For the moment the most of the study programmes are in Western Europe. Netherlands are the leaders with four Master study programmes on bioeconomy. Germany, France, and the United Kingdom have more than one study programme on bioeconomy. Seven Master study programmes are University study programmes, two are joint Master study programmes and one is Erasmus Mundus Joint Master study programme. The overall focus of study programmes is on bioeconomy with specialization in different aspects of bioeconomy, such as forestry, biotechnology, circular economy, chemical engineering, biobased materials, bio innovations, etc.

The sampling resulted in the following 10 study programmes presented in Table 2.

TABLE 2. MASTER STUDY PROGRAMMES ON BIOECONOMY

University	The name of the programme	Study time	Description
Maastricht University (Netherlands)	Biobased Materials	2 years full time	Focus on discovery of new materials and sustainable production methods of bioresources [35].
Utrecht University (Netherlands)	Bio Inspired innovation	2 years full time	Focus on development of circular business-models and bio inspired research & innovations [36].
Wageningen University and Research (Netherlands)	Biobased Sciences and Biosystems Engineering (and Biotechnology)	2 years full time	Focus on biobased economy from an interdisciplinary perspective [37].
University of Edinburgh (UK)	Management of Bioeconomy, Innovation and Governance	2 years full time	Focus on such aspects of bioeconomy as sustainable innovation and bringing new technologies to existing and emerging markets [38].
University of Strathclyde (UK)	Industrial Biotechnology	1 year full time	Focus on understanding of the current developments in industrial biotechnology [39].
The University of Hohenheim (Germany)	Bioeconomy	2 years full time	Focus on biobased economy through inter- and transdisciplinary approach [40].
University of Helsinki (Finland)	Forest Sciences	2 years full time	Focus on forest bioeconomy business and policy [41].
Joint Study Programme: University of Eastern Finland, AgroParisTech (France), University of Freiburg (Germany), University of Lleida (Spain), University of Natural Resources and Life Sciences (Austria), Transilvania University of Brașov (Romania)	European Forestry	2 years full time	Focus on sustainable resource management with an emphasis on current bioeconomy issues [42].
Joint Master: University of Bologna, University of Milano-Bicocca, University of Naples Federico II, University of Turin (Italy)	European Master in Bioeconomy in the Circular economy	1 year full time	Focus on bio-based goods and services industry using biological resources and bio-technological processes [43].

Erasmus Mundus Joint Master: Paris Institute of Technology for Life, Food and Environmental Sciences (France), University of Reims-Champagne-Ardenne (France), Aalto University (Finland), Tallinn University of Technology (Estonia), University of Liège (Belgium)	European Master in Biological and Chemical Engineering for a Sustainable Bioeconomy	2 years full time	Focus on biotechnology, bioprocess design and upscaling, and biobased products engineering, with complementary focus on soft skills including project management [44].

A framework of analysis was developed using competences for bioeconomy defined by Wiek *et al*. [31], Repko *et al*. [33], Barth and Burandt [34] and Tejedor *et al*. [29], and competences acquitted in the study courses of each study programme. The research used competences for bioeconomy as the basis for the analysis of study programmes. Each competence was interpreted in the competence scheme. For the analysis syllabus, study programmes descriptions and study course descriptions for each study programme have been used. The goal was to express the integration of the competences for bioeconomy in each study programme: (1) little or no integration, (2) minimal integration, (3) moderate integration, (4) good integration. Table 3 provides an overview of results of analysis of University of Edinburgh study programme "Management of Bioeconomy, Innovation and Governance".

TABLE 3. EXAMPLE OF ANALYSIS OF STUDY PROGRAMME INDIVIDUAL COMPETENCE MATRICES

Competences for Bioeconomy / Study programme competences	System-thinking competence	Anticipatory competence	Normative competence	Strategic competence	Interpersonal competence	Transdisciplinary competence	Learning competence	Interdisciplinary competence
Analysis of trends, opportunities and challenges along the life science innovation pathway [45]	4	4	3	3	2	4	3	4
Facilitating entrepreneurship and thinking creatively about the future of the bioeconomy [45]	3	3	4	4	4	4	4	4
Creating business plans and mapping routes to market for new technologies [45]	3	3	2	4	3	3	3	3
Foresight and scenario-based techniques for managing risk and uncertainty associated with emerging technologies [45]	4	3	4	3	3	4	2	4
Negotiation and communication skills in interdisciplinary teams [45]	4	4	3	4	4	3	4	4

Legend:		
	1	little or no integration
	2	minimal integration
	3	moderate integration
	4	good integration

Considering the fact that analysed study programmes are designed especially for the bioeconomy studies, overall bioeconomy and sustainable development competences are well integrated into the study programmes. In existing study programmes on Bioeconomy in Europe transdisciplinary competence, learning competence, interdisciplinary competence and system-thinking competence are strongly integrated into study programmes. The integration of other competences, like anticipatory competence, normative competence, strategic competence and interpersonal competence can be stronger. This illustrated that translation towards these competences for sustainable development and bioeconomy in a future must be intensified.

The result of the analysis on the integration of bioeconomy competences in study programme competences are shown in Table 4.

TABLE 4. THE INTEGRATION OF BIOECONOMY COMPETENCES IN THE STUDY PROGRAMME COMPETENCES

Competences for Bioeconomy / Competence matrix of Master study programmes	System-thinking competence	Anticipatory competence	Normative competence	Strategic competence	Interpersonal competence	Transdisciplinary competence	Learning competence	Interdisciplinary competence
Biobased Materials	3	4	3	3	3	4	4	4
Bio Inspired innovation	4	3	3	3	4	4	4	4
Biobased Sciences and Biosystems Engineering (and Biotechnology)	4	3	3	4	3	4	4	4
Management of Bioeconomy, Innovation and Governance	4	3	3	4	3	4	3	4
Industrial Biotechnology	3	4	3	4	4	3	4	4
Bioeconomy	4	4	3	4	3	4	4	4
Forest Sciences	3	4	4	3	3	3	4	3
European Forestry	4	3	3	3	4	4	4	4
European Master in Bioeconomy in the Circular economy	4	3	4	3	4	4	4	4
European Master in Biological and Chemical Engineering for a Sustainable Bioeconomy	4	3	3	3	3	4	4	4

Legend:		
	3	moderate integration
	4	good integration

4. CONCLUSIONS

For the achievement of Green deal, new thinking, learning, teaching and acting strategies should be used. The transition towards bioeconomy is a challenging process and requires cooperation of different stakeholders. Universities, one of the main stakeholders in creation of innovation and sustainable invention, play an important role in implementation of bioeconomy goal through preparation of bioeconomy professionals. Bioeconomy programmes graduates will be the protagonists of a transformation to sustainable bioeconomy and will need to apply acquitted competences and knowledge in creation of new technologies and green innovations in general. This article has reviewed the indicators of sustainable innovation and bioeconomy and sustainable development competences for the education for bioeconomy. Defined competences include transdisciplinary competence, learning competence, interdisciplinary competence and system-thinking competence, anticipatory competence, normative competence, strategic competence and interpersonal competence. All of these competences have showed to be the most important for the implementation of bioeconomy goals and transformation to knowledge-based sustainable bioeconomy.

The analysis of 10 Master study programmes on bioeconomy revealed that the overall bioeconomy and sustainable development competences are strongly integrated into study programmes.

Authors state that more research is needed on the link between the integration of the competences and green innovations. Definition of competences is only one of the steps in the integration of sustainable bioeconomy and is only a part of a broader process, combined with knowledge, skills, intellectual capital and inventions for sustainable bioeconomy.

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Full Length Article

The tango between the academic and business sectors: Use of co-management approach for the development of green innovation

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A B S T R A C T

This study explores a co-management approach to prepare future environmental engineers for green innovation and commercialisation by improving cooperation between academia and industry. Collaboration between academia, government, agencies, and industry is a top priority due to the significant impact of the availability of qualified environmental professionals on the economy. The potential for collaboration among parties with different interests and principles remains largely unexplored. Compared to tango dance, the paper discusses the co-management approach, combining two disciplines with other goals and expectations. The methodology adapts brainstorming for studying environmental engineering to improve students' competencies and diversify study methods. Studying classical idea co-creation approaches in higher education, evaluating their results, and analysing stakeholders' opinions - involving 65 students, six industry and government representatives, and 14 lecturers. This study identified crucial factors that form a model for successful collaboration between academia and industry to train environmental science specialists and develop green innovations. These factors include party participation activity, the definition of primary evaluation criterion, and student motivation. The study concludes that the co-management approach could enhance competence education quality by promoting skill diversification and teamwork and providing greater motivation to work.

1. Introduction and literature review

Green innovation is crucial in raising the quality of future generation life and solving environmental challenges (Bataineh et al., 2023; Prieto-Sandoval et al., 2022). Organisations and communities in recent years have been directed towards green innovation to achieve environmental protection and maintain sustainability and economic growth (Ho et al., 2023; KarimiTakalo et al., 2021; Wang et al., 2022). Green innovations are crucial for the environment, financial profitability, and social sustainability (Fliaster & Kolloch, 2017) of all society; nevertheless, a significant challenge in implementing green innovation is the availability of a skilled workforce and the interaction between academia, government, and industry (Avelar et al., 2019; Fernández-Manzanal et al., 2015; Leal Filho et al., 2018). Academia and industry, with the support and guidance of the government, must balance their interests in educating young professionals and commercialising environmental technologies, as this contributes to the economy's move towards climate neutrality (Leyva-de la Hiz, 2019; Ribeiro & Cherobim, 2017).

In the scientific literature, the role of higher education and research activities in advancing Sustainable Development and the role of collaboration with the private sector and the need for improvements to make interactions more efficacious has been discussed (Adomβent et al., 2014; Annan-Diab & Molinari, 2017; Gómez et al., 2015; Sidiropoulos, 2014; Sinakou et al., 2018; Österblom et al., 2020). According to the literature, to promote the sustainability of green innovation, all sides need to critically assess their proper role in training students and respect the various factors that influence joint achievement (Bag et al., 2022; Marcon et al., 2017; Stål & Babri, 2020). Stall and Babri (Stål & Babri, 2020) discussed the influence of translating knowledge and educational intervention; Marcon et al. (2017) analysed best innovation practices and the role of sustainability–oriented education. The academic sector needs to take bolder solutions to modern education and become a partner for proactive dialogue with the industry, respecting the existing competition between higher education institutions (Ellis & Childs, 2019; Gutierrez-Martin & Hüttenhain, 2003; Kopnina, 2019) and the opportunities provided by alternative online education platforms. The paradigm shift in society has also affected the academic sector, which has a growing demand from policymakers and industry for appropriate teaching methods - research also shows that academic personnel need to improve their performance (Kennedy, 2016; Sharif, 2019), including cooperation, use of

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co-creation and co-management approach. Accordance to Sharif (Bag et al., 2022), the advancement of higher education is impossible without innovation and creativity. The industry insists on the way academia teaches innovations. The unique challenge educators face at the interface of management, and technology is the need for integration and the difference in worldview between managers and technologists (Linton, 2015). Therefore, becoming a proactive dialogue partner for the academic sector means reviewing the current external communication strategy and working with the academic staff's motivation to become a full-fledged stage bridging the university study process and the industry expectations (Augusto & Coelho, 2009; Huang & Tsai, 2014; Roh et al., 2022; Souto & Rodriguez, 2015). Bridging organisations provide a forum for interacting with these different kinds of knowledge and coordinating other tasks that enable cooperation: accessing resources, bringing together different actors, building trust, resolving conflicts, and networking (Gatti et al., 2019). Already Berkes in 2009 (Berkes, 2009) concluded that social learning is one of these tasks, essential for the cooperation of partners and the outcome of the cooperation. It occurs most efficiently through joint problem-solving and reflection within learning networks (Berkes, 2009).

On the other hand, the industry lately has done a lot to implement green innovations into production lines. The considerable role it plays in government and legislative obligations. For businesses, sustainability is becoming a commanding and essential principle (Genç & di Benedetto, 2015; Srivastava et al., 2019; Tejedor et al., 2018a). The value for the private sector is the competitiveness of business and integration into the green value chain. The sustainable corporation should create profit for its shareholders while protecting the environment and improving the lives of those with whom it interacts; it should operate so that its business interests and the interests of the environment and society intersect (Orecchini et al., 2012).

Each of the parties engages with their confidence based on previous experience of the specialization. If this experience is synchronised, companies' confidence in their leadership skills, including in developing green technologies, can lead to the development of successful solutions (Walsh & Linton, 2011). Meanwhile, technologists often feel that technology matters and need help paying attention to the end customer's preferences and other business (non-technical) concerns (Caetano & Amaral, 2011; Malhotra, 2005; Taylor et al., 2005). Considering the above, it can be concluded that a new form of partnership between different actors participating in the development and intensification of green innovation is needed.

Cooperation and collaboration lead to effective green innovations. Conducting events like simulation games, role games, and hackathons can improve teaching and learning outcomes by integrating practical aspects and strengthening acquired competencies like problem-solving. A co-management approach can be used to build balanced cooperation between two parties, one of the applications of which is co-management in solving problems - seen as collaborative problem solving and is task-oriented, concentrating on the function rather than the formal structure of the arrangement. The role of government in the co-management approach was described by Carlsson & Berkes (2005), who convinced that co-management is a "power-sharing arrangement" and entails shared decision-making. Collaborative hackathons have been used for resolving environmental problems (Kvamsås et al., 2021), as open innovation methods (Temiz, 2021) and for the advancement of innovations (Temiz, 2021), Kamariotou and Kitsios, 2022. The existing scientific literature lacks procedures for improving cooperation between the academic sector, government through higher education institutions, and industry in preparing future environmental engineering specialists by the requirements of green innovation commercialisation.

The authors of this study compare the collaboration between academia and industry in Argentine tango dance, which reflects the challenges and opportunities in the interaction of two dissimilar partners. The two dancers symbolise two different worlds, united by a common goal: to take a series of activities during a limited period to prepare young environmental engineers for developing and commercialising green innovations.

Impulsive dance movements reflect unexpected developments - different interests and strategies of the academic sector and industry, which must be able to synchronise in a short period while respecting the choice of the partner. This tango dance (partner interaction) creates both tangible and intangible value - measurable indicators (skilled workforce, number of new technologies and applications, as well as import substitutes) and a social effect on the organisational culture of both parties.

Collaboration can be as fiery as dancing when seemingly insurmountable obstacles arise from strategic or technical challenges. However, "it takes two to tango" to achieve a goal. According to research, tango dancing has more than a rehabilitative effect on the health of dance partners (in their organisations and the development of green innovations). Still, its application proves the connection between the dancer's temperament and artistic performance (the enthusiasm of the partners involved affects the collaboration quality) (Lolich et al., 2015; Peter et al., 2020).

The present study is expected to contribute to our understanding of a methodology for a set of integrated activities that ensure a successful interaction between academia and industry to develop future environmental engineers with the skills to find innovative, sustainable, and well-managed solutions in the field of green innovation, thus contributing to the economic development, the competitiveness of the national economy and society's efforts to implement climate change.

The study's authors anticipate that the goal will be achieved by identifying critical factors and developing a model that allows stakeholders (academics, students, industry, mentors, etc.) to become key actors in the green innovation value chain.

2. Methodology

The approach is based on forming a model of cooperation between the academic sector and industry, which is aimed at training qualified environmental scientists to develop green innovations that meet the requirements of the national economy (Morgan & Anokhin, 2020; Pham et al., 2019; Sinha et al., 2020). A hackathon is used to simulate collaboration, as it is determined as a valued tool (Yousaf, 2021). The main sections in the methodology (see Fig. 1) are:

- Characterisation of human resources (see Section 2.1.).
- Partnership – co-creation model development (see Section 2.2.):
  - Final presentation evaluation (see Section 2.2.1.).
  - TRL assessment (see Section 2.2.2.).
- Green innovation commercialisation.

The innovation of this method lies in its ability to be applied to various other disciplines, where the presence of competent specialists directly impacts the growth of the national economy and contributes towards addressing global challenges, making it a valuable approach. The broader application of the methodology will allow universities to strengthen their efforts to develop green innovations, thus demonstrating their contribution to decreasing the adverse effects of climate change and improving the quality of life of the world's population (Lambrechts et al., 2013; Shamzzuzoha et al., 2022).

The method has several practical applications. The higher education institutions will promote the training of qualified specialists to promote the development, application, and recognition of green innovations. In turn, companies in the environmental sector will acquire a skilled workforce and, by engaging in the methodological process as a strategic partner, will be able to achieve the goals of corporate social responsibility more effectively. Meanwhile, national policymakers in the field of environmental protection will be able to implement a better course of the green economy and strengthen their participation at the international level in achieving Sustainable Development goals related to the

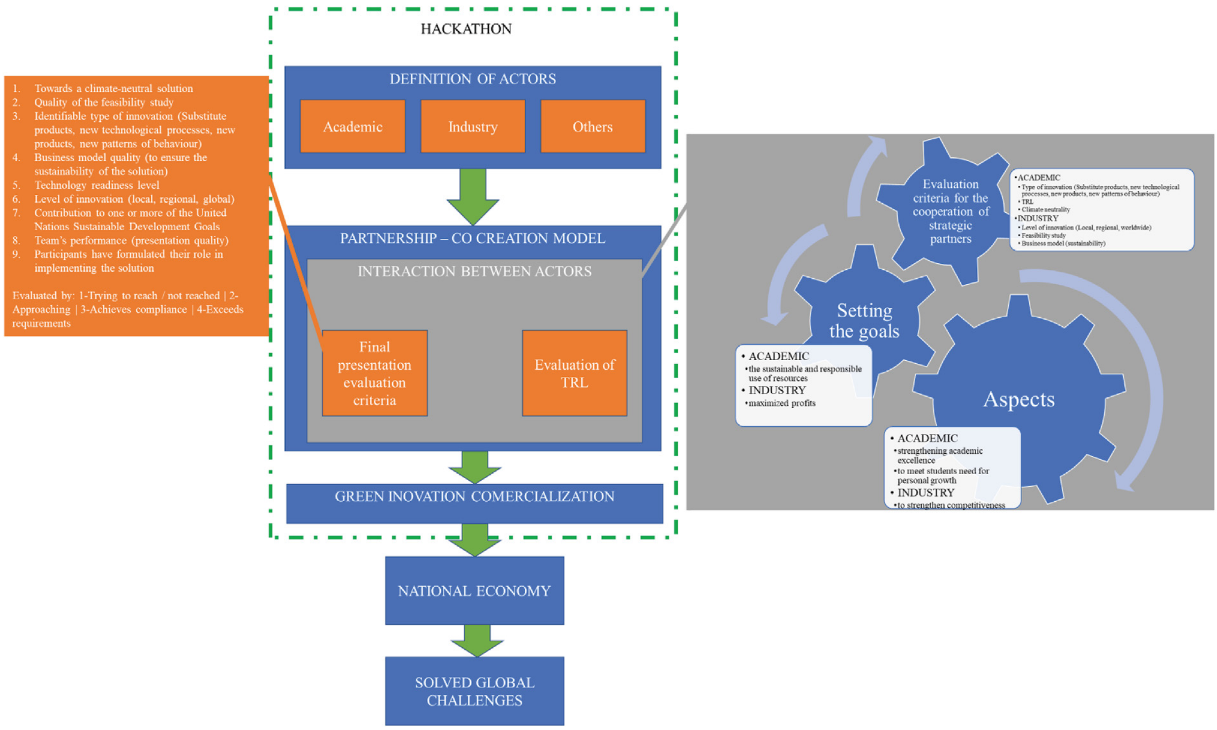

Fig. 1. Methodology for enhancing academia-industry collaboration in training green innovation-focused environmental engineering specialists.

environment and climate (Cheng, 2019; Faludi & Gilbert, 2019; Stough et al., 2018; Tejedor et al., 2018b).

This research methodology envisages the adaptation of brainstorming as a format for studying environmental engineering to promote the improvement of students' competencies and diversify the study process methods.

The methodology is considered by studying classical idea co-creation approaches in higher education, evaluating their results, and analysing stakeholders' opinions - with a total of 65 students, six industry representatives, and 14 lecturers.

2.1. *Characteristics of human resources*

The first task is to define the actors in the green innovation value chain and their roles. The leading players considered in the study are academia - students, academic staff, the industry - a company, mentors, industry experts, and other stakeholders. The university, as a partner, provides motivated students, which is one of the critical elements of the model. Their involvement in the brainstorming of green innovations promotes knowledge-based entrepreneurship, strengthens the cooperation of the academic sector with industry, as well as ensures the availability of a qualified labour force for economic development in the future.

2.1.1. *Requirements for students*

1. Communication and cooperation, skills for productive interaction within the team, prior knowledge of environmental technologies, understanding where and how to look for more information beyond the scope of the study course, and the ability to create know-how.

2.1.2. *Requirements for academic staff*

The university's academic staff has a critical role in ensuring student results, whose awareness and active participation in the study process motivate students to solve challenges. The involvement of the teaching staff aims to provide a continuous learning process and to persuade the industry to trust the competencies of the academic sector and the ability of students to create and potentially commercialise scientific achievements in the field of green inventions.

The other major player in the model is the industry represented by the company with its problem case. A company can be defined as a "shareholder" who has an economic interest in the results of cooperation and whose active participation significantly contributes to the quality of environmental science education and the availability of labour forces essential for economic development. Industry input formats - preparation of information and sharing of competencies of high profile specialists-one of the most expensive resources in business and helps students to create practical solutions that meet the needs of the "shareholder". If the company saves resources on this - it will be less likely to get the expected result.

2.1.3. *Requirements for the company*

Ability to precisely define the challenges faced by the company itself, knowledge of the process of commercialisation and development of environmental technologies, ambitions aimed at international competitiveness, readiness to provide competent representatives, incl. The ability to look at collaboration in a broader context, also taking into account noncommercial interests, to provide business advice and to find standard solutions to the challenges that may arise in cooperation with academia.

It is the joint responsibility of both key partners - academia and industry - to attract the following competence partners, whose presence strengthens the partners' capacity and opportunities to ensure a full-fledged knowledge exchange process in developing green innovations. Those external mentors and social partners have a role to play in assessing the solution's positioning in the broader context.

2.2. *Designing a successful partnership model*

The interaction between the partners is based on the needs of each stakeholder - their scale and depth determine the degree of involvement and the amount of investment. Aspects, where the parties' needs coincide have the most significant impact on the research results; for example, the student has future career opportunities for personal growth. At the same time, the university is essential to strengthening its status as a modern educational institution, but the company's interest is through this interaction.

To a large extent, the academic staff's attitude and enthusiasm also influence students' motivation to work. Therefore the primary task of the university is the motivation of the teaching staff to get involved - strengthening academic excellence:

1. Updating of study program teaching methods by the spirit of the era.
2. Closer links with industry to promote applied research.
3. Meeting the demands of education policymakers (fulfilment of the requirements of the accreditation process).

At the same time, the university also motivates students to get involved - to meet their need for personal growth:

1. A well-paid profession of the future.
2. Acquisition of competitive knowledge.
3. Modern study process.
4. Opportunity to prove their knowledge and skills to themselves and demonstrate to others both in direct communication with the company's representatives and by presenting the team's achievements.

To strengthen student participation, they must be able to choose a topic closer to themselves. Students indicate their choice in the order of priority - so that process supervisors can ensure that the case assigned to the student is a statement of their importance. This approach motivates students and makes them take responsibility for their choices. This avoids the accusations of students for not respecting their interests.

In turn, the company's task is to formulate its primary motivation to get involved - to strengthen competitiveness:

1. The commercialisation of new green innovations.
2. Optimisation of the business model for gaining competitive advantages.
3. Attracting a skilled workforce to create a value-added product.

To strengthen the company's participation, the university can formulate "healthy ambitions" for the benefits of the partnership, such as the development and implementation of green innovations by Technology readiness levels (TRL) 5–7, so that the company can achieve the goals set by its shareholders. As an added value of participation in the event, the company has the implementation of corporate social responsibility activities - support for academic education to improve the quality of the study process and involvement in the development of the state "green policy", strengthening the qualification of the future workforce (see Fig. 2).

The academic sector needs to devote more effort to motivating stakeholders since students' readiness to act depends on academics' involvement and entrepreneurship and competence partners' involvement. When the academic and private sectors engage in collaboration, the first step is to find a balance between economic, environmental, and social impacts as crucial factors in decision-making:

(a) In the field of the environment, the primary goal of the academic sector is the sustainable and responsible use of resources because the solutions are aimed at increasing the public quality of life;
(b) In business, the primary goal is to maximise profits - this is required by both business owners and the need to ensure stable financial flow, competitiveness and growth. Profit reduction is accepted in the public interest if it is required by law, as in the case of waste management, where companies must carry out general information and education activities in parallel with their economic activities, thus contributing to sustainable development goals.

Based on the above, the university has a decisive role in the development of events and technologies as such. In turn, the industrial sector, represented by companies, guided by its strategic interests, makes decisions on the optimal work of student teams.

In cooperation between the university and the company, there may come a time when both parties must agree on the goals and methods for achieving them. In this case, an alternative approach is possible, which allows balancing interests in such a way that they satisfy both parties. This approach involves designating 3–5 critical criteria and assigning weight to them. However, this can be a lengthy process due to the different perspectives of the partners.

The authors of this study propose to create two systems for evaluating the interests of the parties that would meet the needs of both partners (the company and the university). Criteria such as inventiveness, quality, environmental impact and the commercialisation potential of the idea (innovation) are evaluated. Each criterion is scored on a scale from 1 to 10 (where one is the lowest and ten is the highest). Each criterion, depending on the significance (which must be achieved within the framework of the event and/or research) concerning the result, is assigned its weight (Table 1).

2.2.1. Evaluation criteria for a final presentation

The spirit of competition and the game element can significantly affect the event's final result. The creation of teams directly affects competition and cooperation at the same time. The opportunity to test your knowledge and experience in competitive disciplines contributes to a better, deeper and more versatile assimilation of information, and understanding of the limits of your capabilities and, not

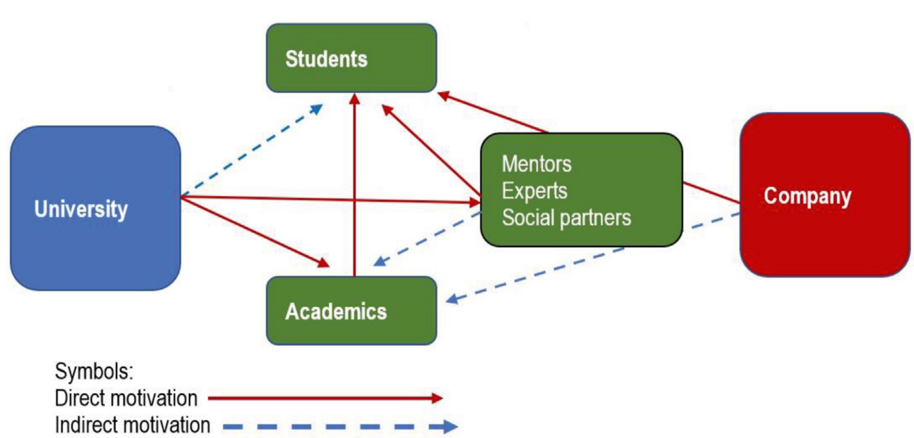

Fig. 2. The contribution of strategic partners to the motivation of all sides.

Table 1
Evaluation criteria for the cooperation of strategic partners.

Nr.	Academic sector		Industry	
	Technological quality of the invention		Commercialisation opportunities	
	Criteria	Weight	Criteria	Weight
1.	Type of innovation (Substitute products, new technological processes, new products, new patterns of behaviour)	0.4	Level of innovation (Local, regional, worldwide)	0.2
2.	TRL	0.2	Feasibility study	0.5
3.	Climate neutrality	0.4	Business model (sustainability)	0.3

Table 2
Evaluation criteria for the final presentation.

Evaluation criteria	Trying to reach/not reached	Approaching	Achieves compliance	Exceeds requirements
	1	2	3	4
	Students' activities are inaccurate, and the approximate performance can only be partially attributed to the acquired competence.	Student performance is generally related to the competence to be acquired.	Students' performance is accurate; it is based on judgments about these criteria	Students' performance is accurate and convincing; it shows the limitations and complexity of competence.

least, promotes close cooperation not only within the team but also with representatives of the academic staff and companies (consultants).

A variety of methods in the learning process allows cooperation between the teaching staff and students to a new level, allowing students to expand their knowledge of the environment and test their knowledge in practice. Since the focus is often on the results of team competitions, the authors offer a structured approach that will allow objective evaluation of the quality of the team decision and the quality of the final presentation (Table 2).

Additionally, the study's authors offer a table of evaluation criteria that can be adapted to various educational programs. Each criterion is scored on a scale from 1 to 4, where 1 - tries to achieve/not achieved and 4 - exceeds the requirements. Each is given a weight depending on the requirements of the study program (Table 3), which experts determined. The idea development model is a set of elements, the application of which leads to a successful result. The model can be compared to a sieve, in which, after sifting through a large number of different types of information and innovation, meaningful knowledge and activities are separated to satisfy the interests of all parties involved. The model consists of the main predetermined parameters - the novelty of the idea, economic feasibility and presentation. Before the start of the event, students should receive all possible information about the different types of innovations in the bioeconomy (substitute products, new technological processes, new products, new behaviours, etc.). This information will allow students to understand the course's objective better and perform the task better (Bröring et al., 2020).

Table 3
Evaluation of criteria.

Nr.	Criteria	Weight
1.	Towards a climate-neutral solution	0.20
2.	Quality of the feasibility study	0.20
3.	Identifiable type of innovation (*Substitute products, new technological processes, new products, new patterns of behaviour*)	0.15
4.	Business model quality (to ensure the sustainability of the solution)	0.1
5.	Technology readiness level	0.1
6.	Level of innovation (local, regional, global)	0.1
7.	Contribution to one or more of the United Nations Sustainable Development Goals	0.05
8.	Team's performance (presentation quality)	0.05
9.	Participants have formulated their role in implementing the solution	0.05
Total		1.0

2.2.2. Evaluation of TRL

The next step in the study is to understand the technological readiness of the project. This understanding would allow for setting a goal that the team can achieve in the allotted time.

The amount of information the team provides directly depends on the curriculum requirements and the TRL criteria. For example, in the case of TRL1-4, it will be: a) research; b) concept description; c) results of analytical and experimental work; d) documented test performance, etc. Information includes, for example, cost-benefit analysis, business model, market research, etc. Based on the company's turnover (for example, the number of products produced), the team makes an economic analysis of the project. A financial analysis of an innovative solution project is necessary to prove this project's success. An additional advantage of this analysis is acquiring knowledge regarding the economic aspect, which undoubtedly increases the student's competitiveness in the market. Creating a transparent project logistics chain, starting with the resource producer and ending with the buyer, is the second significant indicator of the proposed solution.

The implementation of a business model is the second indicator of the quality of a student team solution from an industry perspective. It is common for business models to be examined from the value chain perspective in combination with other theories and enterprise practices. A business model articulates a value proposition for customers (Teece, 2010) and considers how an organisation creates, delivers, and captures value (Osterwalder & Pigneur, 2010). Academics and business managers have different understandings of the concept of sustainable business models, and there is still a debate about whether sustainable business models might supersede traditional business models in the future (He & Ortiz, 2021).

3. Results

As part of this study, a pilot hackathon event was held, organised by the Institute of Energy Systems and Environment of Riga Technical University (Latvia). The main actors were established - both the academic staff of the university and students took part, as well as the waste management company.

The purpose of the hackathon was to promote the ideas of recycling complex types of waste and to develop innovative recycling solutions. During the hackathon, one criterion was established: to find and justify the possibility of using a specific type of waste in producing a new high-value-added product. The event is based on the cyclical nature of the production cycle, which positively affects the enterprise's economy.

The task of the working groups (students) was to develop a business plan to process a problematic type of waste. The development consisted of situation analysis, search and evaluation of alternatives and technological solutions, economic justification, and identification of potential intellectual property rights. The criteria chosen in the study helped create value for an idea and understand its evaluation from various perspectives. The criteria use of the TRL was valuable as it allowed both academia and industry partners to come to a common understanding of the criteria for evaluating team performance.

The team's diversity made it possible to simulate situations from real life when people with different life experiences and views need to find the optimal solution to the problem. According to participants' feedback, the need to cooperate in a highly competitive environment between teams allowed them to take the initiative in difficult situations, feel responsible and take on obligations. Such an experience positively affects a person's character, allowing him to open up and understand their abilities and capabilities.

As part of the hackathon training course, teams worked with the following types of difficult-to-recycle waste:

(a) Refuse Derived Fuel - municipal solid waste, the treatment of which has created a uniform fuel mass. It can be used as an additional fuel for energy production in thermal power plants or incinerated for energy production in special equipment;
(b) Used tires - possibilities of economically advantageous recycling technologies;
(c) Fibreglass - this type of waste is regularly delivered to the landfill of the hackathon participant. Given this, the company can predict the demand for the processing service.

The hackathon allowed students to more effectively and visually master the curriculum of the course, which is also aimed at developing "green" innovations. The course includes elements of developing competencies necessary for the competitiveness of young professionals in the field of environmental sciences.

The event consisted of three stages dedicated to one of the three types of waste. Three teams took part in each step. According to the final results, the expert jury determined the finalist, who was allowed to participate in a large hackathon by the company.

Even though the competition in each stage was insignificant, each team participated passionately. The participants were driven by team competition and the desire not to "fail" with poor-quality performance.

A valuable experience and result was the teams' in-depth study of intellectual property rights. The teams could evaluate their solutions' novelty and compare them with existing technologies. Some teams were also interested in getting involved in business and becoming cooperation partners of the company.

Based on the results of this experience, it was concluded that as a result of multilateral cooperation, students were able to strengthen the following skills:

- work with scientific literature and various sources of information;
- using digital tools to analyse options and scenarios;
- development of innovative technological solutions;
- business thinking for environmental technology commercialisation;
- the creation of a project that meets the goals of sustainable development;
- confident presentation of results;
- teamwork, cooperation and finding a common language in stressful conditions.

The method developed and used in the case study allows for significantly improved cooperation between the academic sector and industry in preparing future environmental engineering specialists by the requirements of green innovation commercialisation. The study focuses on building partnerships between academia and industry as a precondition for developing green innovation.

4. Discussion

The study results and the positive feedback from the participants indicate that this methodology can be successfully used to train qualified specialists in various disciplines. The ability to create elaborate solutions is a necessary condition for the student's competitiveness. The format of generating ideas borrowed from business is one of the methods to improve the quality of education and university rankings.

Several factors related to adapting the method to the educational process could influence the hackathon results. The main factors can be called the difference in the opinions of the parties of the hackathon and their Motivation. The need to conduct the event remotely could also affect. However, all sides of the event were ready to cooperate and look for compromises to solve these factors.

The study identified the following factors:

(a) **Party participation activity**– although the division of roles was initially organised, the performance of specific tasks did not always meet the requirements. For example, the company wanted to receive theoretical confirmation of the proposed idea's effectiveness and the experiment results. However, the active participation of the students themselves should be noted. By asking the right questions to experts from the company and employees in a particular field, students could simulate real situations theoretically.
(b) **Definition of the primary evaluation criterion**– this work showed the need to find a balance between the priorities of the university and the company. In this hackathon, priority was given to the technological novelty of the idea. In the first stages, the university was the leading evaluator, while the company evaluated the final.
(c) **Motivation of students to participate**– the results of the study and the feedback from the participants themselves showed that the monetary prize fund is not the primary motivating factor. Factors cited include the desire to test oneself, gain new experience, gain professional connections that may be useful in the future, and the potential opportunity to get a job in the company. An important role is played by the clarity of the task, the even distribution of the teaching load, the successful integration of study subjects (in the case of a multidisciplinary study process), and the interest and activity of the other parties involved. Hackathon organisers should consider the emotional factor of the event. The team itself, relationships and distribution of responsibilities and activity within this team play an essential role. Therefore, it is important to form groups based on the qualities of each participant.

However, successful cooperation requires the participants' Motivation and the academic staff's interest. The enthusiasm and welfare of the teacher may be higher than that of the one who formally manages. According to students, the active participation of teachers gave additional inspiration to the work. The teacher's motive may be to improve the quality of education and gain new experience and knowledge for themselves. If the teacher has yet to previously participate in such events (hackathons), it is recommended first to participate in regularly held events as a participant. With such experience, the teacher can better understand and explain to the student his tasks and the course of work.

It is recommended to divide the entire preparatory period (from the Creation of a team to the final performance, not including) into stages to obtain a good result:

(a) **Creation of team uniqueness.** Discussing the team's name, image, logo and motto, its members communicate and get to know each other better. Such a creative task helps to strengthen the team spirit and gives the initial mood and impetus for further work.
(b) **Defining Team Roles.** Such a task allows one to determine who can better cope with what tasks. Critical when time is limited.
(c) **Intermediate Results Hearings.** Teams present what they have achieved and receive expert and consultant assessments. The team can use the received comments and advice to improve their project so that by the final presentation, the project is as close to reality as possible and considers the maximum possible number of specific nuances.

Given that this event requires knowledge not only in the field of ecology and environmental engineering but also in economics and business management, it is recommended to strengthen the subjects of this area in the university's teaching program (Osterwalder & Pigneur, 2010). This can be achieved, for example, by involving in the educational process a lecturer who is familiar with this topic and can demonstrate and analyse real examples.

Valuable input can come from social partners - professional industry associations and representatives of policymakers (ministries, state agencies), who can help teams define the social impact and the role of solutions in economic development.

Linking the principles of the hackathon event with the Sustainable Development Goals not only strengthens the individual responsibility of the parties involved but also allows connecting the parties interested in the result. Such cooperation is especially relevant for complex processes in which many parties participate with even more interests, goals and ways to achieve them. The already mentioned Sustainable Development Goals and Simon Sinek's Golden Circle approach can help achieve an optimal result (Sprijt et al., 2013).

This study included a survey of the opinions of all parties involved. It was essential to get an idea both about the method itself and its value, as well as about the expectations of the parties and assessing the contribution of the parties and individuals, in particular to the final result of the hackathon. All this made it possible to evaluate the results achieved objectively.

Students mentioned that they could better understand the educational process's goals thanks to the acquired skills. Some respondents described their first emotions caused by participation in the hackathon - stress and nervousness due to lack of experience in such events. However, as more and more information was obtained, these students became more and more confident in their knowledge and abilities. Understanding how to achieve the result allowed them to get to work with passion. Students reacted positively to such an experience and described it as “attractive” and “dynamic”, pointing out that “a hackathon brings more than just knowledge and skills.” The event allowed learning more about their opportunities to work with unfamiliar people, create technologically sophisticated solutions and endow them with commercial value. Surprisingly, students do not consider this event a chance to show themselves to company representatives or social partners.

In turn, the teaching staff highly appreciated the development of presentation and argumentation skills among the teams. Particular progress was observed in each of the subsequent intermediate stages when the teams, based on the results of the previous steps and comments on them, took into account experience and attention not only to the content of the presentation but also to the same method and manner of presentation. The teaching staff highly appreciated the contribution of each party to the result and indicated that the participation of companies in hackathons plays a significant role. Companies can provide a professional perspective on business modelling and economic sustainability issues.

Conducting this research using a hackathon fostered collaboration between academia and industry and has contributed significantly to strengthening the skills of young environmental engineers. Skill strengthening creates more confidence and motivation in students to transfer their knowledge. Therefore, using the hackathon more often in the study process can be recommended. Promoting hackathons in the academic environment and industry strengthens this cooperation, and it is possible to more precisely determine the intersection of the main goals of the activities of both parties and their harmonisation. Future research findings and their practical applications can boost the number of patent applications, generate industry interest in the university as a competent partner, elevate the average salary of environmental engineering students relative to other fields, and accelerate the development of green innovations.

5. Conclusion

Analysing company representatives' feedback, the study's authors can conclude that the company begins to recognise certain needs only at the end of the event. Close cooperation with academic staff allows identifying of hidden goals.

The survey results show that, in general, the participants are satisfied with the event itself and its effects. Team members highly appreciate their contribution to the team's overall result and assume that the experience gained will help them achieve results more successfully in the future.

The authors of the study conclude that for the further use of the hackathon method in the educational process, it is necessary to conduct additional research. Further consideration must be given to developing strategic partnerships, documenting results and improving team performance. All this means the following:

1. **Development of guidelines for the protection of Intellectual Property Rights** to define the rights and obligations of the parties involved,
2. **Modelling the profile of “shareholders”** (companies, public administration institutions, public-private partnerships, European Union level institutions, etc.) and matching the interests with the academic sector
3. **Widening the opportunities for students and empowering team performance**, for example, by strengthening team capacity through self-assessment tests, creating a platform for more ambitious demonstration of student knowledge, team interaction in the case of distance learning, digitalisation of results and accessibility to a broader range of stakeholders.

Despite the challenges to be balanced the acquisition of theoretical and practical knowledge during the study, such activities as part of the study process can make a significant contribution to improving the quality of competent education (Rayna & Striukova, 2021), as they create conditions for students to develop new skills and provide greater Motivation to work if a future promise is received that their solutions have opportunities for further development.

Declaration of competing interest

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Biodiplomacy Attractiveness in Bioeconomy Education. Case Study

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***Abstract* – Biodiplomacy involves searching for a delicate balance and establishing a dialogue on the necessity to achieve international goals to develop the bioeconomy. The substantive basis of biodiplomacy is understanding bioresources, technological solutions for their extraction and use, indicators, and evaluation possibilities. The article is devoted to the establishment of a biodiplomatic institution. Such institutions will help young specialists in various economic sectors to develop competence approaches, acquire knowledge and build awareness that will make them competent to solve problems related to bioeconomy development and future, looking for efficient use of bio-resources and high value-added production. The aims and objectives of biodiplomatics are ambitious, which means that forms of study training must be attractive and multi-layered. Thus, the authors have analysed formative work assessment in the form of group work. With the help of a role game, the participation of different sections of society in developing the bioeconomy in agriculture, forestry and aquaculture was simulated. The article is devoted to the situation analysis, creating a model for building competencies, awareness, and knowledge of biodiplomats, and approbating it in the formative assessment work of the Riga Technical University bachelor's study program in environmental engineering, organised as a role game.**

***Keywords* – Agriculture; biodiplomats; competencies; post-game performance level rubric; role game**

1. INTRODUCTION

Latvia, like all other European Union (EU) countries, must shape public policy in such a way as to achieve the goals set by the Green Deal, energy, climate neutrality and other binding documents. To a large extent, policies need to be subordinated in such a way as to comprehensively ensure the development of the whole economy and progress towards these goals. As this issue involves global solutions, the work of biodiplomats needs to be updated to ensure that the goals are met. Biodiplomats are international experts who will implement innovative paradigms in the bioeconomy to provide new and innovative products using new technologies and processes. [1] have studied the concept of biodiplomacy and defined the main characteristics. The main emphasis in this study is on the development of new mechanisms to promote a circular and sustainable, socially inclusive bioeconomy.

Latvia does not currently implement biodiplomacy. Therefore the question remains in which sectors it would be possible to develop it. It is necessary to find a niche against which

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Latvia's product would stand out against the offerings and services of similar countries, highlighting its unique ideas, experience, competence, and activities. It would give recognition, prestige, leadership, and state influence. Therefore, the next step in its implementation would be to incorporate legitimate strategies for niche biodiplomacy in legislative documents. Although the government currently intends to develop an action plan that would define the tasks of making Latvia attractive to exporting companies in the international environment by creating a single brand to attract foreign interest, this definition is more than an interpretation, as the government does not mention public diplomacy in national planning policy framework [2].

When creating a niche biodiplomacy, the primary goals that Latvia could offer to other countries must be set to be identified as competitive, of course, considering the country's primary interests. It should be emphasised that niche biodiplomacy would focus on a specific sector field, sifting out other areas and specifying what could lead to opposition from different fields. The implementation of positive biodiplomacy can be implemented only when successful cooperation between institutions and sectors and scientific institutions is expected in the long run because only then are the results desired [3].

In 2008, the Latvian Institute conducted a study on the image of Latvia [4]. As a result, Latvia is not ready to create an image. The main arguments are as follows: (1) geographical location outside the capital's periphery is not attractive to investors, (2) ecological and other environmental issues outweigh the promotion of industrialisation, (3) national identity challenges – it is necessary to be able to find a unifying motive for Latvia's identity, (4) Latvia's future aspirations are not in line with current assumptions, (5) Latvians generally do not support the sale of land to someone who does not have deep roots or ties with Latvia. Recognition with the capital Riga should be promoted, and the slogan used should be 'Plugged into nature'. The audience has not been enthusiastic in the international environment, and assumptions are primarily based on the past. The main cornerstones of niche biodiplomacy would be based on credibility, rationale, reputation, and value.

Considering the above, Latvia's image in the international environment would become competitive by moving in biodiplomacy and developing biodiplomats. The term bio-diplomacy is linked initially to bio-education. Vlavianos-Arvanitis (1993) urges for the need of restructuring the educational framework to 'overcome the threats to the preservation of bios (life in Greek) caused by a crisis in values. International cooperation and facilitating the search for solutions to problems that require prompt and decisive action is by excellence the case in environmental issues [5]. In the following almost 20-year period, the increasingly complex challenges of governing resources in socio-ecological systems made policymakers and practitioners use more and more the so-called serious games (SG), as shown in the systematic review of relevant publications by Edwards *et al.* (2019) [6]. Concerning the ubiquitous climate change challenge, Ahamer (2013) argues that gaming serves better to shape a strategy than fighting, in the sense that the former relates to 'managing unstable equilibria while maintaining societal sustainability'. In contrast, the latter resumes to 'understanding only own standpoint, but not the standpoint of adversaries' [7]. Blanchard and Buchs (2015) illustrate the capacity of role to clarify Sustainable Development for students, a wicked concept with international ramifications, and Thomas *et al.* (2018) detail the use of role game in the case of energy-related decisions in urban and rural municipalities [8], [9]. Various stakeholders engaged as participants with energy conundrums in 6 different locations in the US, wearing the hat of others eliciting valuable insights into complex decision making. In the context of biodiplomacy and the understanding of its operation, role game in the study process provides an invaluable contribution to the training of young specialists. It can support the introduction of transdisciplinarity in the classroom, simulating and enhancing the co-production of knowledge [10]. Role game in the study process is one of the ways to provide students with the opportunity to apply the acquired theoretical knowledge in the practical simulation of reality because the offered way provides a dynamic environment. However, a framework of preparation guidelines is issued in advance, which defines the topic and the problem; students still have to offer their solutions. Role game features among the crucial teaching tools for experiential learning in higher education programmes relating to sustainability [11], [12], [13], [14]. Relevant publications evaluate role games along with study visits or field courses as the most effective tools, especially when integrating social sustainability into the engineering curriculum in Cambridge University [15] and the Swedish Royal Institute of Technology, as seen in Björnberg *et al.* (2015) [16]. Role game was also used 'to provide a solution to actual local problems' in a capacity-building course to educate educators on sustainability in Monterrey Tech [17]. Role game is a handy tool when there need to solve a problem [18].

In the same track, the role game 'Response bioeconomy strategy to COVID-19' was organised in the bachelor study program 'Environmental Engineering' created by the Institute of Energy Systems and Environment of Riga Technical University, the implementation of which effective and result-based distribution of COVID-19 emergency aid (EUR 35.5 million) between the main sectors of forestry, agriculture, fisheries and aquaculture, as well as tourism.

From a pedagogical point of view, the development of competencies is directly related to in-depth learning, which various authors also call deep learning or visible learning [19], [20]. As a result of such a study process, students can develop any of the competencies to be acquired in the course 'Biotechonomy', which are indicated as the results in the study course. The main goal of in-depth learning is to strive for the student to gain an in-depth and conceptual understanding of complex/complicated topics [21].

The article is devoted to the establishment of a biodiplomatic institution. Such institutions will help young specialists in various economic sectors to develop competence approaches, acquire knowledge and build awareness that will make them competent to solve problems related to bioeconomy development and future, looking for efficient use of bio-resources and high value-added production. The aims and objectives of biodiplomatics are ambitious, which means that forms of study training must be attractive and multi-layered.

It is essential to organise a role game to understand biodiplomacy and analyse the results – competencies acquired by the participants. In this case study, the role of the participants in the role game, representing the agricultural group, in the field of biodiplomacy acquired in the context of bioeconomy.

2. METHODOLOGY

The methodology consists of three parts: (1) preparation, (2) role game, (3) post-game performance level rubric (see Fig. 1). In the (1) preparation part, a role game was developed in the course 'Biotechonomy' of the Riga Technical University bachelor study program 'Environmental Engineering' in the amount of 3 ECTS. More detailed information on this section will not be considered. The main emphasis in this methodology is on the role game and the section on participants' post-game performance level rubric. (2) part is a role game that consists of current situation analysis, proposals and solutions analysis, public discussion, and decision making. The role game aims to raise stakeholders' knowledge and understanding of sustainable development of bioeconomy, its objectives, and their achievement, as well as achieve result-based distribution of COVID-19 emergency aid (EUR 35.5 million) among three main sectors. Students are introduced to the problem situation, the game's goal, the parties involved, the division of groups, and the evaluation criteria of the leading offers at the current situation analysis stage. Group consists of 4 students; a doctoral student advises each group. The doctoral student is the group's consultant/mentor and motivates the group to participate in discussions, defend its position and argue its opinion. Various criteria have been compiled to prepare and evaluate proposals submitted by the sectors (see Table 1). These criteria allow one to evaluate and compare proposals, choose the most optimal and distribute the funding more efficiently.

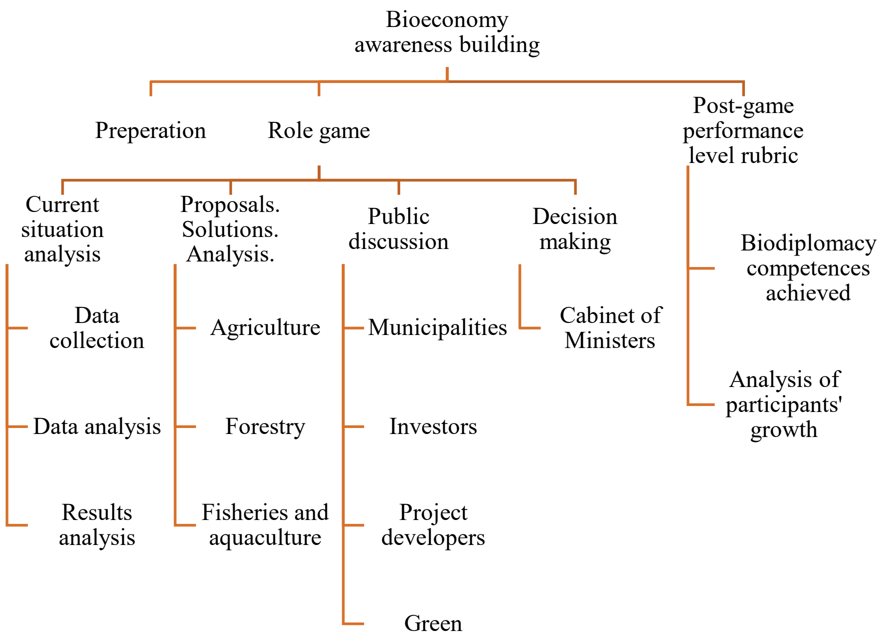

Fig. 1. Integration of role game in the modular structure of bioeconomy awareness building.

TABLE 1. MAIN PROPOSAL EVALUATION CRITERIA FOR GROUPS

Group title	Criteria	Units
Forestry Agriculture Fisheries and aquacultures Cabinet of Ministers Investors Environmental activists Municipality representatives	Number of persons employed in rural and urban	Thousand of people
	Increase of value-added	Thousand EUR/year
	Added value per employee	Thousand
	Contribution to GDP	%
	Export	Thousand EUR
	Share of renewable energy in industrial and energy consumption	%
	Renewable energy and total (final) industrial energy consumption	GWhREN GWhfinal

Each group has its framework and task to complete during the role game:

1. Forestry – to prepare a proposal that would include the necessity to receive the support to prevent the consequences of the pandemic, to develop bioeconomy and to achieve goals set in bioeconomy strategy; to present main difficulties that the forestry sector is facing because of the pandemic, what aspects hinder the development of the bioeconomy, what are the policy instruments could help to achieve the goals; deliver a proposal for the investment of the Emergency support funding and its necessity, what will be the results if the funding will be granted, and what are the consequences if not!
2. Agriculture – to prepare a proposal that would include the necessity to receive the support to prevent the consequences of the pandemic, to develop bioeconomy and to achieve goals set in bioeconomy strategy; to present main difficulties that the agriculture sector is facing because of the pandemic, what aspects hinder the development of the bioeconomy, what are the policy instruments could help to achieve the goals; deliver a proposal for the investment of the Emergency support funding and its necessity, what will be the results if the funding will be granted, and what are the consequences if not!
3. Fisheries and aquaculture – to prepare a proposal that would include the necessity to receive the support to prevent the consequences of the pandemic, to develop bioeconomy and to achieve goals set in bioeconomy strategy; to present main difficulties, that fishery and aquaculture sector is facing because of the pandemic, what aspects hinder the development of the bioeconomy, what are the policy instruments could help to achieve the goals; deliver a proposal for the investment of the Emergency support funding and its necessity, what will be the results if the funding will be granted, and what are the consequences if not.
4. Cabinet of Ministers – to prepare criteria for evaluation. Each group must be allocated funds as the result of fund distribution. Ask groups questions, engage in discussions, announce results: (1) actively participate in the meeting, where three primary sectors will present and argue their strategy plans; (2) main task – distribute the COVID-19 emergency support funds to 3 sectors (forestry, agriculture, fisheries and aquacultures).
5. Investors – (1) main task – ensure that the idea provided by presenters is innovative, viable, realistic and economically correct; (2) necessary support tool for investors to mitigate risks; (3) “Green channel” for investors to work in Latvia.
6. Environmental activists/NGO – (1) actively participate in the meeting, where different alternatives of bioeconomy strategy will be presented; (2) ensure that funding will be granted to the most environmentally friendly and sustainable proposals.
7. Municipality Representatives – (1) actively participate in the meeting; (2) main task – ensure that best solution for a municipality is chosen – receives the highest amount of taxes, local people are employed, and environmentally and climate-friendly solutions are used.

The methodology’s last part (3) is the post-game performance level rubric used for biodiplomacy competence evaluation for the bioeconomy. Table 2 shows the general form of the rubric, which provides four levels of performance.

Fig. 2 introduces evaluation criteria for biodiplomacy competence (the authors recommend up to four criteria, as the most relevant and focused criteria for a given competence must be selected from a wide range of possible criteria).

TABLE 2. GENERAL FORM OF THE RUBRIC FOR PERFORMANCE EVALUATION

	Trying to reach / not reached	**Approaching**	**Achieves compliance**	**Exceeds requirements**
Evaluation criteria	1	2	3	4
	Student activity is inaccurate and approximate; performance can only be partially attributed to the acquired competence.	Student performance is general, generally related to the competence to be acquired.	Student performance is accurate; it is based on judgments about this criterion.	Student performance is accurate and convincing; it shows the limitations and complexity of competence.

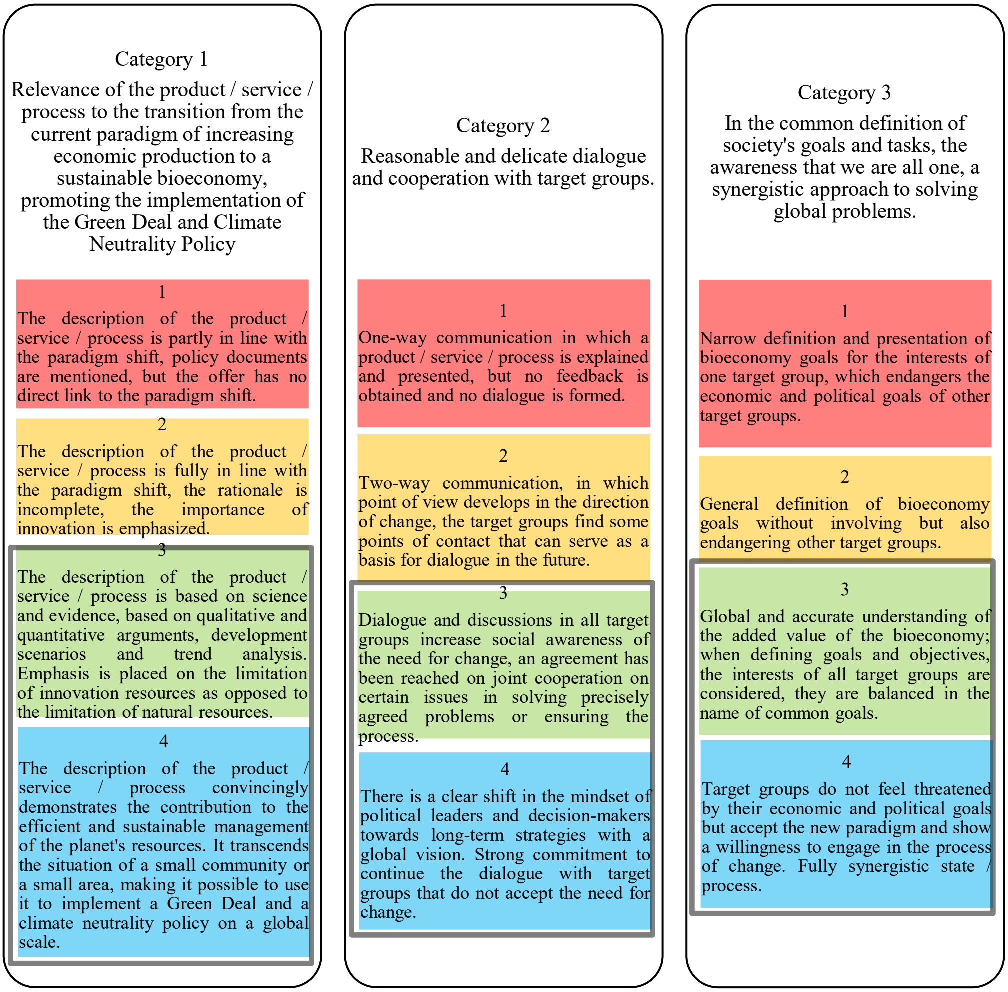

Fig. 2. The progressive performance rubric for developing biodiplomacy competencies role game in bioeconomy studies (1 – Trying to reach/not reached; 2 – Approaching; 3 – Achieves compliance; 4 – Exceeds requirements (explained in Table 3)).

1210

Each level of performance is associated with a level of biodiplomacy competence. Competencies are assessed from 1 to 4, where a Level of 1 reflects only a small activity (inaccurate, mediocre, incomplete achievement of the competence). Level 2 already defines the direction towards the general achievement of competence. Level 3 establishes the achievement of competence, where student participation is accurate. Level 4 indicates that the student is competent in the field and can analyse complex systems. Students are given performance level sections for each competence to be developed in the study course 'Biotechnology' in preparation for the role game; the biodiplomacy performance rubric is one of the many competence development rubrics. Students use these rubrics as guides in the study process as they prepare for the role game. The role game takes place in the middle of the study course and is a formative assessment tool. The role game observer and the student, performance level assessor, are issued performance rubrics and the corresponding assessment table. It is recommended that the game be watched by several observers who calibrate their understanding of the performance level signature before the game. During the game, the assessors identify the biocompetence criteria listed in the table and determine the level of student performance. After the game, the assessors provide feedback to the students and discuss the student's performance in individual episodes, justifying the level achieved by the students with that described in the performance level rubric.

The progressive performance rubric for developing the biodiplomacy competencies role game in bioeconomy studies (adapted by [22]) is shown in Fig. 2.

The target groups mentioned in the Table 2 are representatives of other economic sectors, environmental activists, local governments, investors, politicians.

3. RESULTS AND DISCUSSION

During the role game, participants answered the key question - how to invest the COVID-19 emergency support funds to mitigate the effects of pandemic (sustainable recovery of the economy) and maintain the transition sustainable bioeconomy development. Each target group - forestry, agriculture, fisheries and aquaculture - formulated what they thought were the best solutions based on research. The Bioeconomy strategy, which defines that the most significant support is to farmers and food producers to ensure food security, must consider that the remainder will have to be shared between fisheries and forestry.

As a result of the role game, the agricultural group received the most financial support, so this group was further analysed using the post-game performance level rubric. The post-game performance level rubric for the agricultural group for the assessment of biodiplomatic competencies is shown in Fig. 3.

The post-game performance level rubric makes it possible to assess students' skills in the relevant assessment categories. Thus, for example, the competencies of students represented in the agricultural sector were evaluated in 3 categories – (Category 1) Relevance of the product/service/process to the transition from the current paradigm of increasing economic production to a sustainable bioeconomy, promoting the implementation of the Green Deal and Climate Neutrality Policy, (Category 2) Reasonable and delicate dialogue and cooperation with target groups and (Category 3) The figure shows that students have acquired competencies in the areas indicated in the specific categories, as they reach close to the highest grade in each category. In Category 1 are reached Level 3, where students present their advanced knowledge in bioeconomy and innovative tools for achieving bioeconomy goals. In Category 2, students knowledge dynamic is expressed in all four levels, which shows students dialogue development dynamic. In Category 3, students participate in role game, leading the development of their attitude and proposed proposals for reaching common goals, wherein they finally reach Level 3 in their skills.

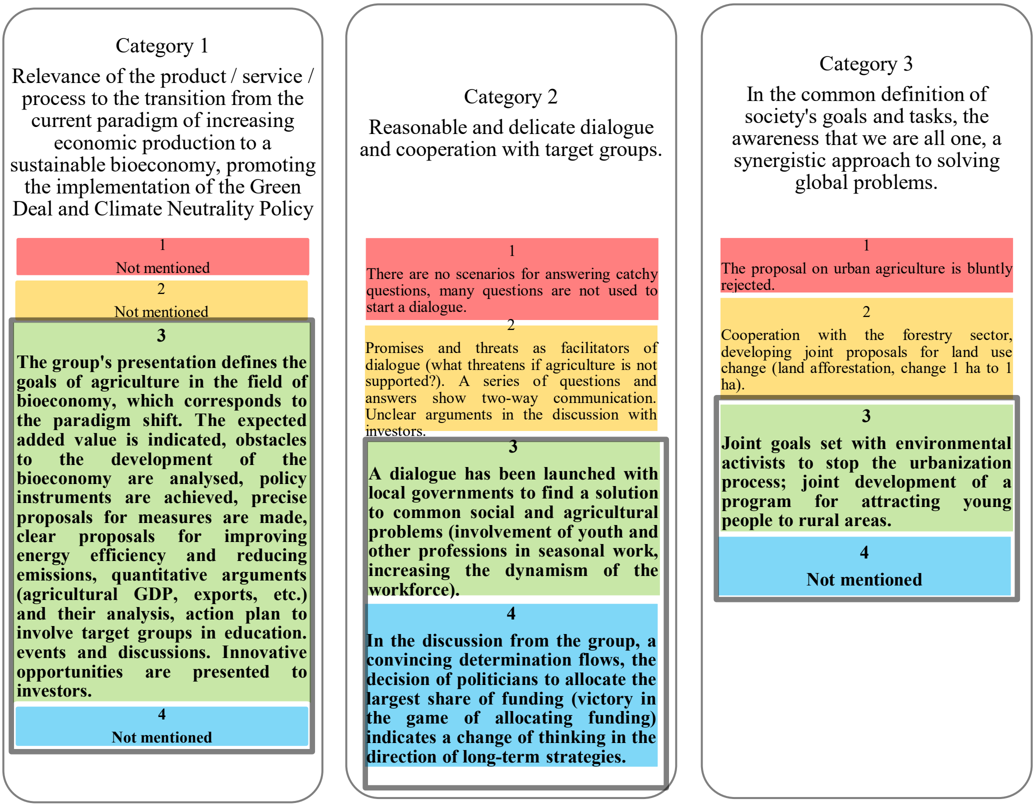

Fig. 3. Post-game performance level rubric for agricultural group.

Formative assessment achieves its objective; students know the areas that still need to be explored to acquire better competence in biodiplomacy. It was assessed that it is desirable to supplement the performance level rubric with didactic and methodological tasks that train students to delve into aspects of biodiplomacy competence, develop self-directed studies and increase competence.

4. Conclusions

The main conclusions of this case study are: (1) the goal of the role game was achieved – to distribute the funding for COVID-19 emergency recovery support, taking into account the objectives of the EU bioeconomy strategy and the impact of COVID-19 on the production and use of primary resources among the three main groups of bioresources: forestry, agriculture; fisheries and aquacultures; (2) taking into account the lessons learned, the ideas should be presented to the Cabinet of Ministers, local governments, various responsible institutions, etc.; (3) members of the agricultural group have acquired biodiplomacy competencies in the context of the bioeconomy, which characterise biodiplomats. The higher the evaluation of the criteria in the category for the relevant competence, the more likely it is that the goals set by the Green Deal will be achieved.

Next steps: (1) together with the students, discuss the passages that show the performance of their biodiplomacy competence, compare what is shown in the passage with what is described in the performance section, draw conclusions, and make suggestions about what and how to speak, present, answer differently; (2) analyse various situations given by the lecturer with conflicts, problems, the solutions of which as action or dialogue scenarios students must invent and justify.

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To Be, or Not to Be – the Question of Forestry Resources in Bio-Diplomacy

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Abstract **– This analysis aims to identify the potential of bio-diplomacy focused on forestry resources in Latvia. As the resources are scarce, small states must calibrate their foreign policy to gain a global vision by offering strategic products or services. In order to identify this potential, there are employed the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) analytical methods. The results indicate that economy, climate and environmental and social factors are the most important elements to be considered. The most important driving forces for using forestry resources for bio-diplomacy are demand, volume and renewal.**

Keywords **– Bio-diplomacy; forestry; foreign; policy**

1. INTRODUCTION

The etymology of diplomacy is found in the Greek word 'diploma'. Since the 18th century, the term 'diplomate' has become more popular, which is a derivative of the ancient Greek terms 'diplo', folded into two, and 'ma', an object related to travel [1]. As such, diplomacy means forming national relations through negotiations, emphasising shaping foreign policy [2]. During this process, countries often employ official representatives to push forward national interests consistent with their objectives through visits, correspondences, and lobbying activities [3]. However, it is important to highlight that diplomacy is not a foreign policy duly on its terms but, instead, it acts as a supplementary method concerning policy implementation instruments. These instruments are reflected in foreign policy formulation and efforts to achieve objectives according to national interests, making diplomacy an important part of foreign policy implementation [4]. It employs specific skills, procedures, methods, norms, and rules to coordinate bilateral dialogue between nations to optimise international relations at the global level. These activities are entrusted to the Ministry of Foreign Affairs. Their diplomatic representation act as the primary link for promoting their own diplomatic activities and communicating with officials located in embassies and consulates of the host state [5].

As time progresses, so does diplomacy to reflect ever-evolving current and future challenges. One such challenge is related to the externalities of the current globalisation trend, which has boosted the ability of countries to become more integrated into global value chains and enhance their relevance globally [6]. At the same time, in parallel, the potential for diplomacy activities to reach new target audiences has broadened [7]. In particular, it has brought forward a relatively new type of diplomacy into perspective, 'bio-diplomacy' [8].

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Dr Agni Vlavianos Arvanitis from Biopolitics International Organization, who originally coined this term, defines it as centred around pressing environmental issues whereby diplomatic means to international relations with a specific focus on climate policy can aid to preserve the environment and establish strategic autonomy of resource industries [9].

The guiding theme and focus of bio-diplomacy are suited adequately to the current environmental situation globally in light of the Paris agreement [10] and the European Union Green Deal agreement [11].

1.1. Is There a Demand for a New Wooden Bicycle?

By examining diplomatic activities already undertaken by other similarly positioned countries with a long-term focus, small states can gain perspective [12] on means to adjust their diplomatic policies:

- As developed by Denmark, the Green Diplomacy adapts to the global environmental challenges and demands. A separate department within the Department of Affairs is solely positioned to promote a strategy that considers environmental matters for its diplomacy activities, offering the world its solutions for climate change [13];
- Denmark is also active in diplomacy's technology front, creating technology diplomacy TechPlomacy in 2017. Denmark appointed the first Minister of Technology (Casper Klynge) to pursue these activities in the world. It became the first country to focus policy priorities directly on technology and digitisation for cross-border foreign policy activities. A few of Mr Klinge's primary responsibilities are finding the next success story of major technology firms and working together with them, helping start-ups with financial and enterprise support, and assessing the impact of artificial intelligence and automation on Danish jobs and industry in the future [14];
- In Iceland, 63 % of its territory consists of stones, sand, lava, and tundra; glaciers and lakes occupy 12 % and 3 %, and only 23 % is a fertile land. As a result, the environmental challenges are important for Iceland. Iceland must develop long-term sustainable solutions with an emphasis on renewable energy to limit the effects of climate change. In practice, it places itself as an expert in acquiring renewable resources from the earth [15];
- Being the most technologically advanced Baltic country, Estonia has engaged in small state diplomacy activities based on cyber diplomacy. In 2019 Estonia established a designated department in the Ministry of Foreign Affairs for cyber diplomacy. Cyber diplomacy is primarily linked to national cyberspace action and compliance with cyber norms, confidence-building measures and existing international law. The country is a representative example of how overcoming vulnerabilities (cyber) can become a success story for niche diplomacy. In 2007 Estonia held a debate regarding the resettlement of the monument of a bronze soldier left by the Soviet Union [16]. It was then when Estonia first faced widespread cyber-attack, which was later recognised as the first cyberwar in the world. As such, it warranted Estonia to its turning point in foreign policy [17]. The country learned from the experience, and fourteen years later, it has become a global force in areas related to cyber security, advising many countries on similar issues. In the long-term, based on this, Estonia has positioned itself as amongst the leaders in all cases related to the cyber environment – 99 % of the services provided by the country can be carried out remotely (excluding marital and purchase of property) [18];

The abovementioned examples of similarly positioned countries indicate that smaller countries can use resources at their disposal and promote national awareness and influence by offering their services to address pressing issues. This study challenges the current political direction of Latvian foreign policy and analyses the possibilities pro-actively by offering bio-diplomacy activities that will focus on exploiting forestry resource capabilities – a prudent resource in the implementation of foreign policy actions that can provide credibility in the international environment.

It is often more difficult for small countries such as Latvia to compete globally and establish strong links globally unless full advantage of local knowledge is utilised. There are binding constraints globally on various resources that create opportunities for endowment rich countries to explore [19].

For Latvia to become more competitive, it must emphasise exploiting diplomatically the relatively large endowment of wood resources from strong local industries (forestry and timber) through bio-diplomacy. Latvia is one of the most forest-rich European countries. It has 3.4 million hectares of forests (52 % of the total territory) that is steadily expanding [20]. The economic contribution of the forestry sector is significant and increasing each year. EUR 1.32 billion in 2018 or 5.1 % of the country's GDP, EUR 1.08 billion in 2017 or 4.6 % of the country's GDP, EUR 1.03 billion in 2016 or 4.7 % of the country's GDP, EUR 1.02 billion in 2015, or 4.8 % of the country's GDP [21]. In addition, data from 2018 showed strong exports of wood related particles, which amounted to EUR 2.64 billion, or one-fifth of total exports. As a result, the forestry sector is an important niche of the Latvian economy and, conditional on the future global trends forecast in environmental degradation. It also can become a strategic sector to be used as an instrument in Latvian bio-diplomacy activities. However, Latvia's potential has not drafted a comprehensive strategy to push itself forward on this front. Using forestry resources as part of potential bio-diplomacy activities can thus be equitable to improve its position and relevance globally.

2. METHODOLOGY

Two multi-criteria techniques were used where the results of one method (Analytic Hierarchy Process (AHP)) lead us into the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). They are used to determine the importance of different criteria and alternatives for the potential of forestry resources for Latvian bio-diplomacy. The survey was filled by researchers from the Institute of Energy Systems and Environment at the Riga Technical University to identify the bio-diplomacy potential of wooden and forestry resources. This approach was designed to clarify the views of environmental science researchers and scientists focusing on wooden and forestry resource demand and supply capabilities. In light of the answers provided, it is possible to interpret the assumptions and predict potential future direction for the importance of wooden and forestry resources for the Latvian bio-diplomacy.

The scheme of the research methodology is shown in Fig. 1.

The AHP method is a decision-making framework that provides a structured technique to organise and analyse complex decisions based on mathematics and psychology [22]. By following the AHP algorithm for this case study, there were identified the relative importance of ten qualitative criteria (economic, social, climate and environment, science and research, engineering, internal policy, external policy, access to finance, examples from other countries and regional policy) that are difficult to measure in absolute values towards the formation of Latvian bio-diplomacy, with a focus on the forestry sector. It is reasonable to quantify each criterion's importance, as indicated by weights, towards understanding the most important factors for our purposes [23], [24]. In order to calculate these weights for the decision-maker, first, need to normalise the pairwise criterion comparison matrix by manipulating the ten by ten matrix [25]. Following these manipulations, the importance vector, the eigenvector of the normalised pairwise criterion matrix, indicates the ranking for the importance of criteria [26].

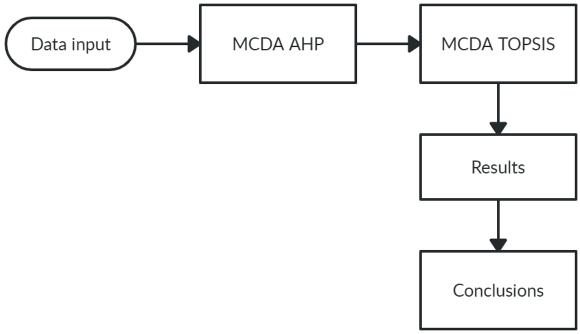

Fig. 1. Research methodology.

Following AHP results, transition into TOPSIS analysis (Hwang and Yoon developed it in 1981 [27]) should be done. It is used to make decisions and analyse the significance of objectives from various information and data – qualitative and quantitative data. For example, information from the physical and social sciences, politics, and ethics to evaluate problem solutions [28]. The TOPSIS uses the distance from best alternative and worst alternative to defining the suitable alternative ranking, starting from the most suitable [29].

In general, the process for the TOPSIS algorithm starts with forming the decision matrix representing the satisfaction value of each criterion with each alternative [30]. The following steps involve matrix normalisation with a desired normalising scheme and matrix multiplication by the criteria weights from AHP analysis. In the end, the positive-ideal and negative-ideal solutions are calculated, and the distance of each alternative to these solutions is calculated with a distance measure. Only the alternative from the positive-ideal solution should be reported, and the alternatives based on their relative closeness ranked.

3. RESULTS

Ten AHP criteria are economic (C1), social (C2), climate and environment (C3), science and research (C4), engineering (C5), internal policy (C6), external policy (C7), access to finance (C8), examples from other countries (C9) and regional policy (C10) were formulated. Based on their opinions, the researchers filled the survey to identify their relative bilateral importance on the following fundamental comparison scale shown in Table 1.

TABLE 1. THE SCALE OF RELATIVE IMPORTANCE

Intensity of Importance	Definition	Explanation
1	Equal relative importance	Two factors are equally contributing to an objective
2	Average relative importance	One factor is marginally superior over other
3	Above-average relative importance	One factor is strongly superior to other
4	Strong relative importance	The highest level of superiority of one factor over other

Quantifying, ranking and analysing these answers is the next step to evaluate the most dominant criterion for the potential of forestry diplomacy based on a simple weighting scheme. Furthermore, robustness checks (i.e., the consistency check) on the stability of the results are also performed before transitioning into the TOPSIS analysis.

TABLE 2. PAIRWISE CRITERION COMPARISON MATRIX

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	3	2	2	2	2	2	2	3	2
C2	0.33	1	2	2	2	2	2	2	2	2
C3	0.50	0.50	1	3	3	3	3	3	3	3
C4	0.50	0.50	0.33	1	2	3	2	2	3	3
C5	0.50	0.50	0.33	0.50	1	3	2	3	2	2
C6	0.50	0.50	0.33	0.17	0.33	1	2	3	2	3
C7	0.50	0.50	0.33	0.50	0.50	0.50	1	2	2	2
C8	0.50	0.50	0.33	0.50	0.33	0.33	0.50	1	2	2
C9	0.33	0.50	0.33	0.33	0.50	0.50	0.50	0.50	1	2
C10	0.5	0.50	0.50	0.33	0.50	0.33	0.50	0.50	0.50	1

Table 2 shows the survey results from the Institute of Energy Systems and Environment at the Riga Technical University. The experts highlight relative differences of each criterion towards the forestry sector's potential to become part of the Latvian bio-diplomacy in the table. Each element of the pairwise comparison matrix represents the decision makers' preference for one criterion concerning the other criteria regarding the potential importance towards the Latvian bio-diplomacy. For example, the economic criteria are three times more important than the social criteria for forestry resources being part of the potential Latvian bio-diplomacy. Therefore, social criteria are one-third as important as the economic criteria. In order to derive the importance, vector-matrix normalisation manipulation should be performed on the pairwise criterion comparison matrix. The results are shown in Table 3.

TABLE 3. NORMALISED PAIRWISE CRITERION COMPARISON MATRIX

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.194	0.375	0.273	0.194	0.164	0.128	0.129	0.105	0.146	0.091
C2	0.065	0.125	0.273	0.194	0.164	0.128	0.129	0.105	0.098	0.091
C3	0.097	0.063	0.136	0.290	0.247	0.191	0.194	0.158	0.146	0.136
C4	0.097	0.063	0.045	0.097	0.164	0.191	0.129	0.105	0.146	0.136
C5	0.097	0.063	0.045	0.048	0.082	0.191	0.129	0.158	0.098	0.091
C6	0.097	0.063	0.045	0.016	0.027	0.064	0.129	0.158	0.098	0.136
C7	0.097	0.063	0.045	0.048	0.041	0.032	0.065	0.105	0.098	0.091
C8	0.097	0.063	0.045	0.048	0.027	0.021	0.032	0.053	0.098	0.091
C9	0.065	0.063	0.045	0.032	0.041	0.032	0.032	0.026	0.049	0.091
C10	0.097	0.063	0.045	0.032	0.041	0.021	0.032	0.026	0.024	0.045

Following the above, to complete the AHP analysis, the eigenvector of the normalised pairwise criterion comparison matrix represents the hierarchical structure of the most important criteria towards the forestry sector's potential for Latvian bio-diplomacy derived, matrix normalisation performed, and the results are shown in Fig. 2.

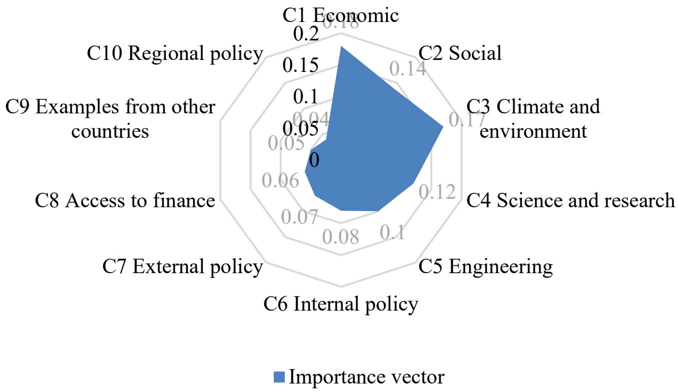

Fig. 2. The importance vector that shows the ranking of absolute importance weights.

Out of all ten possible criteria that could impact forestry sectors' potential for Latvian bio-diplomacy, the economic factor ranks as the most important, followed by social, climate, and environmental matters.

By performing the appropriate consistency check in Table 4, it is possible to reasonably conclude that this ranking is robust to swift changes in the definition of the importance scale as well as for huge variations in the opinions of the experts as indicated by the consistency ratio (0.07) being less than the widely agreed threshold (0.1).

TABLE 4. CONSISTENCY CHECK OF THE OUTCOMES FROM AHP ALGORITHM WITH $N = 10$ CRITERIONS

Term	Value
Consistency index	0.11
Random consistency index (for $n = 10$)	1.49
Consistency ratio	$(0.11/1.49) = 0.07 < 0.1$

For the next step, to better understand which alternatives (volume (A1), acquisition (A2), availability (A3), renewal (A4), disposal options (A5), demand (A6) management/ownership (A7), labour availability (A8) and availability of specialists (A9)) are the most significant in driving each criterion overall in the decision making process, TOPSIS analysis are used. It is a reasonable approach to help us understand the potential of forestry resources when one accounts for more factors beyond bilateral comparison. Table 5 shows the decision matrix where the alternatives have been weighted concerning the criteria.

Following this, the matrix should be normalised (Table 6). Matrix normalisation enables us to systematically compare the alternatives across different criteria, irrespective of the underlying generating process.

TABLE 5. WEIGHTED DECISION MATRIX

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	2.7	3.6	3.3	3.1	3.2	3.7	2.9	3.1	3.1
C2	3.1	2.6	2.6	2.8	2.4	2.7	3.2	3.4	2.8
C3	3.7	3.2	3.0	3.4	3.1	3.1	2.7	2.2	2.4
C4	3.0	2.7	2.9	3.1	3.6	3.7	2.3	2.0	3.2
C5	3.2	3.2	2.8	3.5	2.9	3.2	2.6	2.6	3.3
C6	3.5	3.1	3.5	3.1	3.6	3.2	3.0	2.9	2.6
C7	3.4	2.4	3.5	2.6	2.6	3.2	2.8	2.6	2.0
C8	3.0	3.1	2.9	2.9	3.1	3.3	2.8	2.3	2.7
C9	2.5	2.7	2.3	2.6	2.9	2.7	2.4	2.1	2.6
C10	3.0	3.0	2.8	3.2	3.1	2.9	2.9	3.1	2.7

Then the next step is to determine the best and worst alternatives in this range of alternatives A1–A9. That is, starting by determining which alternative is the most adequate and least adequate for each criterion. To do so, minimising the difference of each alternative from the worst and best alternative regarding each criterion. As such, calculating the separation measures in order to quantify how far away each alternative is from the ideal and worst alternative. The separation measure is shown in Table 7, along with the closeness ratio (*C*) to the best alternative.

TABLE 6. NORMALISED WEIGHTED DECISION MATRIX

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	0.05	0.07	0.06	0.06	0.06	0.07	0.05	0.06	0.06
C2	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.04
C3	0.07	0.06	0.05	0.06	0.06	0.06	0.05	0.04	0.04
C4	0.04	0.04	0.04	0.04	0.05	0.05	0.03	0.03	0.04
C5	0.04	0.04	0.03	0.04	0.03	0.04	0.03	0.03	0.04
C6	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
C7	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02
C8	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
C9	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.02
C10	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01

TABLE 7. CLOSENESS RATIO TO THE BEST ALTERNATIVE

	A1	A2	A3	A4	A5	A6	A7	A8	A9
d a +	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.03
d a –	0.04	0.03	0.03	0.03	0.03	0.04	0.02	0.02	0.02
da+ + da–	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
C=da-/da+ +da–	0.62	0.55	0.53	0.61	0.57	0.69	0.36	0.31	0.39

The closeness ratio's rank is summarised to highlight the best alternative in the range of A1–A9 in Fig. 3.

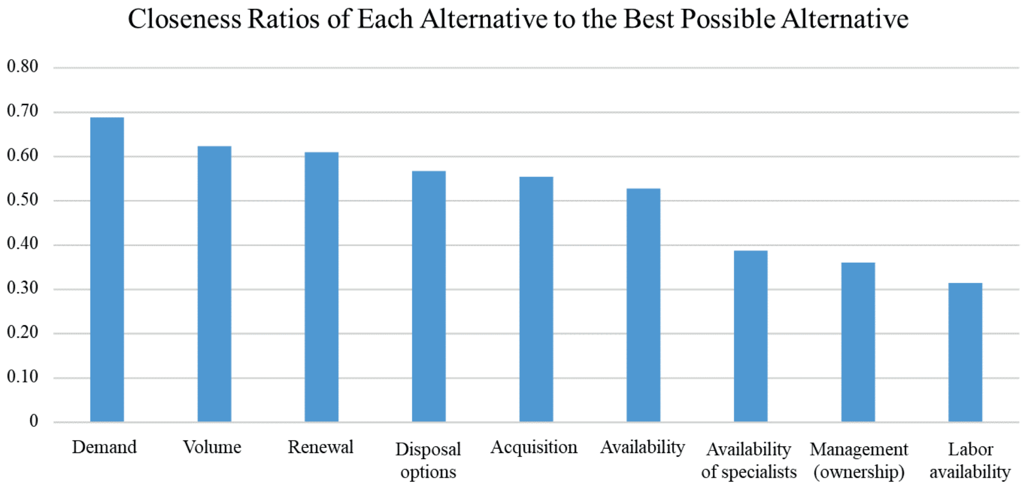

Fig. 3. Prioritisation of alternatives.

From Fig. 3 it is inferred that for the forestry resources, the most important factors that can help to determine the potential of forestry resources for Latvian bio-diplomacy are driven by its demand, volume, as well as renewal because they are intuitively closest to the adequate alternative when decision-maker considers all the alternatives appropriately. Labour availability is the last important driving force in this analysis.

Demand, volume and renewal after analysis go together because to build a biodiplomacy, it should be understood whether there is demand, which is considered as the leading indicator, and whether volume will satisfy demand and over above – in processes should be considered a renewal. These results mean that the next step in promoting biodiplomacy is understanding what kind of forestry product needs to be developed to increase demand. This product should consider eco-design principles, as volume is the next important driving force. Renewal is a third important factor. Ofcourse, other driving forces, which are in the other part of the priority as availability of specialists, management (ownership) and labour availability, should not be forgotten even those are not considered as key issues by developing the biodiplomacy.

4. Conclusions

The forestry resources have the potential of being a vital part of the Latvian bio-diplomacy. Suppose it is discussed according to the criterion importance, starting from economical, climate, environmental, and social aspects. In that case, the decision-maker can make informed conclusions in light of its most significant drivers, which are demand, volume and renewal. The significance of the results is that policy-makers should build biodiplomacy, considerate the main driving forces as demand, volume and renewal, where the emphasises should be.

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Development of Massive Online Open Course 'Energy Transition and Climate Change'

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Abstract – This study focuses on designing a massive open online course (MOOC) to enhance students learning about the energy transition process and its connection to climate change in theory and complex dynamic systems. The course 'Energy transition and climate change' covers one of the United Nations' 'Sustainable development goals' and is one of twelve MOOCs that will enable a comprehensive education in system thinking and its applications. It shows how system thinking methods and tools can be applied to tackle current and future energy and climate problems. The goal of the MOOC is to introduce users to the internal dynamics of modern energy systems and energy transition toward CO_2-neutral energy systems. The target audience of the course is students who study Environmental Engineering, Energy, Systems, or similar program and anyone else interested in insights into the topic. The course builds on previous energy supply and demand models by updating and adapting them to the existing situation. MOOC is designed by the Competency-Based Education (CBE) approach, and a literature review is used in the study to cover theoretical parts of the course. Technology Readiness Level (TRL) methodology describes the main steps of the course model development progress, and testing of MOOCs pilot version on five students is included in the final stage of the study.

***Keywords* – Competency-based education; energy efficiency; renewable energy sources; system dynamics**

Nomenclature		
MOOC	Massive Online Open Course	–
TRL	Technology Readiness Level	–
CBE	Competency Based Education	–

1. INTRODUCTION

The educational model that focuses on the learning course outcome and is reached by changing from knowledge-based pedagogy to a skill-based pedagogy is called 'Competency-Based Education' [1]. Competency-based education is primarily focused on defining what the student should be able to achieve at the end of the program. Then the specific course is being modelled, moving backward to each activity to ensure that each objective is achieved. This form of education contributes to skill and competency development with student–centered and self–directed methods. According to the definition, competence is 'a combination of cognitive and metacognitive skills, demonstration of knowledge and understanding, interpersonal, intellectual and practical skills and ethical values' [2]. Competencies offer the

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knowledge necessary for successful problem-solving in different situations and encourage acting in the given context. These skills can't be taught only by theoretical lectures; those must evolve with gaining learners' experience during practical tasks [3]. Key competencies, also called core skills or essential skills, are flexible items used in education models that support learning by practical tasks in real-world situations to understand the most effective solution for solving the given problem. Focusing on achieving different competencies allows students to use their knowledge, skills, and past experiences while performing a task [1]. Integrated knowledge includes different concepts, theories and data complemented with skills and components which leads to better social and cultural influence [4]. According to the Sistermans' publication on integrating competency-based education in online health sciences, there are six steps in planning a competency-based curriculum. First, the compilers of the educational program need to understand and define abilities that students must develop at the end of their studies. Then it is possible to point out exact competencies and their components. After that, 'the route' for achieving those competencies needs to be designed with key turning points. When the bases of the program are defined, appropriate educational activities, experiences, and educational methods need to be chosen and the most suitable assessment tools. The last step is to evaluate results at the end of the curriculum [5].

Climate change is a major environmental, economic, and political threat. The international community has recognized that education, which is a direct way of spreading awareness at different levels, is an essential element in identifying and highlighting the problem and training and mobilizing young people to face the main challenges of climate change [6]. Study courses focused on topics related to climate change should be able to provide good content and concepts to understand its magnitude, causes, and consequences. It is essential to provide information on the impact of climate change, both domestically and globally. Students need to understand the consequences of not responding and avoiding action. Climate change is a complex issue requiring additional technical and scientific sources in the study process, but the preliminary information should be clear and simple [7]. Implementing new learning tools contributes to student productivity and overall academic performance achieved during the course. The time spent creating an online course is compensated by the possibility of using such a course on several occasions [8]. Interactive learning environment approaches developed to create education more convenient, accessible, and affordable to anyone interested are called massive open online courses (MOOC). Various studies on the effectiveness of MOOCs have shown that users are more successful in learning the course content through self-regulated learning (SRL) when they need to study and read the course materials on their own [9]–[11]. The MOOC's online environment is found in a wide variety of formats, with some common characteristics collected by [12]. MOOCs, thanks to their extensive capabilities in acquiring content, materials, and skills, represent changes in studying process that soon might be a fundamental part of education system [13]–[15]. There is a wide diversity of the categorization of massive open online courses [9]. xMOOCs: based on traditional pedagogy and certification, with lectures, practical tasks, and more commonly used study model [16]. Problems such as high number of dropout cases and low co-operation among users would need to be addressed [16]. However, although MOOCs open up extensive technological opportunities and use of different teaching methods, in practice it has often maintained a standard educational approach where teaching content is represented and evaluated on the part of the teacher and not by the interaction between users [17].

The study addresses two research questions regarding the production context of an online course designed to be taken without the direct involvement of a teacher:

- How to design an adaptive online interactive learning environment for users that effectively encourages studying in and about themes regarding energetics and its

binding topics?
- How interface tools can be used in education to describe complex dynamic systems of the energy sector and the energy transition process towards CO_2 neutral energy systems?

This study has three main objectives:
1. Design a pilot version of a free massive open online course suitable for the target audience with a means of obtaining adequate competencies to tackle current and future energy and climate problems through theory and prism of system thinking;
2. Analyse and integrate CLD models and stock and flow structures of supply and demand sides of the energy sector in the content of the course and supplementing those with appropriate interactive tasks;
3. Test the developed version of the course for five students with advanced knowledge of system dynamics and energy systems.

2. METHODS AND METHODOLOGY

Technology Readiness Level (TRL) is a method used to assess the maturity phase of a new idea and the necessary actions in its development process. TRL consists of 9 levels which can be seen as a measurement of such an assessment. The benefits of this method are a structured and comprehensive view of the status of the prototype in its research and production process [18]. The TRL method aims to develop and test prototypes in their real application environment and is divided into three phases:
- Research;
- Prototype development;
- Product implementation.

A summary of TRL methodology according to the study is provided in Table 1. Levels 1–7, which include research, prototype development, and testing, are discussed in the study. At the beginning of the study, the research is made, which is compared to TRL 1–2. It starts with an introduction to the project – the expected content of the course and its main outcomes, as well as definition of the research questions. Similar courses from the partner universities were found and studied to understand the structure of the massive open online courses. One of them was 'Natural Resources Management' which is developed by the System Dynamics groups at the Department of Geography at the Faculty of Social Sciences at University of Bergen. This MOOC provides learning to manage various natural resources like fisheries, animal herds, water reservoirs and climate while focusing on complex dynamic systems. An important step in the study was the understanding of the MOOC's digital building tools, which is why different sources of information on the technical side of development of such courses were included in the research process.

TABLE 1. SUMMARY OF TRL ACCORDING TO THE STUDY

TRL	Description	Goal	Product/Evaluation	Outputs
1	Introduction in the current situation and goals of the project	Research	Feasibility of concept	Set of similar MOOCs from the partner universities
2	Definition of research questions	Research	Feasibility of concept	Publications regarding to the development of MOOC
3	Analytical studies and literature review	Development	Prototype	Scientific research and publications relevant to the topics included in the MOOC

TRL	Description	Goal	Product/Evaluation	Outputs
4	The basic components are integrated to test the operational capability of the MOOC	Development	Prototype	CLD models designed in *Stella Architect* Tools of the practical tasks available in the Moodle platform
5	The basic components are integrated to test the performance of the MOOC	Development	Prototype	CLD models designed in *Stella Architect* integrated in the content of the MOOC Tools of the practical tasks available in the Moodle platform used for theoretical and practical task development
6	Shaping of representative prototype	Development	Prototype	Collection of theoretical information and tasks included in the content of the MOOC
7	Testing of the prototype	Implementation	Prototype	Results of the tests carried out in the relevant environment
8	Research project to finalize the project	Implementation	Certified product	Defined main enhancements of the MOOC
9	Launch of the MOOC	Implementation	Deployed product	Functional final product developed

The next phase includes a literature review to establish a theoretical justification for the course model, which would be implemented as readable material for users in the study process. It's defined as level 3 of the described TRL method used in the study. More than 60 scientific research, publications, and books relevant to the MOOC's topics were used in the literature review, which was the most time-consuming part of the course development. The available tools for supplementing the theoretical part with practical tasks were examined in the following course development phase (TRL 4), as well as given casual loop diagrams (CLD) which were designed in *Stella Architect 2.1.5* software. These two CLDs of the supply and demand sides of the energy sector were created during 'Deliberation platform for energy transition policies: how to make complex things simple' research made by the Institute of Energy Systems and Environment at Riga Technical University in which an internet-based interface tool for the national energy simulation model as a tool for 'hybrid forum' was made [19]. Given casual loop, diagrams were converted into the generic stock-and-flow structures and used as study tools to explain how multiple parties of energy supply and demand sides interact in the energy sector by updating and adapting it to the existing situation (see Fig. 1). By creating interactive stories which visualize how elements of stock-and-flow structures affect different indicators like energy tariff, installed capacity of technologies using different fuels, and probability of investments users learn through the system dynamics how barriers to energy transition process are caused.

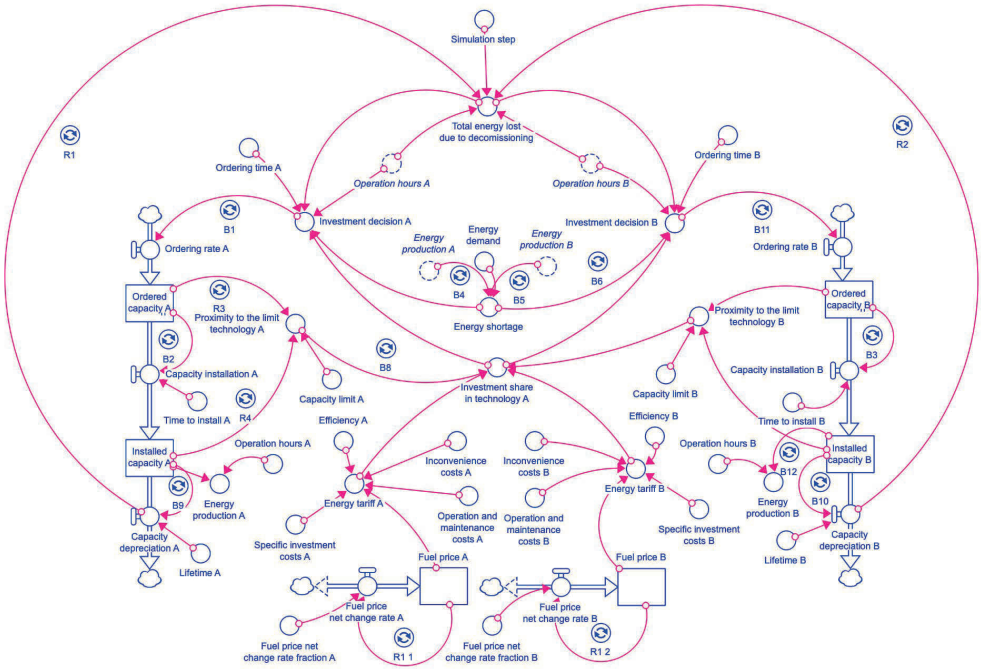

Fig. 1. Stock and flow structure for energy supply sector [12].

Reference [9] discusses that levels TRL 5 and TRL 6 include prototype validation in an environment like the actual environment, which in the case of this study was *Moodle* platform supported in the student course portal of the Riga Technical University called *ORTUS* [20]. A new course page was created which functions as the base of the developed prototype and includes all resources needed for both parts – theoretical and practical. *Moodle* platform allows building course structure by adding main sections of the topic and subsections, which include theory sheets and interactive content, such as interactive videos, question sets, 'drag and drop' questions, questions with answers, presentations, etc. Practical tasks used in the study course 'Energy transition and climate change' differ – some are made to aim student's knowledge of the described theory in the form of multiple-choice or 'true/false' questionnaires, but some involve practical work with interface after which user must answer quiz questions regarding the results reached by manipulating with different variables.

The final stage of the study was testing the pilot version on five students with advanced knowledge of system dynamics and energy systems after which the results were obtained through structured interviews (TRL 7). Students were chosen from Riga Technical University and the criteria was to have test users who had completed the System Dynamics course during their bachelor's studies. The following sections will set out the main points for the development of the MOOC 'Energy transition and climate change' with the Technology Readiness Level approach.

2.1. Research

In the first phases of course development research had to be made to evaluate the current stage of the MOOC, the goals of the content, and protentional outcomes of the user's knowledge and skills after studying. Useful research was made by completing one of the MOOCs that was published recently – 'Natural Resources Management' by the University of Bergen. It allowed an understanding of the basic structure and the most effective tools used to create an online course with a focus on the system dynamics approach.

The given MOOC 'Energy transition and climate change' which was one of the objectives of the study had almost no theoretical background and an important stage was to gather valid information for the content. That was done by selecting more than 60 resources relevant to the topics discussed in the course. Information had to be transformed in an educational manner to reach the target audience.

2.2. Prototype Development

Main structure of the created pilot course sections includes several steps, which contain practical tasks to determine the knowledge of users before, during, and after the studies. It contains the sections divided into chapters and subchapters (see Fig. 2). First, the student's knowledge of the following subject is tested through the training task. The results of these tasks are not included in the course final grade and are designed to give the student an idea of the content of the following topic. After completing students can look at the correct solution to the task. The 'Retry' function is provided for these tasks which allow the user to perform them multiple times. This structure is created to target the progress of the student and learning in practice. The basic section provides a theoretical insight into the subject. It is developed by literature review from publications and books that covers the main topics of interest. Some chapters also include additional training tasks, video materials, diagrams, interfaces, etc. for learning purposes. At the end of each chapter, the student must perform the practical assessment and the score of it forms part of the final rate of the course. Types of the tasks differ – there are multiple-choice, single choice, true/false questionnaires, as well as other interactive forms of tasks included. These tasks are designed to evaluate the user's understanding of the theory and behaviour of the system dynamics model (see Fig. 3). Practical assessments in the course can only be performed once. After completing the task, the student can look at the correct solution immediately and view a video that presents correct answers. For a positive rate, students must reach a minimum of 50 %.

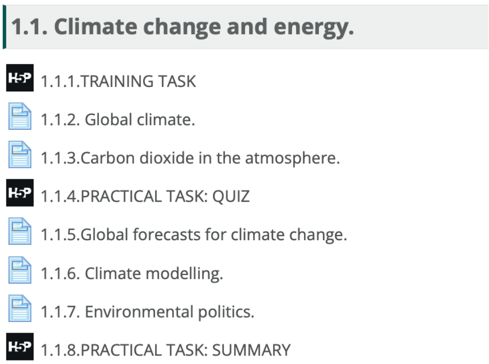

Fig. 2. Structure of the course chapter 'Climate change and energy' (icons represent various types of activities used in the MOOC).

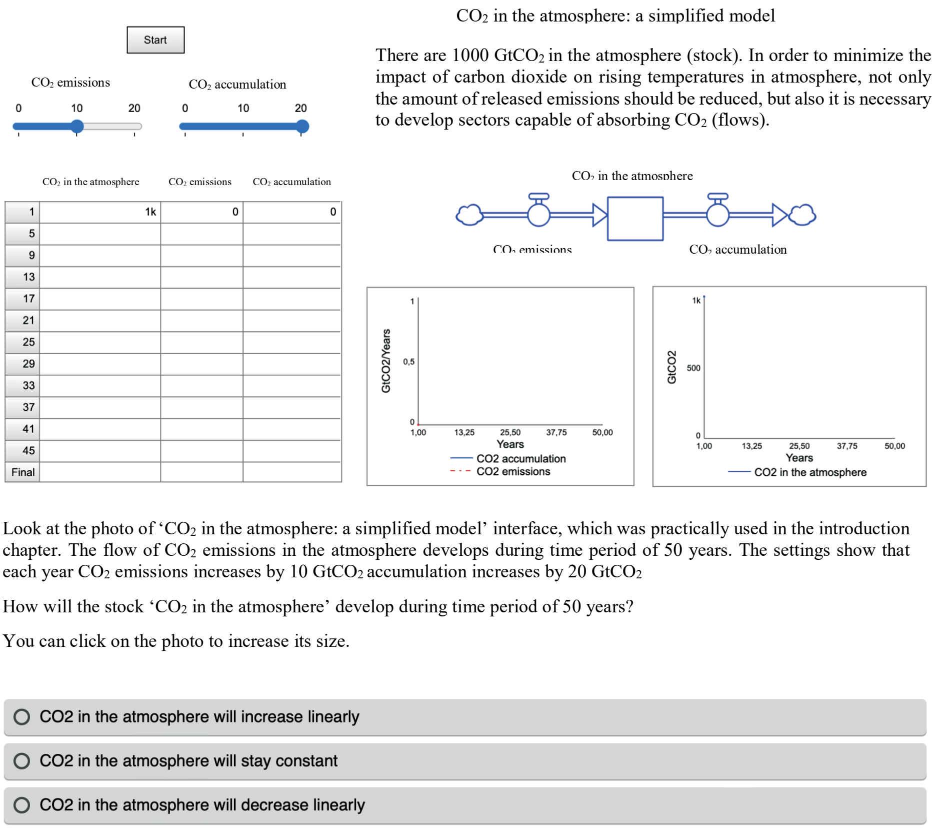

Fig. 3. Single choice question regarding simplified model of CO_2 concentration on the atmosphere.

2.3. Product Implementation

After finalizing the pilot version of the course testing had to be made to get results from the target audience about the focus areas of the course development in the future. For this reason, five students at Riga Technical University were selected. All the students had advanced knowledge of system dynamics. Selected users had three days to complete the course and structured interviews regarding their experience took place afterward.

3. Results

MOOC 'Energy transition and climate change' is developed in English and designed to be attended 100 % online. It allows students to learn at their own speed and deals with three important and interrelated aspects of modern energy policy: energy efficiency, renewable energy, and climate change. It describes the socio-technical transition of the current energy system, including innovative solutions in energy and climate technologies, discusses learning curves and economics, human behaviour as one of the main drivers of changes, as well as diffusion of different technologies to reach climate and energy policy goals. This knowledge is given to the user through the prism of system dynamics by explaining how the supply and demand side of the energy sector works. The course consists of five sections of which three were included in the pilot version development. You can see the full course table of contents in Annex I. Each chapter includes practical tasks to test the knowledge of users before, during, and after the studies. The training task takes place at the beginning of each part of the course and the rate of it is not included in the final grade. Practical assignments are rated and included in the final note of the student.

The introduction part of the course explains what climate change is and how the energy sector relates to it. The outcomes of this part include knowledge about the main causes and impacts of climate change, dynamics of the carbon cycle in the atmosphere, and the basics of global policy measures for climate change. After finishing the first part of the course, students can distinguish the supply and demand sides and how they are interlinked, as well as name energy supply sources and differences in energy consumption tendencies in multiple sectors of the demand side. After the introduction course student can also describe the energy transition process, lock-in barriers, understands the dynamics of energy transition from fossil-based energy to renewables, and improved energy efficiency.

First, an introduction to Earth's climate and its natural and human-caused influencing factors is explained, focusing on greenhouse gas (GHG) emissions. The chapter includes material about the carbon cycle, which illustrates how the concentration of CO_2 in the atmosphere is constantly changing because of emissions and the accumulation process. Also, the influence of increasing concentration of GHG emissions on global warming is discussed, as well as policy tools for limiting it.

The second chapter dives deeper into the supply and demand sides of the energy sector. A short introduction in examples of different fuels used to produce energy is included, followed by the importance of energy efficiency and growing numbers of prosumers in the demand side of the energy sector. This part of the course includes an introduction to the supply and demand side relationship through the prism of system dynamics.

In the following chapter key features of the main sectors of energy users (residential, industrial, public, etc.) regarding the usage of electricity and heating/cooling systems are described. Finally, the last chapter of the introduction part of the course explains the importance, opportunities, and complications of the energy transition process [21]–[23]. It includes the transition theory, 'Shifting the burden' archetype, possible lock-ins in the energy transition process to more sustainable technologies, and how bridging fossil energy systems with renewable energy systems occurs. Decentralized energy management, which is the essential aspect of sharing economy as well as aggregators is also discussed.

Sections 'Supply-side' and 'Demand-side' are designed using a similar approach – information from publications that cover the main topics of interest are given first, following with the examples from the stock-and-flow structures of energy supply and demand sectors. Users can assess, describe, and evaluate the main driving forces of the energy transition on both sides from the system dynamics perspective. The Supply-side includes different current and future energy sources while the demand side sub-models include energy consumption sectors, such as households, tertiary, industry, public, and transport. Practical tasks using interfaces are included where users can plan different scenarios for the development of energy transition towards CO_2 neutral energy systems, major leverage points in energy systems, short- and long-term effects, as well as the impact of delays, non-linearities, and feedbacks in the process of the energy transition.

Topics discussed in the supply side section of the course include definitions of the main technologies used in energy production and their price range data followed by an interface explaining how the stock-and-flow structure of the energy supply sector is built (see Fig. 4). Users then have to design different scenarios to investigate which are the variables in the structure that have the highest impact on energy tariff, the quantity of energy produced by fossil-fuel-based and renewable energy-based technologies, as well as installed capacity in power plants for different technologies. The chapter explaining how capacity is built between competing technologies using fossil-fuel and renewable energy sources (RES) with the theoretical examples from two power plants running on natural gas and wind energy is included. Factors like delays in capacity installation, public acceptance, and resource availability, explain how important land space is and how much land footprints are made by power plants using different types of fuels.

The demand-side section describes internal and external barriers to the implementation of energy efficiency measures, which often occur in terms of low-quality construction works during renovation projects [24], [25]. The behaviour of residents during the period of deciding whether to support or not to support the renovation of the building to increase its energy efficiency is also discussed and the effect of this decision is included in the stock-and-flow structure of the energy demand sector. While navigating through the interface, users are introduced to each element of the structure with theory and examples. Similarly, as it was in the supply side section, the interface includes a simulation model in which students build multiple scenarios and in the following chapter answer a quiz questionnaire about their experience. Energy efficiency in different end-use sectors (public, residential, industry, tertiary) is also discussed.

Each section of the course includes practical tasks to test the knowledge of users before, during, and after the studies. The training task takes place at the beginning of each part of the course and the rate of it is not included in the final grade. Practical assignments are rated and included in the final note of the student.

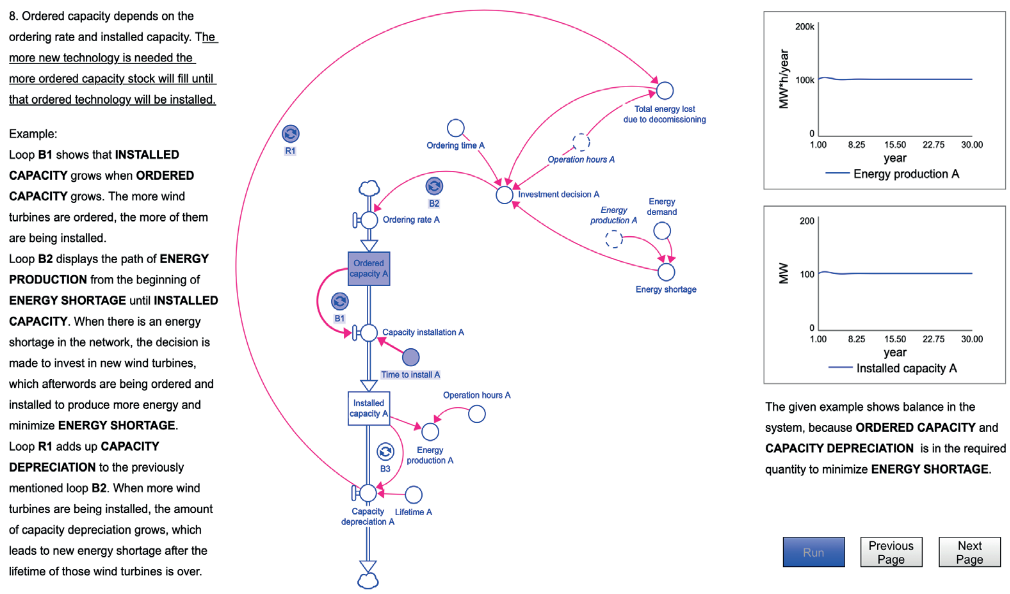

Fig. 4. Interface explaining how the stock-and-flow structure of the energy supply sector is built.

The Likert rating scale from 1 (Strongly Disagree) to 5 (Strongly Agree) was applied to evaluate the course in eight question groups. The average score for content was 3.65, learning and support 3.45, visual design 3.15, navigation 3.36, accessibility 3.27, interactivity 3.80, self-assessment and learnability 3.35, motivation to learn 3.71. The lowest rate (3.15) in course evaluation has been given to the visual design of the MOOC. The MOOC prototype has not yet been developed to the stage where visual design for the course is being created. Users provided valuable comments and insights, which will be further used to improve the MOOC.

4. Conclusion

Study shows that Technology Readiness Level (TRL) method can be used to effectively measure the progress in the product development process, also it works as a useful guideline for understanding the following main steps in the building of the course. During the study, TRL approach proved to be a helpful tool to design an adaptive online interactive learning environment for users that effectively encourages studying in and about topics regarding energetics and its binding topics.

During the study a pilot version of a free massive open online course suitable for the target audience with a means of obtaining adequate competencies to tackle current and future energy and climate problems through theory and prism of system thinking was developed, which contains three from five sections intended in the project.

Acknowledgement

This study has been carried out with the support of the Erasmus+ programme of the European Union project 'System analysis MOOCs for sustainability transformation (SYSSUS)'.

Annex

Massive open online course 'Energy transition and climate change' table of contents:

1. Introduction;

1.1. Climate change and energy;
- 1.1.1. Training task;
- 1.1.2. Global climate;
- 1.1.3. Carbon dioxide in the atmosphere;
- 1.1.4. Practical task: quiz;
- 1.1.5. Global forecasts for climate change;
- 1.1.6. Climate modelling;
- 1.1.7. Environmental politics;
- 1.1.8. Practical task: summary;

1.2. Supply and demand;
- 1.2.1. Training task;
- 1.2.2. Supply side;
- 1.2.3. Demand side;
- 1.2.4. How supply side and demand side interlink;
- 1.2.5. Prosumers;
- 1.2.6. Practical task: supply side, demand side or prosumer?;

1.3. Sector specifics;
- 1.3.1. Training task;
- 1.3.2. Introduction;
- 1.3.3. Residential sector;
- 1.3.4. Industry sector;

1.3.5. Tertiary sector;
1.3.6. Public sector;
1.3.7. Transport sector;
1.3.8. Practical task: quiz;

1.4. Energy transition;
1.4.1. Training task;
1.4.2. Energy transition;
1.4.3. Transition theory;
1.4.4. Shifting the burden;
1.4.5. Aggregators;
1.4.6. Energy accumulation;
1.4.7. Smart technologies;
1.4.8. Internet of things;
1.4.9. Practical task: summary of introduction chapter;

2. Supply side;
2.1. Training task;
2.2. Casual loop diagram: energy sector;
2.3. Technologies;
2.4. Stock and flow structure: single energy supply technology;
2.5. Practical task: quiz;
2.6. Capacity building;
2.7. Stock and flow structure: two competing technologies;
2.8. Practical task: quiz;
2.9. Delays;
2.10. Public acceptance;
2.11. Resource availability;
2.12. Practical task: summary of supply side chapter;

3. Demand side;
3.1. Training task;
3.2. Stock and flow structure: energy demand;
3.3. Practical task: quiz;
3.4. Barriers to energy efficiency;
3.5. Decision making and behavior;
3.6. Energy efficiency in different end use sectors;
3.7. Practical task: summary of demand side chapter.

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Education for Advancing the Implementation of the Green Deal Goals for Bioeconomy

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***Abstract* – Evolving complex concepts, such as bioeconomy, in the most effective way, can be applied through the education of students and professionals. In recent years changes in the education system can be observed with the development of knowledge-based learning. Competence-based learning will also be used more and more in higher education. Higher education plays a crucial role in achieving the goals of the Green Deal and the bioeconomy. The main emphasis is on creating new and innovative technologies and methods to achieve these goals. A new master's study program, 'Environmental Engineering', has been established at the Institute of Energy Systems and Environment of Riga Technical University. One of the study directions is 'Bioeconomy'. Considering the developed direction 'Bioeconomy', the importance of this sector is visible. Attention should also be paid to the goals of the Green Deal. This study summarised research on education, bioeconomy and Green Deal topics and analysed the interrelationships between these studies using the *VOSviewer* tool. During the analysis, it is possible to conclude the main keywords that characterise these studies. The obtained keywords should indicate the development trends of future research, which is in line with education, the 'Green Deal', and bioeconomy.**

***Keywords* – Competency-based education; higher education; sustainable education; VOSviewer**

1. INTRODUCTION

In global developments, it is crucial to consider development trends and the necessary solutions to achieve the goals. In 2012, the European Commission set five critical goals under the Bioeconomy Strategy:

1. Ensuring access to food and nutrition;
2. Sustainable management of natural resources;
3. Reducing dependence on non-renewable, unsustainable resources;
4. Limiting and adapting to climate change;
5. Strengthen European competitiveness and create jobs to foster the development of the bioeconomy [1].

Also, in the Latvian context, the 'Bioeconomy Strategy' was introduced in 2016, which defines several pillars based on knowledge and innovation, one of which is the provision of excellent educational services for the needs of the bioeconomy sector [2].

In 2020, the Institute of Energy Systems and Environment of Riga Technical University accredited the master's study program 'Environmental Engineering' with the direction 'Bioeconomy'. The establishment of this direction justifies the even greater need and

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importance for bioeconomy specialists and their role in the future and in achieving the goals of the bioeconomy. Therefore, in the context of changes in education, the competencies (knowledge) acquired by students play an essential role [3].

At the end of 2019, the European Commission issued an action plan, 'Green Deal', which defines the action directions to accelerate the intensity of innovation and activate education [4].

The number of research in bioeconomy education has been growing over the past years to stress the necessity for new specialists in the field to devlope innovative technologies and products [5]–[11]. [12] writes that implementing bioeconomy goals and transforming to a knowledge-based sustainable bioeconomy should be considered transdisciplinary, learning, interdisciplinary and system-thinking, anticipatory, normative, strategic and interpersonal competence, where [13] ads policy and decision-making skills. Another paper [12] mentions that lectures, site visits, group coursework, practical laboratory work, and role-play support those competencies. Fig. 1 illustrates solving problems – a basic structure linked to key competencies for sustainability, which is described in [7].

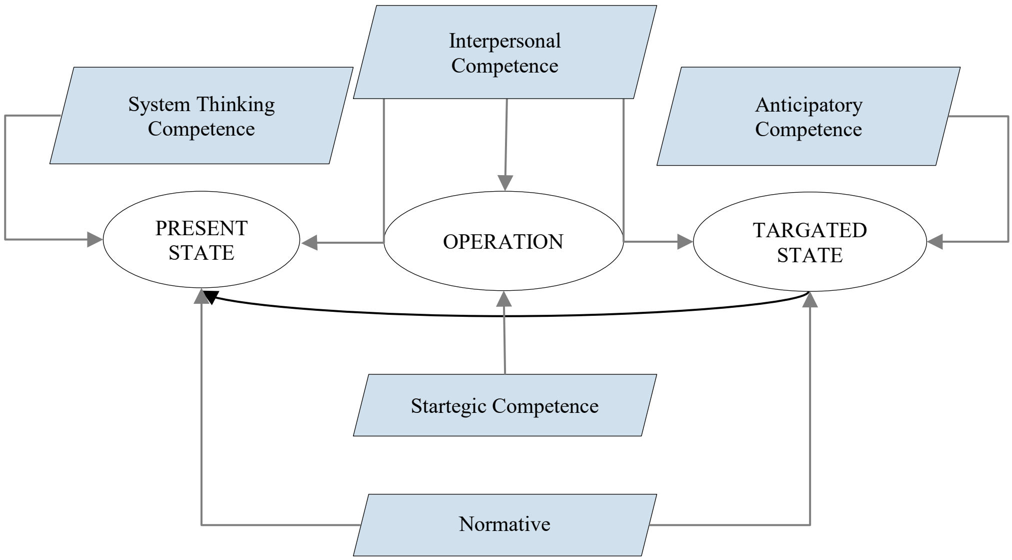

Fig. 1. Solving problems—basic structure linked to key competencies for sustainability [14].

In the [15], it is mentioned that skills are the solution to the bioeconomy and Green Deal goal-reaching victory. The agenda says a 'twin transition' supporting the green transition and digital transition skills in how the European Commission will support those skills. This agenda sets out the conditions under which the European Commission will support skills for the green transition, such as defining a system of skills and agreeing with the EU Member States on sets of indicators to monitor and analyse the development of green skills.

This study gathers information on research related to the bioeconomy, Green Deal, and education. The study's primary goal is to identify the most used keywords deciphered in the studies so far, using the bibliographic software *VOSviewer* to identify research trends.

2. Methodology

The research methodology consists of

– Selection of articles from the Scopus database;
– Processing of articles using the bibliography visualisation program *VOSviewer*;
– Analysis of results;
– Conclusions (see Fig. 2).

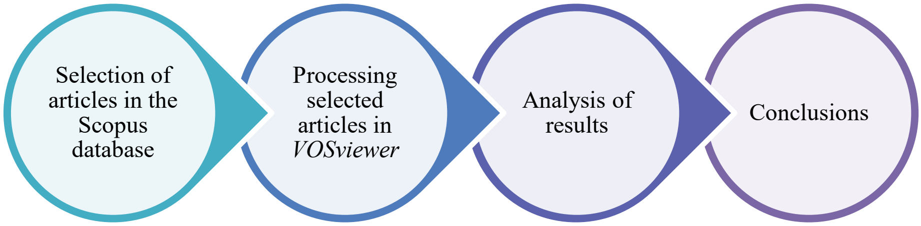

Fig. 2. Research methodology.

Articles were selected using the Scopus database and entering 'Article title, Abstract, Keywords' word combinations in the search fields. These word combinations are:

– 'Education' AND 'Bioeconomy';
– 'Education' AND 'Bioeconomy' AND 'Competences';
– 'Education' AND 'Bioeconomy' AND 'Innovation';
– 'Education' AND 'Bioeconomy' AND 'Skill';
– 'Education' AND 'Green deal';
– 'Education' AND 'Green deal' AND 'Innovation'.

Articles were selected in the period starting from 2012 if the word 'bioeconomy' was included because in 2012 bioeconomy goals were set. If the word combination contained 'green deal', then the articles were selected starting from 2019 because the goals of the Green Deal came into force starting from 2019.

3. Results

This study focuses on the research in the scientific literature related to education and bioeconomy, the link between education and the Green Deal, and the addition of additional keywords that are specific to the field of study. *VOSViewer* software is a good visualisation tool for bibliographic sources created by Nees Jan van Eck and Ludo Waltman [16], which gives the reader a general idea of the directions and connections of the research topic. In previous studies on sustainable development, circular economics and other environmental policy issues, *VOSviewer* has been used to identify critical keywords, key researchers and scientists in developing research directions, and research in the specific region and journals [17], [18].

Fig. 3 and Fig. 4 show the link between scientific articles using the words 'education' and 'bioeconomy' (articles were selected from 2012 onwards). Sixty-five articles were established in the Scopus database. These figures show significant differences in the minimum frequency of word repetition. In Fig. 3, this minimum frequency of word repetition is twice, but in Fig. 4 – three times. The minimum frequency of word repetition was changed because the authors considered that the connection of words should be visualised, and more relevant related words should be visualised. As shown in the figures (Fig. 3 and Fig. 4), the relationship of these words forms clusters. Fig. 3 shows 101 keywords that form eight clusters. Clusters consist of corresponding keywords and their links.

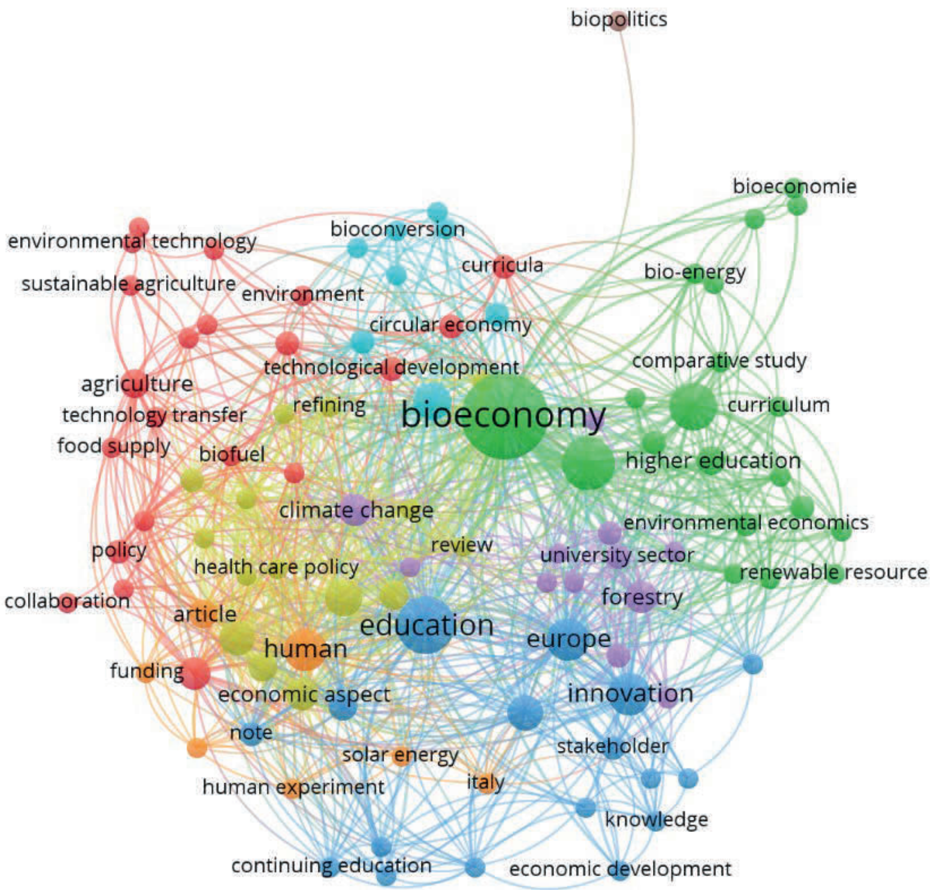

Fig. 3. Visualisation of the bibliography with the word combination 'education' AND 'bioeconomy' since 2012 (minimum frequency of word repetition – 2 times).

Fig. 4 represents 37 keywords, which are classified into 4 clusters. Further, bibliographic data with the word combination 'education' and 'bioeconomy' since 2012 (minimum frequency of word repetition – 3 times) is analysed, keywords identified by 4 clusters.

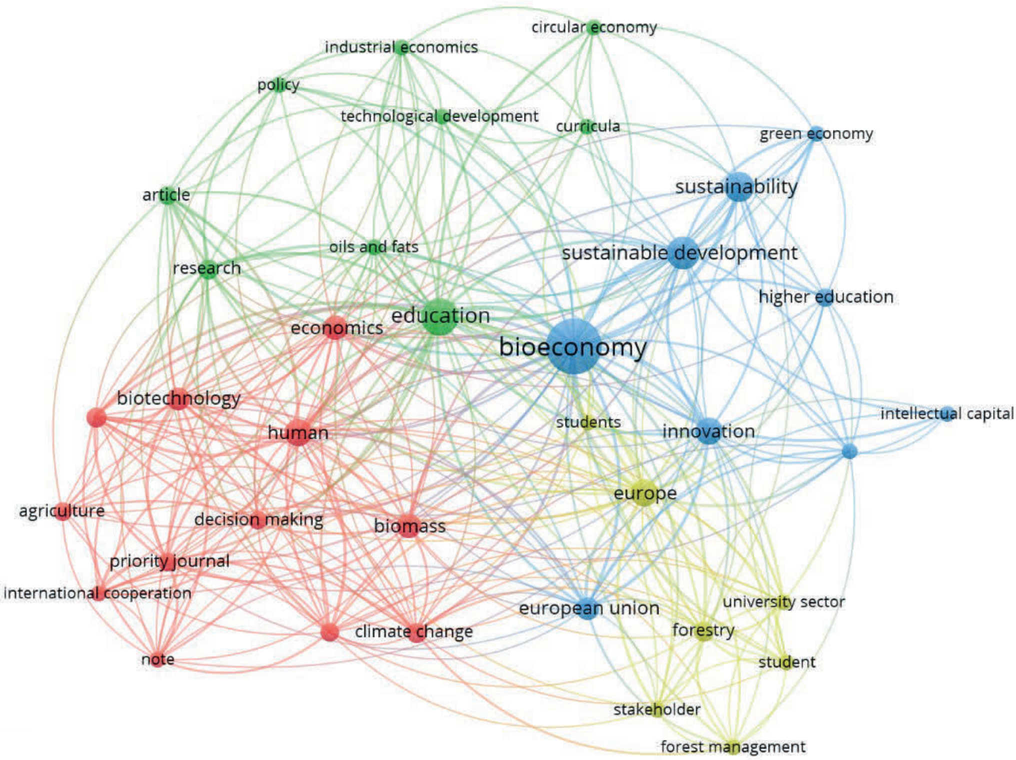

Fig. 4. Visualisation of the bibliography with the word combination 'education' and 'bioeconomy' since 2012 (minimum frequency of word repetition – 3 times).

Fig. 4 shows a network of correlative links between these 37 keywords, consisting of 319 links and a total link strength of 564. The figure shows that the most frequently occurring keyword in publications is 'bioeconomy'. Of course, it could be considered the most relevant word because papers were selected using the keyword 'bioeconomy', which appears in 36 scientific publications and relates to 36 other keywords described as links. The second most relevant keyword is 'education' (32 links), in 16 scientific papers. The third most common word in 13 scientific papers is 'sustainable development' (23 links), 'sustainability' (14 links) in 11 scientific papers and 'human' (28 links), 'innovation' (22 links), 'Europe' (30 links) in 9 scientific papers. 'Bioeconomy' and 'education' are used the most and show up in most publications. Words 'human', 'innovation', and 'Europe' show up in fewer papers than words 'sustainable development' and 'sustainability', but they have more connections with other keywords in the network, which means that authors are using more common language and words in the papers to represent further scientific topic development and their importance in science.

Table 1 represents four clusters with distributed keywords in the bibliographic network, where word combinations 'education' AND 'bioeconomy' were used, selecting scientific papers in the Scopus database from 2012. The keyword appears once in one of the clusters.

TABLE 1. REPRESENTED CLUSTERS IN BIBLIOGRAPHIC NETWORK WITH THE WORD COMBINATION 'EDUCATION' AND 'BIOECONOMY' SINCE 2012 (MINIMUM FREQUENCY OF WORD REPETITION – 3 TIMES)

Cluster 1	Cluster 2	Cluster 3	Cluster 4
agriculture	article	bioeconomy	Europe
biomass	circular economy	environmental economics	forest management
biotechnology	curricula	European union	forestry
climate change	education	green economy	stakeholder
decision making	industrial economics	higher education	student
economic aspect	oils and fats	innovation	students
economics	policy	intellectual capital	university sector
human	research	sustainability	
humans	technological development	sustainable development	
International cooperation			
note			
priority journal			

It should be mentioned that *VOSviewer* is a quantitative analysis software, and qualitative analysis software should be used for further research. Notwithstanding the above, it is possible to understand the field of study in each cluster in which education with bioeconomy is related.

Cluster 1 represents keywords related to human involvement in agriculture and the development of bioeconomy using biotechnologies, where knowledge is essential. Education necessity for industrial economics is shown in Cluster 2, where technological development and research should be considered. Cluster 3 keywords are related to innovation necessity in bioeconomy, which should be done by higher education involvement for sustainable development. Cluster 4 represents the forestry sector and student education necessity for bioeconomy development.

Fig. 5 shows keywords' chronological appearance in the papers, where keywords in yellow, such as 'forest management', 'forestry', 'stakeholder', 'student', etc., appear more in up-to-date publications, for example, in 2019. It could be explained that more significant research is applied to more carbon-neutral applications, for example, forest resources. Keywords in dark blue, such as 'technological development', 'policy', 'industrial economics', were performed already in 2016. Keywords in yellow show the latest development in research, which is considered in the forestry sector. More innovative applications in the forestry sector for bioeconomy development through education will be considered.

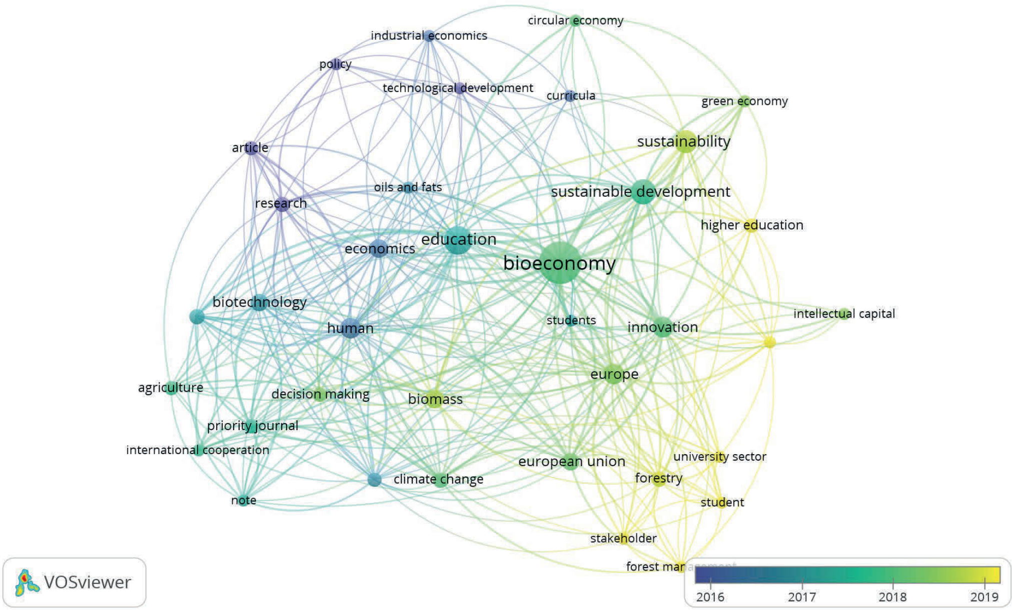

Fig. 5. Overlay (chronological) visualisation of the bibliography with the word combination 'education' and 'bioeconomy' since 2012 (minimum frequency of word repetition – 3 times).

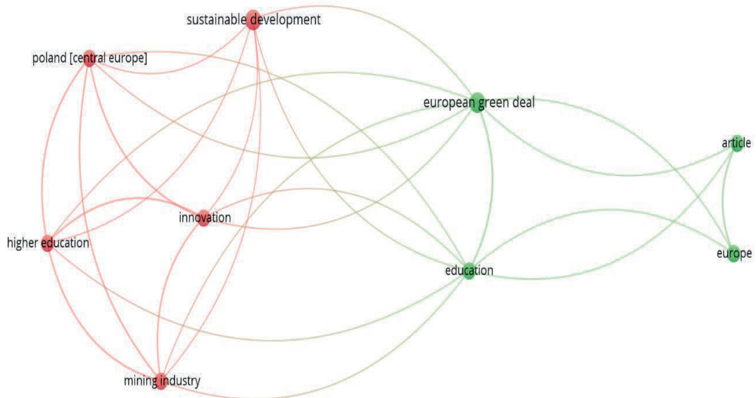

Fig. 6. Visualisation of the bibliography with the word combination 'education' and 'green deal' since 2019 (minimum frequency of word repetition – 2 times).

Fig. 6 shows the connection of scientific articles with the word's 'education' and 'green deal'. Papers were selected from 2019, as the Green Deal document was published this year. In total, there are nine articles. It should be noted that the number of articles is much smaller compared to the above word combinations.

4. CONCLUSION

Recently, the question of how the goals of the bioeconomy will be achieved is becoming more and more important, considering the framework of the Green Deal. One cornerstone is higher education in achieving these goals by implementing competence-based study programs, resulting in highly qualified bioeconomy specialists.

The study's primary goal was to identify the most used keywords deciphered in the studies so far, using the bibliographic software *VOSviewer* to identify research trends by selecting research papers in Scopus database, and choosing papers using words 'education', 'Green Deal', 'bioeconomy', in different combinations. Word combinations such as 'education AND bioeconomy AND skill', 'education AND bioeconomy and competence', 'education AND bioeconomy AND innovation', and 'education AND Green Deal AND innovation' were also compiled. Scientific publications with these word combinations alone were not selected and were therefore not used for further analysis. Instead, 'education AND bioeconomy', where minimum keyword occurrence is 3, and 'education AND Green Deal', where minimum keyword occurrence is 2, were used for further analysis. Scientific papers where the words 'bioeconomy' and 'Green Deal' were included were selected starting from 2012 and 2019, respectively. Thirty-seven corresponding keywords were obtained for visualisation, contained in four clusters: linking the bioeconomy and education in the agricultural sector (Cluster 1), connecting the bioeconomy and education in the industry (Cluster 2), linking the bioeconomy and education to innovation (Cluster 3) and linking the bioeconomy and education to forestry (Cluster 4). Also, 'forest management', 'forestry', 'stakeholder', 'student' are the most commonly used words in research in recent years. The research results have been obtained and help identify how research in higher education is currently underway through the bioeconomy and for developing new trends.

Further research should focus on how education explores these identified areas in clusters considering topics as bioeconomy, Green Deal, skills, education, competencies, and innovation as a whole.

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The Versatility of the Bioeconomy. Sustainability Aspects of the Use of Bran

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***Abstract* – As food consumption increases, so does the number of agricultural by-products. That is why it is necessary to find the best possible uses for them, operating by the principles of the bioeconomy. This work aims to gather information on the possibilities of using grain byproducts to develop new products and evaluate which bran products are the most suitable for commercialisation based on economic, environmental, social, and technical factors. Two methods were used in this work: literature review and multi-criteria decision analysis. As a result, 30 products were identified that could be made by using wheat bran, straw, husk, and dust. The products were divided into six groups – packaging materials, building materials, adsorbents, fuel, thermal insulation materials, and chemicals. In multi-criteria decision analysis, it was looked at seven bran products of which the best alternative for further commercialisation is mycelium-based biocomposite.**

***Keywords* – Grain byproducts; multi-criteria decision analysis (MCDA); sustainable development; TOPSIS; value-added products; wheat**

1. INTRODUCTION

The bioeconomy is one of the main directions of economic development that will allow achieving the goals of the European Green Deal [1]. An essential aspect of the bioeconomy is gathering the existing knowledge and highlighting and evaluating new strategies and technological processes to choose the best directions for development, considering global, regional, and local specificities [2]. Global food consumption is projected to increase by 59 %–98 % by 2050 compared to 2005 [3]. All of this indicates that agricultural production and the number of byproducts generated will increase. Approximately 1.3 billion tons of food waste, including food byproducts, and yearly losses are generated worldwide. At the level of food production, 39 % of food waste and loss occurs [4]. The circular economy model promotes byproducts as a raw material for new products, thus creating new business models with more resource-efficient industrial management [5]. The circular economy aims to move away from a linear economy model and introduce an economy based on the 3Rs principle of reducing, reusing, and recycling [6]. Traditionally, grain byproducts are disposed of as waste or added to livestock feed [7]–[10]. It harms the environment, such as wheat bran disposal releases 259 $kgCO_2eq$ into the air [11]. Also, the possibility of producing value-added products such as single-cell oil is lost [12]. The use of agricultural residues in higher value-added products is in line with at least three of the seventeen UN Sustainable Development Goals (Goal 2;9;12) [13]. The concept of a cascade implies using biomass in a resource-

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efficient and closed-loop manner [14]. The idea has appeared in European Union (EU) policy planning since 2012 in documents such as the EU Forest Strategy, the EU Bioeconomy Strategy, and the EU Circular Economy Action Plan [15].

In Europe, the cultivated area under cereals in 2020 was 52.5 million hectares, and the yield was 286.5 million tons [16]. Globally, wheat is the most common type of cereal and one of the primary raw materials in the food industry. In 2017, the world produced 770 million tons of wheat, of which 150 million tons were grown in Europe [9]. In 2020, the wheat harvest in Europe was 126.7 million tons [16].

In 2020, the agricultural land in Latvia accounted for 36 % or 2.3 million hectares, of which 753.7 thousand hectares of the area was under cereals. Cereal production is one of the most important agricultural sectors in Latvia, as it does not only provides food for people and feeds the livestock sector. The grain yield in 2020 was 3.5 million tons, and the yield per hectare was 46.4 quintals. In 2020, 20 314 farms were engaged in growing cereals in Latvia. In recent years, summer and winter the growth of wheat was the highest, up to 66.2 % [17]

The cereal sector can be divided into three stages – 1) grain cultivation and harvesting, 2) grain primary and secondary processing, and 3) grain food retail and consumption [5].

Byproducts such as grain screenings, husk, bran, germ, dust, and straw are generated during cultivation, harvesting, and processing stages [10], [18], [19]. In grain cultivation, straws are produced, which can be used as a raw material in various industries, such as medicine and animal farming [20]. In the case of wheat, approximately 1.3 to 1.4 kg of wheat straw is produced per kilogram of grain obtained [21]. In primary processing, the grains are cleaned and dried. Grain screenings and dust are generated in this stage [19]. They account for about 0.9 % of the total weight [22], [23]. Dust, husk, bran, and germ are generated in secondary processing. Husk and bran are byproducts of flour milling, representing approximately 14.5–25 % by weight of the grain [8], [11], [24].

There have been several studies on what can be obtained from grain byproducts. Berthet *et al.* studied wheat straw as a source to obtain lignocellulosic fibres, which can be used as a filler in Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV). The material is further used as a film for fresh food packaging [25]. Wheat straw can be used as a source to get bio-polyol. It is a partial substitute for castor oil in biodegradable polyurethane foams, which can be used as a thermal insulation material in the agricultural sector [26]. Hernández-Martínez *et al.* described how to extract silicon from wheat husk ash, which can be used to produce solar cells [27]. Katileviciute *et al.* compiled several studies on using wheat bran to produce enzymes, proteins, organic acids, and other products [28]. The studied products can be classified into six groups: packaging materials, building materials, adsorbents, fuel, thermal insulation materials, and chemicals. The most studied grain byproducts are bran, straws, and husk. There are studies on their use as raw materials [29], [30], filler [9], [11], [31], binder [32], nutrients [5], [28], [33], and the source of various chemicals [34]–[36]. Most of the research looks at only one of the grain byproducts.

Looking at several articles on bioeconomy [37]–[40], we observed that the literature review is regularly used to gather information. It is used to collect data and data, which is further analysed using other methods, depending on the purpose of the work. In a review of the extraction and use of phenolic compounds from coffee byproducts, a literature review was conducted to identify and evaluate research on the studied topic [37]. Fiallos-Cárdenas *et al.* use the literature review method in their paper to compile quantitative studies on the use of banana lignocellulosic residues [38]. An overview of current scientific, technological, and commercial trends in using bio-waste in various industries conducted a literature review on the circular bioeconomy of agri-food and forest processing waste [39]. Corrado and Sala provided an overview of studies on food waste generation worldwide and in Europe. Ten scientific articles were selected using a literature review, and the underlying quantification methodologies of these studies were further systematically analysed [40]. For the current research it is necessary to do a literature review to compile scientific articles that review products obtained from grain byproducts.

A multi-criteria decision analysis (MCDA) method can compare options and set priorities [41]. Lokesh *et al.* used a two-tier MCDA to identify promising biological value chains essential for EU bioeconomy planning. Twelve EU-based value chains, such as 'Starch to Bioplastic Food Packaging,' were selected for the study and evaluated against six criteria. As a result, the authors recommend using the research methodology in practice to make informed decisions about bio-based products that have the potential to replace fossil-based products [15]. Pieratti *et al.* conducted a study using MCDA to evaluate different forest management strategies at the local level. Six criteria based on the 4R principle of the circular bioeconomy were set, and five scenarios were analysed. The authors conclude that the main advantages of this method are that the results are easy to understand and compare. But before the results are used in practice, they should be analysed and checked [42].

Stephen *et al.* in his work he used a combination of MCDA and visualization technique to analyse the long-term and sustainable use of forest resources. The results obtained during the survey for obtaining criteria for MCDA were presented in the program for 3D visualization of various scenarios for the development of the task. This combination allowed the author to determine a number of optimal tools and measures to solve the problem and put forward ways to solve it.

Barney *et al.*, using MCDA, explored scenarios for decarbonizing the energy sector by converting it to renewable energy sources. The author included in the analysis the factors of three directions – economic, social and environmental, which made it possible to carry out the analysis as versatile as possible for the chosen task. The use of additional programs such as EnergyPlan, LCOE and TOPSIS deepened the result, making it closer to reality. Combining MCDA with various programs and methods allows you getting a result that can be applied in practice, regardless of the location of the object or territory under consideration.

The analysis of the literature on the optimal research methodology indicates that MCDA will show the required result for this work as well. Based on the conclusions about the method, this study will use MCDA to compare different products that can be made using wheat bran.

Several studies have been conducted on this topic, but primarily byproducts are considered separately. Review articles already summarise information on a specific byproduct and its use [28]. However, as far as we know, no summary of several grain residues has been made in one study. Therefore, this study aims to gather information from the scientific literature on the possibilities of using grain byproducts in developing new products and to assess which bran product is the most suitable for commercialisation based on economic, environmental, social, and technical factors.

2. METHODOLOGY

The methodology was selected based on the reviewed scientific articles in the bioeconomy field and their suitability for this research. Two methods have been chosen to identify and evaluate the products that can be made using grain byproducts – literature review and MCDA. The operation algorithm can be described by the following 5 steps, all of which are important and in order to get precise result, cannot be skipped:

1. Product identification. The step required to determine the main product, its needed properties and qualities;
2. Collection of information in the available literature and its analysis for a deeper study

of the selected product, its availability and diversity on the market;
3. Based on the analysis of the literature, the choice of criteria required for subsequent analysis. The right choice of criteria will allow you to comprehensively evaluate the product based on the required qualities. In case of technology, these criteria may be its readiness level, availability on the market and sustainability;
4. Conducting MCDA analysis based on selected criteria;
5. Product realization based on the results of the MCDA analysis (see Fig. 1).

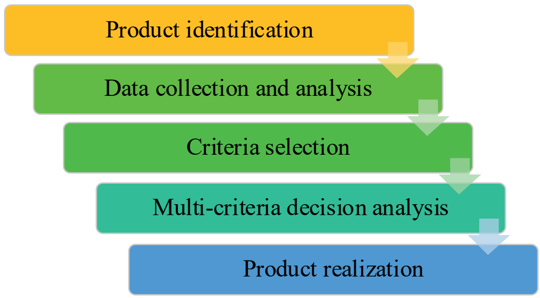

Fig 1. The stages of the research methodology.

The scientific databases ScienceDirect and the Web of Science were used in the literature review. Publications were searched using keywords. They were based on 'products from grain…' and in ellipsis place, different words were used: 'byproduct', 'germ', 'pulp', 'husk', 'chaff', 'bran', 'straw' and 'screenings'. Twenty-nine studies published between 2006 and 2021 were selected for the next phase, in which articles were grouped and analysed. The selected papers were in English and corresponded to the topic of this study.

The selected articles were grouped based on the byproduct used in the study and the final product. All final products were divided into the six groups shown in Table 1. The selected articles are about wheat byproducts because most articles on this topic research wheat residues. Wheat is also the most common type of cereal in Latvia and the world [2], [17].

TABLE 1. PRODUCT CLASSIFICATION INTO GROUPS

Product group	Wheat byproducts	The final product
Packaging materials	Bran, straw, dust, and husk	Bio-based composite with polypropylene (PP) [11], [43], food film with antioxidant properties [24], bio-based food packaging [5], biocomposite – film for fresh food packaging [25], thermoplastic [8].
Building materials	Straw, husk	Concrete [10], lightweight concrete [9], [31].
Adsorbents	Bran, straw, and husk	Siliceous lignin microparticles as an adsorbent [35], adsorbent for Reactofix golden yellow 3 RFN dye [44], carbon microspheres [45], and absorbent for eliminating dyes and other toxic effluents from the textile industry [29].
Fuel	Bran, straw	Fuel pellets [30], phenolic bio-oil and biochar [46], biofuel [28], [47].
Thermal insulation materials	Bran, straw, and husk	Thermal insulation biocomposite [32], clay bricks [48], mycelium-based composite [33], polyurethane foam [26].
Chemicals	Bran, straw, and husk	Silicon [27], hydrogen [7], organic acids – ferulic acid, lactic acid, itaconic acid and fumaric acid [28], [49], enzymes [28], protein [28], medicines and vitamins [28], cosmetics [28], single cell oil [12], antioxidant and antimicrobial extracts [50], xylanase [51], lignin [34], mesoporous biogenic silica nanoparticles [36].

MCDA method can be used to compare several options using different criteria. This method helps to process large amounts of information consistently [41]. In MCDA, the input data can be quantitative and qualitative [42]. The Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) was used to compare different products and determine the optimal option. Obtained result of the TOPSIS method is the distance of alternatives to an ideal point. Alternative with the shortest distance to the ideal point is the best. Calculations this study performed analyses using formulas and calculation steps. Study calculations were made in *MS Excel*. MCDA three steps:

1. Input data Regardless of the chosen MCDA method, input data is an essential part of the analysis, as all calculations are based on them. It is necessary to set criteria and alternatives [52]. Alternatives in our study are products that can be obtained from grain byproducts, and the criteria are from four categories: environmental, economic, technical, and social. The selected six criteria are shown in Table 2.
2. Weight of criteria. Criteria need a weight that reflects their importance compared to other criteria. The Analytical Hierarchy Process method can be used at this stage. The weights obtained in this method can be further used in all MCDA methods [52]. In our case, the weight of the criteria was obtained using Sensitivity Analysis. Sensitivity analysis can be performed to investigate the effect of criterion weights on alternatives [53]. The resulting weights are used in the TOPSIS calculations to obtain the results of the Sensitivity Analysis. This was done for all criteria, and based on the results, the criterion weights were selected for the final TOPSIS analysis.
3. Calculations of the TOPSIS method. The TOPSIS method was used after defining input data and the criteria weights.

TABLE 2. CRITERIA FOR MULTI-CRITERIA ANALYSIS

Criteria category	Criteria
Environmental aspects	Sustainability – compliance with the 12 UN Sustainability Goals (1–5)*
	Environmental impact – comparison of emissions from the production process for the new and existing product (1–5)*
Economic aspects	Product price comparison – the price difference between the product currently used and the new product (%)
	Market demand – global market size assessment (1–5)*
Technical aspects	Availability of technologies – assessment of the production of the new product, taking into account the level of technological readiness (TRL) (1–5)*
Social aspects	Social aspects – product job creation assessment (1–5)*

* The criterion is evaluated in a 5-point system: 1 – does not meet the requirements; 5 – meets the requirements.

As a result, the best alternative can be determined by comparing the relative proximity to the ideal solution.

3. RESULTS

The literature review summarised 30 products shown in Table 1. The studied products were obtained from four wheat byproducts – bran, straw, husk, and dust. Of these byproducts, bran is the most widely used, while dust is used to produce only one product, bio-based packaging [54]. This study divided the products into six groups: packaging materials, building materials, adsorbents, fuels, thermal insulation materials and chemicals.

From the reviewed products, seven products were selected for MCDA. The analysis aims to find the product with the most significant potential for commercialisation, considering environmental, social, economic, and technical aspects. Of all product groups, fuels and building materials weren't considered further, as these products don't have a relatively high added value. This study found that wheat bran is the most widely used raw material, so their products were examined in MCDA. For bran, nine publications were reviewed, summarising information for thirteen products. When evaluating the data available for these products, the products shown in Table 4 were selected for MCDA.

Table 3 shows the input data for MCDA. Except for the product price comparison, all criteria were assessed on a five-point scale based on aggregated data and expert judgment. As the products are novel, they have not yet been studied extensively, and in many cases, data were taken from similar products.

The TRL of the product was evaluated for the availability of technology. TRL was assessed based on expert opinion. If the TRL was four or less, it was given a score of 1 to 2; if the TRL was 5 or 6, it was 3 points; and if the TRL was 7 or 8, the product received 4 points [55].

TABLE 3. INPUT DATA OF MCDA

	Alternatives						
Criteria	Mycelium-based composite	Adsorbent	Bio-based PP composite	Bio-based film	Enzymes	Lactic acid	Single-cell oil
Availability of technologies	3	4	3	3	4	4	3
Sustainability	5	4	4	4	5	5	5
Product price comparison, %	92.5	92.6	14.2	0.01	50	32.6	37.9
Market demand	4	2	4	2	2	3	5
Environmental impact	4	5	3	2	3	4	5
Social aspects	5	4	5	5	3	3	4

The product's sustainability was assessed for compliance with the UN Sustainable Development Goals [13]. Using agricultural residues in higher value-added products aligns with at least three of the seventeen goals. If the product met all three goals, 5 points were given; if there were fewer goals, then correspondingly fewer points.

The possible prices of the products were compared with the products traditionally used and expressed as a percentage of the price difference. Using agricultural and industrial byproducts, the raw material cost of a mycelium-based biocomposite is 0.06–0.15 EUR kg^{-1} [56]. There are no data on total production costs, but the authors believe that raw materials make up the majority. Such material was compared to polystyrene, which costs between 1.85–2.02 EUR kg^{-1} [56]. The cost of commercial activated carbon is 5.85 EUR kg^{-1}, which is used as an adsorbent, while bioadsorbents cost is 0.05–0.43 EUR kg^{-1} which is significantly cheaper [29]. Biocomposite with PP was compared to a study where coriander fibres were used instead of wheat bran. For PP granules, adding 40 % coriander fibres reduced the price from 1.27 EUR kg^{-1} to 1.09 EUR kg^{-1} [57]. Food film with antioxidant properties as compared to PLA, a natural material made from fermented vegetable starch. In 2016, PLA film cost 2 EUR kg^{-1}, while low-density polyethylene (LDPE), a fossil-based plastic, cost 1.25–1.45

EUR kg^{-1} [58]. In our case, the product price would probably be lower because it would be obtained using low-cost residue. A rough price comparison for the production of enzymes showed that using wheat bran as a raw material would reduce the price by up to 50 % [28]. The price of lactic acid obtained from the brewery's spent grain is 0.76–1.11 EUR kg^{-1}, but lactic acid usually is 1.64 EUR kg^{-1} [59]. This could be like our lactic acid price because the study also used byproducts as raw materials. If single cell oil was produced using glucose at zero cost, assuming waste or byproduct streams, it would cost 2.99 EUR kg^{-1} at 10 000 tonnes per year. If the price of glucose is assumed to be 351.68 EUR t^{-1}, the cost of producing single-cell oil would be 4.82 EUR kg^{-1} [60]. In this case, the data is also based on assumptions because, in reality, wheat bran has an economic value.

Market demand was measured by the size of the global product market. The global biocomposite market was 18.44 billion EUR in 2020 [61]. In 2020, the global adsorbent market was 3.43 billion EUR [62]. The global bioplastics market was estimated at 5.1 billion EUR in 2020 [63]. The value of the global enzyme market in 2019 was 7.6 billion EUR [64]. The market for organic acids in 2021 was 9.69 billion EUR [65]. In this study [12], the authors believe that single-cell oil could be added to non-biofuel markets such as producing higher-quality fatty acid-based oleochemicals. In 2020, the global market for oleochemicals was 27.62 billion EUR [66]. As the base years of the data differ, experts' opinions were also taken into account. Demand in the market was expressed in a five-point system comparing product market volumes.

Environmental impact was assessed on a five-point basis, considering emissions from the product during production compared to products currently in use. The higher the emission savings, the higher the rating of the product. Collected data were incomplete, so experts were also involved in this criterion. The mycelium-based composite was compared to MycoBamboo, a material with bamboo particles and mycelium. Production of such a sample emits 86 gCO_2eq per plate but 27 gCO_2eq per plate if renewable energy is used instead of natural gas. Each sample of MycoBamboo weighed approximately 33 g [67]. The material could be compared to extruded polystyrene foam with a global warming potential of 13.22 $kgCO_2eq$ to 1.75 kg foam [68]. Using wheat bran fibre to produce biocomposite with PP can reduce emissions by 1470 $kgCO_2eq\ t^{-1}$ and create energy savings of 2130 MJ t^{-1} compared to pure PP material [11]. The food film was compared to a PLA film with emissions of 0.27 $kgCO_2eq\ (m^2)^{-1}$. The weight of the film is 0.6 kg per 10 m^2 [69]. PLA was compared with LDPE film with emissions of 0.11 $kgCO_2eq\ (m^2)^{-1}$ and a weight of 0.5 kg per 10 m^2 [69]. The reviewed studies also consider emissions from the extraction of raw materials, which could be lower for the products in our study because the raw materials are agricultural byproducts.

From a social point of view, the experts assessed the amount of labour involved in the product's production process. If the production of the product is automated and doesn't require a lot of work, then it was given 1–3 points because, in that case, the factory will not create a relatively large number of jobs. But if the production process isn't fairly automated, then 4–5 points were given because the factory would create new jobs that would improve the social situation in the country.

Criteria weights were determined using Sensitivity Analysis. The sensitivity analysis showed that the sustainability aspect has the lowest sensitivity to changes in weight, which can also be determined by looking at the input data, as all alternatives scored 4 to 5 points. Therefore, this criterion was given the lowest weight (0.05). The technical and social aspects also had a small weight change compared to the other criteria, so they were given a weight of 0.15. The environmental impact and market demand became more sensitive to changes in weight when the unitary variation ratio ranged from 0.5 to 1.5, so the importance given to those criteria is 0.2. The product prices comparison reacted the most to the change in weight, most likely because the input data differed more. After all, they were not expressed on a five-point scale. The sensitivity analysis results for this criterion are shown graphically in Fig. 2.

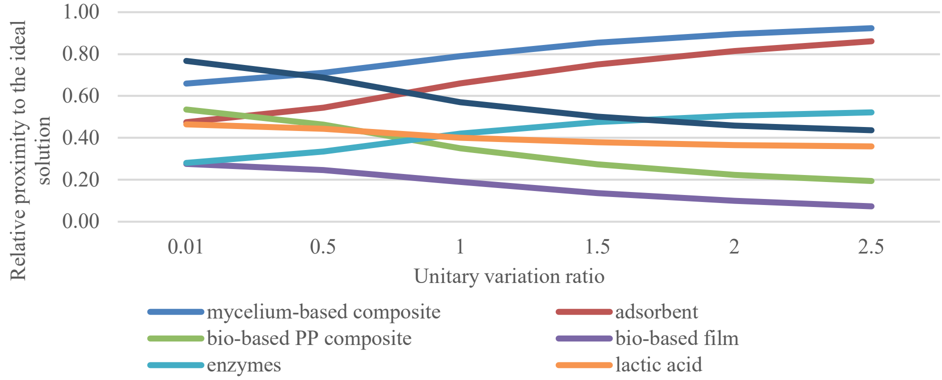

Fig. 2. Results of sensitivity analysis for product price comparison.

All criteria weights are shown in Fig. 3.

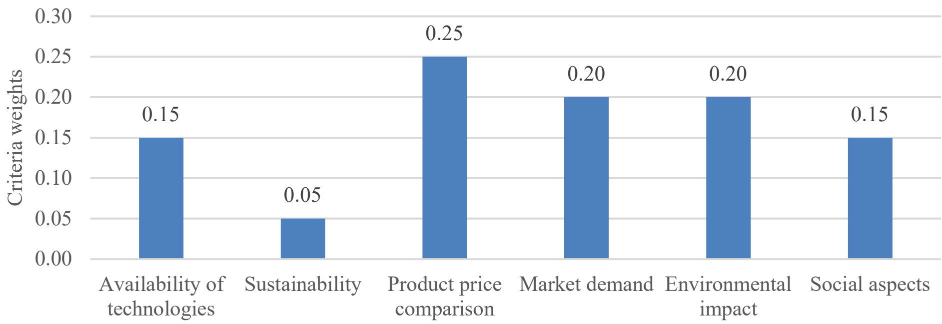

Fig. 3. Weight of criteria in TOPSIS.

TOPSIS calculations were made using the input data and the obtained criterion weights. Obtained results are shown graphically in Fig. 4. The results showed that the highest relative proximity to the ideal solution of the analysed products is for mycelium-based biocomposite material. This has been mainly due to the relatively high difference in product prices. Had this criterion not been considered, single cell oil would have gotten the highest result, which can also be assessed by looking at the input data. The adsorbent also has relatively good results, as its price and environmental impact are much lower than those currently used adsorbents. The worst result got the food film with antioxidant properties. This is because data for this product were used from PLA parameters, and PLA was compared with LDPE, which currently has lower production emissions and prices than bioplastics. Also, bioplastics have smaller market demand, which needs to be improved. However, the data was not taken specifically for our product. Product parameters are better because they are obtained from bran and not maise, with different extraction characteristics, such as water consumption and yield [69].

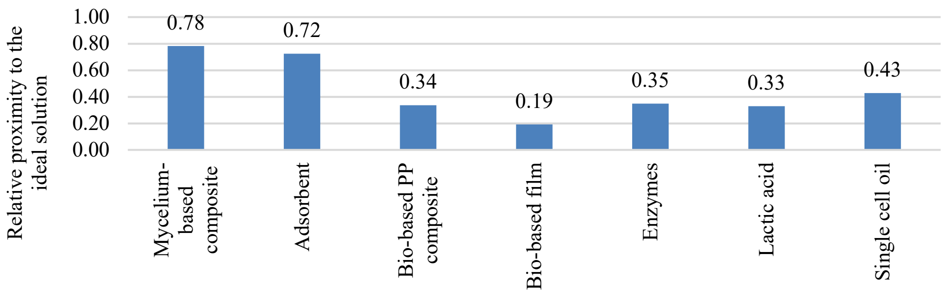

Fig. 4. Results from TOPSIS.

4. Conclusions

Traditionally, grain byproducts are disposed of as waste or added to livestock feed. Therefore, several studies have been conducted to find better applications that provide higher added value. Byproducts such as grain screenings, husk, bran, germ, dust, and straw are generated during cereal production's cultivation, harvesting, and processing stages. This study gathered information on the potential use of grain byproducts in developing new products. It conducted MCDA to find the most suitable commercial product from wheat bran.

In the literature review, we identified 30 products that can be obtained using wheat bran, straw, husk, and dust. The studied products are classified into six groups – packaging materials, building materials, adsorbents, fuel, thermal insulation materials, and chemicals. Most products were obtained using bran, so seven bran products were selected for further analysis.

Six criteria from environmental, economic, technical, and social aspects were selected for MCDA. The analysis showed that the best alternative to move towards implementation is a mycelium-based biocomposite material (0.78). Its price (0.25) and environmental impact (0.20) are lower than the current thermal insulation materials. It is in demand on the market and would contribute to sustainable development.

As the input data for MCDA were based on many assumptions, it is necessary to perform an environmental and economic evaluation study for the mycelium-based composite material before it is commercialised. The study only compared bran products, so straw and husk pr products could be reached in future studies.

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An Analysis of the Extraction Technologies: Fruit Peel Waste

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Abstract **– Advances in technology over the past few years have allowed us to evolve from waste to value. Food waste has been an increased recognition that more attention needs to be paid to this area. With this concern, research on fruit waste valorization into medicinal products has a rich background. This paper approaches the problem with a broader perspective by introducing the fruit waste valorization pathway. The key idea in this paper is to use the multi-criteria analysis method to choose the best essential oil extraction technique from fruit waste. The performance of four different extraction methods i.e., steam distillation, cold-pressing, solvent extraction, and hydro distillation compared in the approach, considering the environmental, economic, social, and technical criteria. The methodology was developed with two scenarios, by using the Analytic hierarchy process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods. Our research highlighted that cold-pressing extraction is the most effective technique for essential oil extraction in both scenarios.**

Keywords **– Bioresources; medicinal use; multi-criteria analysis; valorization pathway**

1. INTRODUCTION

With the worldwide increasing population, production and cultivation of fruits and vegetables is also increasing. Besides, food waste has long-lasting footprints in terms of landfills and socio-economic impacts due to the higher moisture and biodegradability [1]. Therefore, food waste management is becoming a major concern over the world but with advanced technology, food waste can be a versatile environmental bioresource that can be converted to biofuel, value-added products, and biomaterial [2].

This research particularly focuses on the fruit waste valorization pathways because enormous studies have been done on the conversion of fruit waste into landfills, anaerobic digestion, composting, etc. [3]. Pfaltzgraff *et al.* argue that fruit waste is not only a wide source of energy but also has incredible ability to produce industrial products such as essential oil, medicines, cosmetics, organic amendment, etc. [4]. Each part of a fruit, for example, peel, pulp, and seed have a unique residual and chemical composition that can be used to produce various organic products.

Traditionally, fruit peels are the most common waste that can be easily found in the environment. Fruit peels have the best medicinal properties such as antimicrobial, antioxidant, anti-inflammatory, anti-healing, anti-infectious, anti-mutagenic, and hepatoprotective. Essential oil is one of the crucial extractions from fruit peels, researchers have been discovered after several experiments that essential oil has antimicrobial activity

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against bacteria, moulds, yeasts, pathogenic and phytopathogenic microorganisms. As a result, it has been proven that essential oil can be used to confront the microorganisms to the antibiotics [5]. To support the current research some of the examples are mentioned in Table 1.

TABLE 1. FRUIT WASTE INTO MEDICINAL USE

Fruit waste	Value-added product	Medicinal use	Methods	Reference
Banana peel	Essential oil	Antioxidant property	Extraction	[5]
Citrus peel	Essential oil	Alleviates pain Relieves inflammation Dissolve's gallstones	Extraction	[6]
Orange peel	Essential oil	Antimicrobial activity Flavoring agent of medicine	Steam distillation Cold pressing Solvent extraction Enfleurage	[5], [7]
Mango peel	Pectin	Health benefits	Extraction	[8]
Grapefruit peel	Essential oil	Antibacterial and Antioxidant properties Biopesticide against mosquito larvae	Paper disc diffusion	[9]

One of the essential components that can be derived from fruit peel (apple pomace, citrus, sugar beet pulp) is pectin. Earlier research shows that pectin is an effective component at the industrial level and also useful in the medical treatment of cancer, cell apoptosis, and cholesterol [10]. Several studies have discovered that fruit peel waste has a potential application to medicinal products.

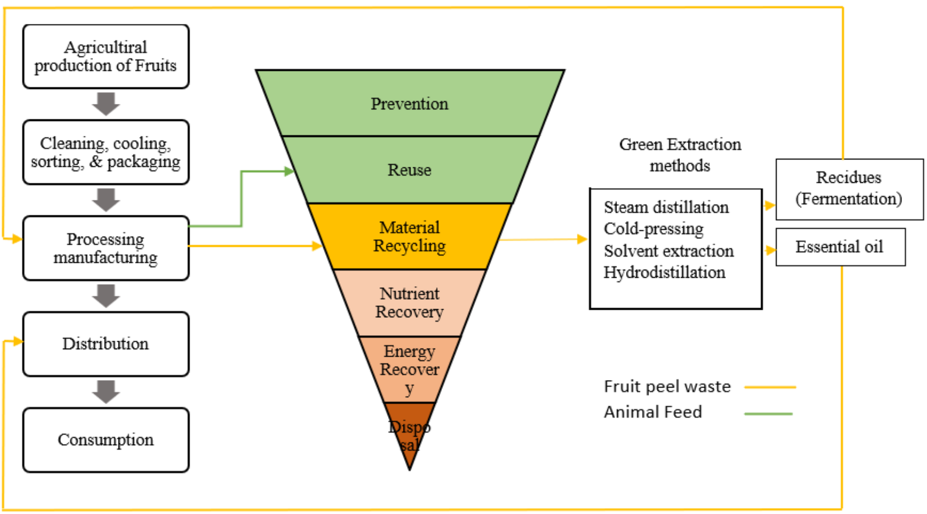

Fig. 1. Essential oil extraction pathway.

Essential oils term is also referred to as volatile oils, ethereal oils, or aethrolea, which contain the essence of a plant fragrance. It is a concentrated hydrophobic liquid, naturally derived from plants [11]. A recent systematic review investigated the extensive use of essential oil in the cosmetic industry, daily life due to the fragrance [12], and pharmaceutical industry [13], which shows the increasing demand for essential oil in the market. A variety of methods can be reliably utilized for extraction. Fig. 1 shows the clear vision of the extraction pathway of essential oil from fruit waste. Here, we presented the essential oil extraction from the fruit peel waste. In the next chapter, a multi-criteria analysis is performed to choose the best extraction technology.

2. METHODOLOGY

The methodology consists of literature review, then it further goes with multiple-criteria decision analysis (MCDA), using Analytic hierarchy process (AHP) with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), after receiving results, which need to be analysed, conclusions should be drawn.

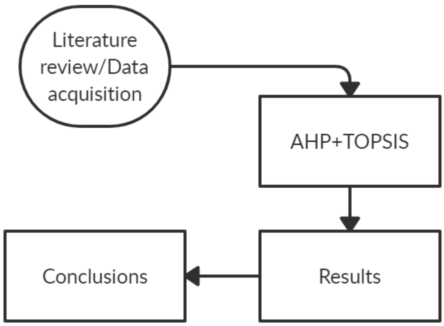

Fig. 2. Research methodology.

MCDA is used to make decisions and analyse the significance of objectives from various types of information and data – qualitative and quantitative data, data from the physical and social sciences, and from politics and ethics to evaluate problem solutions.

TABLE 2. SCALE FOR PAIRWISE COMPARISON

Scale	Definition
1	Equally importance
2	Equally to moderate importance
3	Moderately importance
4	Moderately to strongly the importance
5	Strongly importance
6	Strongly to very strongly importance
7	Very strongly importance
8	Very to extremely strongly the importance
9	Extremely importance

The next step is to identify the criteria weights using AHP. AHP method divides and analyses problems in a hierarchical structure consisting of a goal, a criterion, and a sub-criterion. The AHP methodology was developed in 1980 by Saaty, and the selected criteria are compared in pairs by experts [14]. Researchers from the Institute of Energy Systems and Environment at Riga Technical University are the experts to define the selected criteria for pairwise comparison. Table 2 provides the scale for pairwise comparison adapted from Saaty Thomas L.

The comparison matrix comprises criteria, where each criterion is compared with all other criteria. The next step is to solve the problem of eigenvectors by which the criteria will be arranged. The sum of each column of the pairwise comparison matrix is then calculated and used to divide the corresponding column values, thus normalizing the comparison matrix. The values of each row are then summed and divided by the number of criteria to calculate the eigenvector for each row of the matrix. Eigenvectors indicate the ranking (weight) of the criteria. AHP methodology can be implemented in three main steps. Each step needs to be performed to be resolved in a decision-making matrix with AHP is described below.

- Step 1: Define the objective, selected criteria, and alternatives;
- Step 2: Here, elements can be compared to one another, two at a time, concerning their importance on an element above them in the hierarchy and then structured the comparison matrix;
- Step 3: Geometric mean is used to combined questionnaires for all experts and based on the combined questionnaire the problem is solved;
- Step 4: Weights for pairwise comparisons are calculated;
- Step 5: After calculating weights, decision matrixes are formed;
- Step 6: Final weights of alternatives obtain by multiplying decision matrixes from alternatives toward criteria;
- Step 7: Weights obtained in the last step are raw and need to be normalized to be easily comparable;
- Step 8: Inconsistency and weights of pairwise comparisons are calculated. Consistency Index (*CI*) is calculated by Eq. (1) proceeded by Consistency Ratio (*CR*) in Eq. (2).

$$CI = \frac{\lambda_{max} - n}{n - 1}, \tag{1}$$

where λ_{max} – maximum eigenvalue;

$$CR = \frac{CI}{RI}, \tag{2}$$

where *RI* – Random Index that varies for different matrix.

The next step in the methodology is to use the TOPSIS method. TOPSIS is a popular MCDA developed by Hwang and Yoon in 1981. The method uses the best alternative and worst alternative to define the best alternative [15]. TOPSIS method has been used to compare the possible use of production residues in producing value-added products, such as single-cell oil, from different factories, described in Racko E. *et al.* [16]. The main advantages of TOPSIS are the opportunity of an infinite number of criteria and alternatives, a comparatively simple calculation method, and no need for specific software or specific programming techniques. TOPSIS results provide comparing alternatives in a useful and simply comprehensible form. There should be selected alternatives for the evaluation, which are evaluated by four criteria: technological, economic, environmental, and social. The first step using the TOPSIS method is the normalization of the decision-matrix, followed by calculating the normalized decision-matrix and the best and worst solutions. The best solution corresponds to a theoretical option of the most desirable level of each criterion, while the worst solution corresponds to a theoretical option of the least desirable level of each criterion. Finally, the distance of each alternative is calculated that further allows obtaining the closeness coefficient for the ranking alternatives. Alternatives rank from best to worst [17], in detailed equations for the TOPSIS method that is used in this study are described below.

Step 1: Normalized matrix value can be derived by multiplication of normalized value and weight which is done by following Eq. (3).

$$v_{ai} = w_i \cdot r_{ia}\,, \tag{3}$$

where

v_{ai} Weighted value;

w_i Weight, $w_{i1} + w_{i2} + ... + w_{im} = 1$, $w_i = 1...m$;

r_{ia} Normalized criterion value.

Step 2: Distance for each ideal and non-ideal alternative can be calculated by the sum of the squares of weighted criterion values. The calculation can be done by following Eq. (4). and Eq. (5).

$$d_a^+ = \sqrt{\sum_{j=1}^{n} (v_i^+ - v_{ai})^2}\,, \tag{4}$$

where

d^+_a Distance for each action to the ideal solution;

v^+_i Ideal solution.

$$d_a^- = \sqrt{\sum_{j=1}^{n} (v_i^- - v_{ai})^2}\,, \tag{5}$$

where

d^-_a Distance for each action to the non-ideal solution;

v^-_i Non-ideal solution.

Step 3: Closeness coefficient (Ca) shows the distance to the non-ideal solution, which is determined by Eq. (6).

$$C_a = \frac{d_a^-}{d_a^+ + d_a^-}\,, \tag{6}$$

where

$d^+_a + d^-_a$ Sum of the distance to the non-ideal solution;

d^-_a Distance to the non-ideal solution.

Our approach is to analyse the best extraction method to extract the essential oil from the fruit waste by using multi-criteria analysis.

TABLE 3. OVERVIEW OF THE SELECTED CRITERION

Extraction methods	Technical aspect	Environmental aspect	Economical aspect	Source
Steam distillation	Pressurized container required	Less fuel & High temperature required	High equipment & operating cost	[18]
Cold pressing	High-quality production possibility	Lack of hazardous organic solvent & environmentally friendly	Low cost & less manpower required	[19]
Solvent extraction	Simple equipment used, Low efficiency	High temperature & production of hazardous waste	Low cost	[19]
Hydro distillation	Simple instrumentation	High consumption of energy, no organic solvent	Low cost	[20]

Here we compare the performance of four different green extraction methods like steam distillation, cold-pressing, solvent extraction, and hydrodistillation. The selection of the criterion i.e., technical, environmental, economic, and social acceptability is based on the vast literature analysis. Table 3 shows the detailed overview of the selected criteria and sub-criteria. These techniques are used in the evaluation to extract the essential oil from the fruit waste. Steam distillation is a separation technique, can be applied for the separation of volatile organic compounds [21]. Earlier studies show that 93 % of the proportion of essential oil can be extracted by steam distillation [22]. The cold-pressing method is the standard technique used to extract essential oil from the seeds of plants and fruits. Also, this process can be done at a low temperature below 60 °C [23]. The solvent extraction method is also known as liquid-liquid extraction, is a method to separate compounds based on the solubility of their parts [24]. Hydro distillation is a traditional method used to extract oil or bioactive compounds from plants [25]. Overall, comparatively all four methods have different functionality and apparatus.

3. RESULTS

The author compared technological, economic, environmental, and social criteria pairwise. Results of the pairwise comparison of AHP are shown in Table 4.

TABLE 4. AHP PAIRWISE COMPARISON MATRIX OF CRITERIA

Criteria	Technological	Economical	Environmental	Social
Technological	1	3	2	4
Economical	0.33	1	2	3
Environmental	0.5	0.5	1	4
Social	0.25	0.33	0.25	1

The authors calculated the weights of the criteria after the normalization of the matrix. The results show that the weight of the technological criterion is the most important – 0.45, then as the second most crucial weight is economical – 0.25, then the third and fourth criteria are environmental and social, which – 0.22 and 0.08, respectively.

The comparisons are consistent and used in the following calculations, considering that the value of the consistency rate is *CR* = 0.079. If the *CR* is less than or equal to 0.1, then the discrepancy is acceptable, but the subjective assessment must be reconsidered if it is higher than 0.1.

TABLE 5. TOPSIS DECISION-MAKING MATRIX

Alternative technologies	**Criteria**			
	Technological	Economical	Environmental	Social
Steam distillation	4	4	3	4
Cold-pressing	4	5	4	3
Solvent extraction	3	3	3	4
Hydrodistillation	3	3	4	4

The potential for using the four technologies was rated on a scale from 1, which corresponds to the lowest rating, to 5, which corresponds to the highest rating. Table 5 are shown the evaluation values in a decision-making matrix.

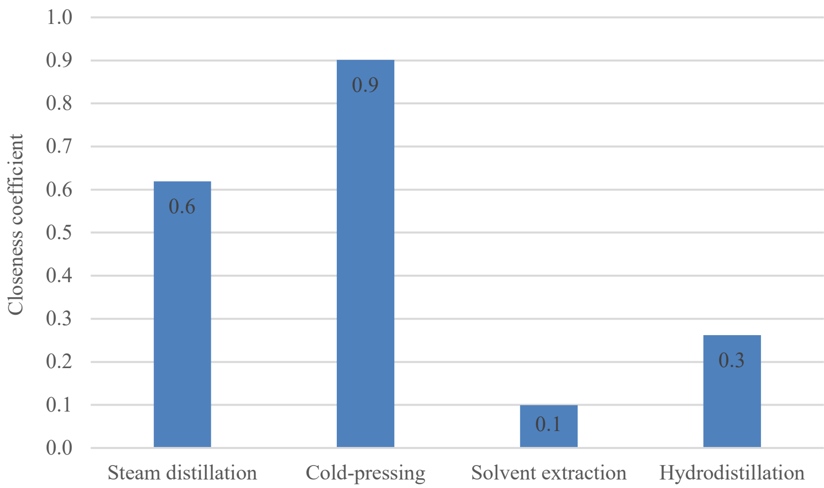

Fig. 3. TOPSIS ranking technologies results.

The TOPSIS analysis results are shown in Fig. 3. Cold pressing (0.9) is the closest alternative for the best solution, not only for the technological criterion that has the highest weight of all criteria (0.45) and good performance in the economical criterion with the second-highest impact on results. Steam distillation ranks as the second technology, with evaluation 0.6, and as a third possible technological solution is hydrodistillation with 0.3, and solvent extraction – 0.1.

4. DISCUSSION

According to the report on the global food waste scenario [26], awareness of food waste has grown. The current research has been made to solve the global problem to some extent. Fruit waste is one of the important areas that need to be focused on. Therefore, this study contributes to minimizing the waste scenario by developing an essential oil extraction pathway from fruit peel waste. The study highlights the use of Multi-Criteria Analysis methods to choose the best extraction technology. By analysing the results, it has been found that in both methodologies AHP and TOPSIS, a cold-pressing method is the best essential oil extraction method.

Several studies have been done on essential oil extraction techniques [22], but our approach provides environmental sustainability by comparing the environmental performances of different alternatives, which leads to the green extraction techniques

However, the MCA methodology requires potential numerical data to perform an analysis. The significant limitation was the lack of quantitative data for the evaluation that cannot negotiate. Therefore, this study suggests that more scientific and laboratory research work is required for more accurate results and to diversify the valorization options.

5. CONCLUSION

The main conclusions of this research are drone together and presented in this section. This research aims to determine an approach for the fruit waste valorization pathway and find the best extraction technique. Firstly, a vast literature analysis was performed to identify the essential oil extraction pathway from fruit waste in a more sustainable way. Secondly, Multi-criteria analysis was performed to find the best extraction technique considering the technical, environmental, economic & social aspects.

Within this research, the publicly available data of existing essential oil extraction pathways were studied, and based on that fruit waste valorization pathway was created. Furthermore, to ensure the extraction technique multi-criteria analysis followed by AHP and TOPSIS was successfully performed.

The outcome of the research leads to the conclusion that essential oil is the most crucial and multi-functional product, which can be extracted by the cold-pressing technique. AHP method is used to evaluate the weight of the criterion, which shows that the most effective criteria are the technical criteria. Based on the AHP weight TOPSIS was performed for further evaluation, which shows that the cold-pressing method is the most suitable technique for the extraction. Overall, fruit waste valorization and various alternative techniques considering the various aspects can be evaluated by the Multi-criteria analysis. This research concludes that the new innovative bioresource valorization pathways can be created and evaluated by Multi-criteria analysis.

ACKNOWLEDGEMENT

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Aggregator as a new electricity market player

(Case study of Latvia)

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***Abstract*—The research focuses on evaluating the chances of a new electricity market player – aggregator – to come into Latvian electricity market in the nearest future. Electricity market in Latvia has been liberalized since 2015 and there is a wide range of electricity suppliers competing on market basis. It is important to understand, what role could an aggregator play in this market, will it be accepted by other market participants and does it have any chances to survive in a rather small economy with much lower number of electricity consumers than in many other European Union's countries that are currently working on implementing the European Union's legislation that would allow for aggregators to operate in the electricity market.**

Keywords— demand response, aggregator, electricity market, flexibility

I. Introduction

Nowadays we are living in a world, where the society, governments and other institutional players are looking for ways of achieving climate neutrality in the global economy. There are the usual ways – energy efficiency in buildings, innovative technical solutions for cleaner manufacturing, ecologically friendly cars and many more possibilities of which the population has become more or less familiar in the last decade. Meanwhile, there are also sector specific solutions that are less common and under-utilized. The aim of this research is to look at one specific solution, which has not yet developed in Latvia at all – aggregator – an electricity market player that has been defined at the European Union's level already for some time, but a player, who has been rather incomprehensible for the Latvian electricity market. This research focuses on the legislative and economic aspects of the aggregators in order to understand, how to introduce them in the Latvian electricity market and what kind of benefit would it give.

To understand the role of an aggregator, it is important to start with the concept of demand response. Demand-side response could be described as changes in the usual pattern of electricity consumption by the final consumer. [1] When a consumer decides on its own to use less electricity when it is more expensive (e.g. in the peak hours) and use it more when it is cheaper (e.g. at night) it becomes demand response, i.e., final consumers (demand-side) responds to the market incentives. There are two pre-conditions:

- Consumer must have a dynamic electricity price agreement with its' electricity supplier;
- Consumer must have a smart electricity meter installed.

A dynamic electricity price agreement with the electricity supplier means that the consumer pays for the electricity the real-time power exchange market's tariff. There will be a risk of high electricity price fluctuations, but it can also become very advantageous for the consumer in a longer low-price period. [2]

The smart meter in comparison to conventional meter shows the real-time electricity consumption and can be paired with the hourly electricity price in the power exchange market. Thus, the electricity consumers can follow the electricity price fluctuations and adapt their electricity consumption in order to save money.

It should be noted that demand-response has been defined in European Union's (EU) legislation already since 2012, when it was introduced by Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. With Directive 2012/27/EU, the Member states of the EU where required to encourage the development of demand response and to create the necessary legal framework for that. [3]

It is important to also understand the reasons, why demand response is promoted at the EU level. Though one of the reasons is the empowerment of consumers, there is also a more general necessity for a better functioning of the electricity market as the demand response can provide the so-called flexibility. More and more electricity globally is produced by variable renewable energy sources such as hydro, wind, solar power etc. The electricity production is very dependent on the weather conditions, so either there needs to be other flexible generation options that can be turned-on when the weather condition are unfavorable for adequate electricity production from variable renewable energy sources or the demand side should become flexible in its demand. [4][2]

II. Methodology

The case study is based on researching the legal and economic aspects of demand response and aggregation, and applying them to the situation in Latvia.

As has been noted in a research by J.K. Juffermans [5], it's hard to predict how much of the conventional generation will be able to aid in providing flexibility in the future,

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because it can be thoroughly based on political decisions on whether these conventional generation units will continue to operate (e.g. cogeneration plants from natural gas). Thus, a bigger role will be played by demand side response.

For the purpose of flexibility, demand response cannot be based on unpredictable actions of consumers, because these are not organized actions but based on personal interests of each individual. To make it organized (also known as explicit demand response), a new electricity market player has been introduced – an aggregator. As defined in the new Directive 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU, an aggregator "combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market". Article 17 further elaborates that:

- all markets (day-ahead, intraday) should be open to demand response, including ancillary services (balancing, reserves etc.);
- any electricity undertakings or consumers may be required to pay compensation to those market participants who are directly affected by demand response;
- compensation, if introduced, shall not be a barrier to demand response and shall only cover the costs incurred by the suppliers or supplier's balance responsible party.[6]

There are two types of aggregators – independent and combined. Combined aggregator means that an electricity supplier or balance responsible party or distribution system operator is also an aggregator, so aggregation is an additional function of an already existing market player. An independent aggregator on the other hand is a separate undertaking working independently from the previously mentioned electricity suppliers, balance responsible parties or system operators. Currently, more common in the EU is the combined aggregator, because it is easier to involve it in the market. It's not only less complex from the legislative perspective, but also from the perspective of the electricity consumers in cases, where the aggregator is the consumer's electricity supplier. [7]

At the same time, authors can argue that an aggregator can be seen as a threat from other market participants such as electricity suppliers. In view of the authors, demand response can be seen as a cost for retailers, because:

- Electricity retailers (balance responsible parties) buy this virtual electricity in the power exhchange market provided by aggregators. It's not actual electricity, but an electricity saving at a particular time. Retailers (balance responsible parties) buy this electricity to fullfill the demand but they cannot bill it to consumers.
- Demand response contributes to physical balancing of electricity market, but it is seen as a financial imbalance by retailers.

Fig.1. reflects all the flexibility mechanisms provided by the agreggators at different wholesale market segments, where aggregator can act as a facilitator for providing flexibility where needed. [8]

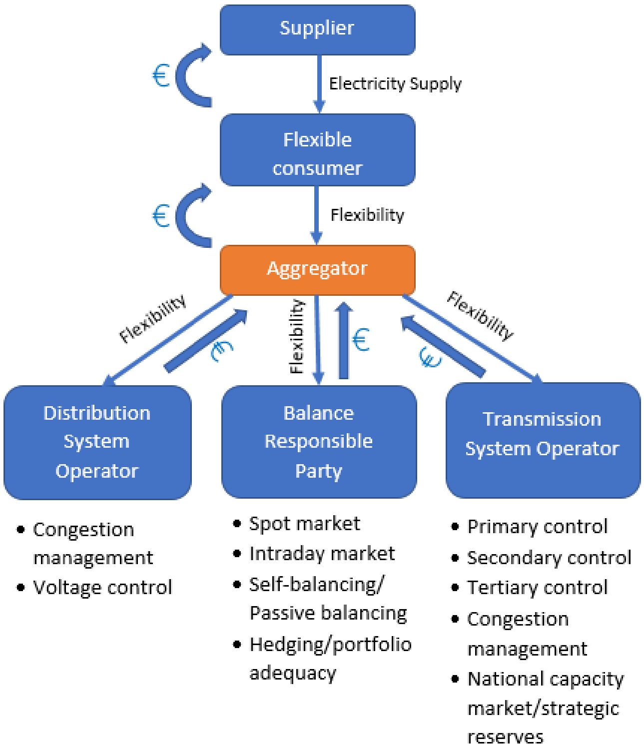

Fig.1. Flexibility services provided by aggregator [8]

There are 6 types of demand-side's electricity consumption management, which are shown in Fig.2. These different types of demand side management, which can be combined all together, allow us to very closely relate to generation. [9]

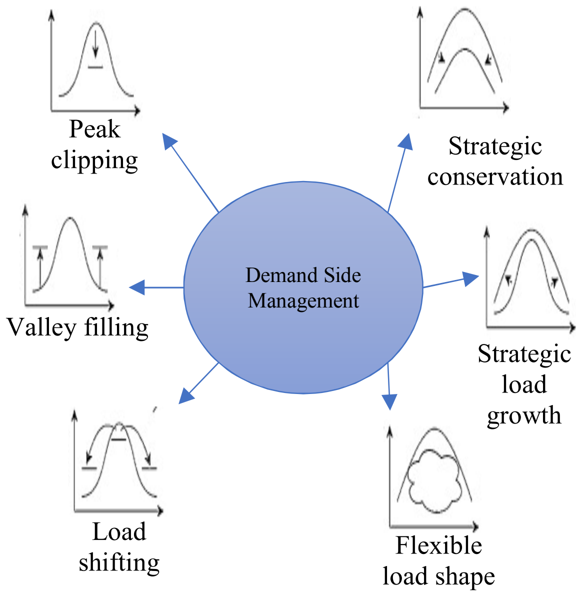

Fig. 2 Types of demand side management [9]

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In growing demand of electricity, this can replace part of the generation that will be needed to fulfil this future demand. These demand side management types show us all the options an aggregator can use – it's not only load shifting to another period of time, but also decrease in electricity consumption in general by using the consumer's appliances more efficiently and thus providing benefits also for the EU's climate policy and climate targets. [9]

III. Case Study

In case of Latvia, most of the local electricity is produced in hydro power plants, where the main three power plants on Daugava river have the capacity of 1558 MW. [10] However, in dry years, the electricity sector is partly dependent on cogeneration from natural gas in two thermal power stations in the city of Riga with the total capacity of 976 MW. Currently, these cogeneration plants generate electricity when the electricity prices in Nord Pool power exchange are high, but they can't compete with cheap electricity and they are subsidized from the state and basically serve for the purpose of security of supply. [10][11] Thus, demands side response with the involvement of aggregation can be a valuable alternative.

Fig.3 shows that as mentioned before, the share of renewable energy in electricity is increasing also in Latvia, this increase is rather persistent for the last 10 years. With this increase, new mechanisms for flexibility in electricity demand are necessary considering the volatile nature of renewable energy sources. As has been mentioned above, when the renewable energy sources fail to provide balance in the electricity system (due to the weather, which impacts the amount of electricity that can be produced by the main renewable energy sources – hydro, wind and sun), aggregators can provide the necessary flexibility (by lowering, shifting or using other previously mentioned demand side management types to change electricity demand) and ensure balance in the electricity system. [12]

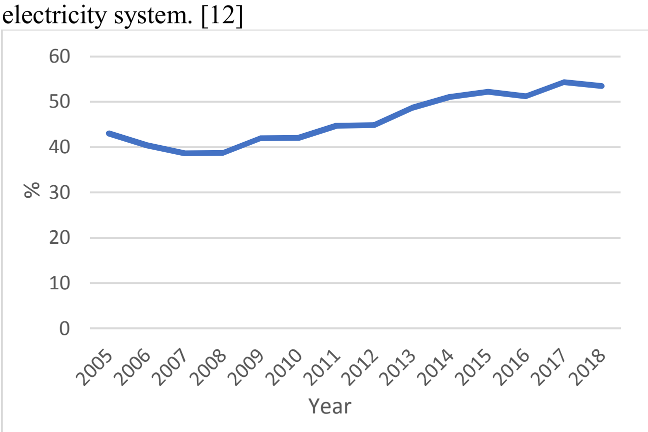

Fig.3. Share of renewable energy in electricity, % [13]

As was explained above, an aggregator should be able to participate in all types of electricity markets. Currently aggregators mostly participate in the balancing market by becoming balancing service provider (BSP). Meanwhile, each electricity supplier has its balancing responsible party (BRP). BRP is responsible for submitting energy generation and consumption schedules to the transmission system operator on the day before electricity delivery. On the other hand, BSP (in this case aggregator) submits balancing service bids to the system operator, who will procure this service. When BRP deviates from the submitted electricity generation and consumption schedule, BSP will activate balancing energy to ensure balance in the electricity system. System operator will pay BSP for its service and allocate these costs to BRP, who will have to pay for the created imbalance. [14]

In the beginning of 2020, following the requirements of the above-mentioned Directive 2012/27/EU, the Cabinet of Ministers of Latvia approved the first rules on the functioning of aggregators in Latvia. [15]

The regulation defines the rights and obligations of aggregators, payments for the services provided by aggregators, as well as define relations between the aggregators and other electricity market's participants. The rules increase the ability of electricity consumers or third parties of their choice to handle electricity consumption information in order to provide a mechanism by which consumption can be adjusted quickly.

Latvian legislation sets that an aggregator is a new type of energy service provider that can increase or decrease the electricity consumption of a group of consumers according to the total electricity demand in the network, thus allowing the consumption to become flexible. It is important to mention that the consumer may be remunerated for participating in the provision of a demand response service. An aggregator may enter into a contract with several customers, on the basis of which it may temporarily reduce their electricity consumption if there is a high demand for electricity. The aggregator then sells this saved electricity to the electricity market. An aggregator can also do the opposite and can increase electricity consumer consumption when electricity prices are favorable. [15]

Fig.4 shows hourly electricity price in the Nordpool power exchange's Latvian price area on 3 August 2020. As can be seen in the figure, the lowest electricity prices are at night between 12 AM and 4 AM, while the highest prices are in the morning hours before work, as well as after the typical working hours at 7 PM.

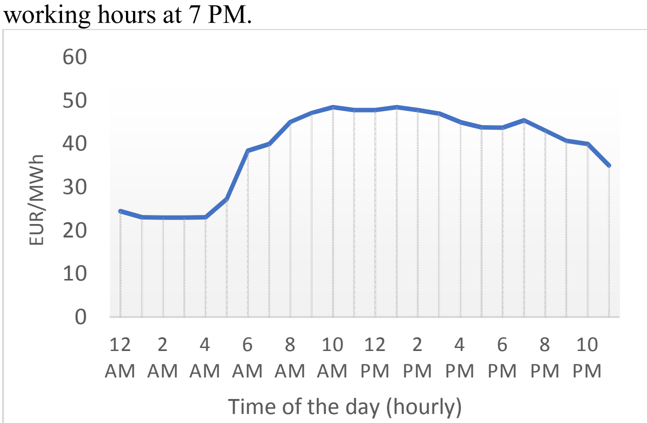

Fig.4. Hourly EUR/MWh in NordPool Latvian price area, 3 August 2020 [16]

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To authors minds we could distinguish between two different approaches to aggregation – household aggregation and aggregation in manufacturing sector. Household sector means that the aggregated electricity amount is much smaller. An aggregator working with households would need to have a large portfolio of households to make an impact and to have a profitable business. As has been explained to authors in an informal interview by an entrepreneur from France working in the field of aggregation and having a pilot project in Estonia, aggregators in households focus on such household appliances as electric heaters, boilers, heat pumps, air-conditioners and thermostats. These can be easily controlled by distance and without disturbing the daily life of consumers, who would not feel discomfort due to limitations in electricity usage. However, as explained by the above-mentioned entrepreneur, the aggregator needs to have at least 10 000 consumers, who save 5 kWh a day to make it a profitable business. For instance, general review of online offers for electrical appliances provides that on average a central air conditioner/heat pump consumes around 5 - 15 kW per hour, so reduction of electricity consumption by 5 kWh a day is actually not so much considering that part of the amount of electricity would still be consumed but at different time of day, when the electricity prices are lower. For example, Fig.5 shows the demand of electricity in Latvia on 3 August 2020. The red line is the actual demand, but the blue line has been drawn by the authors to show how could an aggregator level out the demand in peak hours by shifting it to different time of day.

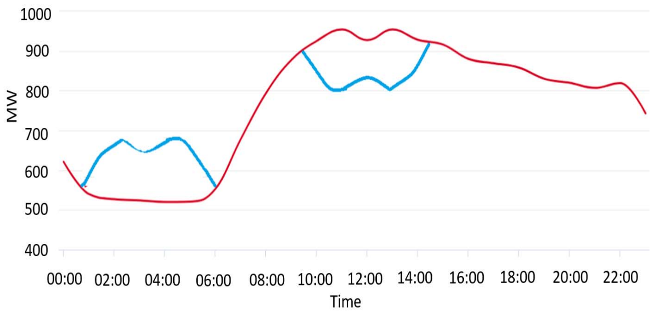

Fig.5. Electricity consumption MWh/hour in Latvia on 3 August 2020 [17]

For example, the state-owned electricity supplier JSC "Latvenergo" has around 700 000 household electricity clients [18], so creating a portfolio of 10 000 consumers that would be ready to engage in the activities of demand response would not be impossible. Moreover, a combined aggregator does not even need so many consumers, because there would be a loop between the aggregator and the electricity supplier, where the income created by an aggregator in substance stays with the same undertaking (the supplier) and thus no actual costs would emerge for the supplier. The second biggest electricity supplier in Latvia JSC "Enefit" has almost 6000 household electricity clients [19], thus also providing an already existing large client basis, where part of them could engage in demand-response.

If an aggregator has aggregation agreements with 10 000 consumer that reduces at least 1 kWh daily (not 5 kWh, because most of the aggregated amount is shifted to another timer period and not reduced), these are 10 MWh a day or 3650 MWh per year by rough calculations. Latvia's yearly consumption of electricity is around 7 TWh. This means that an aggregator could be capable of reducing the yearly electricity consumption in Latvia by at least 0.05%. This may not seem much, but for one aggregator it is not a bad result and would also serve as means for achieving national energy and climate targets. [20]

However, considering the necessary amount of clients needed for the business of aggregators to be profitable, it does not seem realistic for the time-being for an independent aggregator to come in the market unless this is an international investor coming with its business from another EU country, which already has a large market portfolio. This option of combined aggregator is not only the main possibility currently from the economic perspective that can be advantageous for both aggregator and supplier, but also the only technical possibility. The current national legislation does not allow for an independent aggregator to come into the market because there is a requirement for the aggregator to be associated with the same balancing service provider as the consumer's object which is intended to be used in the demand response service. And this balancing service provider should give authorization for aggregation. [15] Basically, it means that the aggregator needs to coordinate its actions with consumer's electricity supplier, which is also the balance responsible party. Thus, if the consumer's supplier disagrees, aggregator cannot participate in aggregation. However, this is not in accordance with the previously mentioned Directive 2019/944, which provides that neither the consumer, nor the independet aggregator has to coordinate their mutual agreement and the use of the demand response with electricity supplier and/or its balancing service provider. The provisions of Directive 2019/944 have to be implemented by 31 December 2020, so it shall change in the nearest time.

The ammended national regulation shall enable aggregators to participate not only in the balancing market, but in intra-day and day-ahead markets as well and the EU legal framework allows member states to introduce a compensation mechanism for suppliers. The question is, how to set a fair compensation, so that the supplier is not pushed in a disadvantageous position by aggregators.

TABLE 1. ECONOMIC ASPECTS OF AGGREGATION

A. No demand response	B. Demand response without compensation
1. Supplier forecasts consumption of 20 MWh	1. Supplier forecasts consumption of 20 MWh
2. Supplier buys on NordPool 20 MWh electricity x 50 EUR/MWh = 1000 EUR	2. Supplier buys on NordPool 20 MWh electricity x 50 EUR/MWh = 1000 EUR
3. Supplier sells 20 MWh electricity to consumers for 50 EUR/MWh = 1000 EUR	3. Aggregator activates demand response and reduces consumers' consumption by 2 MWh

	4. Supplier sells 18 MWh electricity to consumers for 50 EUR/MWh = 900 EUR
	5. Supplier loses 100 EUR (2 MWh x 50 EUR/MWh) due to demand response

Table 1 shows a hypothetic example of the economic aspects of aggregation. Scenario A have the usual circumstances – supplier buys the forecasted amount of electricity from Nordpool power exchange and supplies it to consumers. Scenario B however introduces demand response. Supplier forecasts the same amount of consumption and buys on Nordpool power exchange the amount of electricity that would normally be necessary for consumers. However, due to agreement with aggregator, consumers eventually consume less than it was forecasted. So, supplier has bought 20 MWh, but it can sell only 18 MWh, in result the supplier has lost 100 EUR. This is approximately the same amount that the aggregator will gain (assuming the aggregator has also sold his aggregation services by 50 EUR/MWh x 2 MWh = 100 EUR). While understanding the situation of supplier, if we asked the aggregator to compensate the losses, there would basically be no business case for the aggregator.

However, here is another option that can be considered fair. It has been observed by some studies, that when aggregator provides its services to the electricity market, the overall electricity price in the Nordpool power exchange lowers, because the more expensive generation units are excluded from bidding. [8] As a result, the supplier gains because he has paid less for the 20 MWh than he would have paid if there was no demand response.

As an example, NordPool's price without demand response could be 55 EUR/MWh. Thus, the supplier would have bought the same 20 MWh for 1100 EUR (by 100 EUR more). In this case, the supplier does not lose anything – he paid at NordPool 100 EUR less, which is the same amount that he lost due to demand response by not selling 2 MWh (Scenario B). As a result – there is no net loss for the supplier and the aggregator should not pay any compensation to supplier.

Another example would be, where NordPool's price without demand response is 52 EUR/MWh. In this case, supplier would have paid 1040 EUR for 20 MWh (by 40 EUR more). Here, the supplier has gained 40 EUR at NordPool, while losing 100 EUR by not selling 2 MWh. So, the supplier's net loss is 60 EUR. This is the amount that should be compensated to supplier by the aggregator.

Considering the above-mentioned, it would be fair for both supplier and aggregator to introduce such a compensation mechanism. However, the challenge here is to determine what the NordPool price would have been without aggregation. The possible solution would be for NoordPool to provide such data and for transmission system operator to calculate the settlement amount. That would lead to a central settlement model, where the compensation mechanism is managed by the transmission system operator.[21]

Meanwhile, another detail needs to be considered, that not all electricity consumers currently would be able to make an agreement with an aggregator as not all electricity consumers are equipped with smart electricity meters that were mentioned in the introduction part as a prerequisite for receiving demand response services. Currently about 60% of all electricity meters in Latvia are smart meters, but it is planned that all electricity meters will be updated to smart meters by 2022. [22]

IV. Conclusions

It can be argued that the entry of aggregators into the electricity market can have several benefits, such as:

- aggregators help transmission system operators to ensure a continuous balance of electricity generated and consumed;
- energy savings are achieved both in the final energy consumption phase and in the better use of networks and means of production in the energy production, transmission and distribution phases;
- electricity consumption time can be adjusted according to changes in electricity prices - reduced when prices are highest, but increased when prices are lower without changing the volume of consumption;
- more efficient use of resources while reducing system load.

Thus, the aggregators and demand response can provide benefits not only for the electricity policy of Latvia, but also can serve for the good of climate policy, when reducing the electricity consumption in Latvia.

However, currently the existing electricity market players have not yet engaged in understanding and using the possibilities currently provided for the electricity suppliers who could combine their role of supplier with the role of aggregator. This model can be financially beneficial under the existing market conditions.

Meanwhile, independent aggregators are yet to develop in Latvia. Even if the technical barriers in the legislation are resolved, it will not be enough for independent aggregators to immediately enter the electricity market from the economic perspective as an aggregator would need a rather big client portfolio.

It is important to develop a regulation, which introduces compensation mechanism for suppliers, but there needs to be a middle ground in order not to destroy any business possibilities an aggregator may have,

As this research mainly focused on the residential household area and the aggregators role in it, research could be further developed focusing on the potential that could be provided to aggregators by large manufacturing enterprises.

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