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Modelling of the bioeconomy system using interpretive structural modelling

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Abstract. Due to European and global resource efficiency efforts, the bioeconomy research and the search for new bioresource valorisation alternatives has become topical. Bioeconomy directly concerns such major sectors of the economy as agriculture, forestry, fishery, as well as other indirect bioeconomy sectors. However, the practical implementation of bioeconomy has had quite low implementation rate, which is partly caused by the multitude and variety of factors that affect the bioeconomy system. This paper evaluates seven bioeconomy affecting factors (particularly related to biotechonomy concept) and links between them in order to promote successful implementation of bioeconomy. To evaluate these factors interpretive structural modelling method (ISM) is used. The application of ISM method allows to not only identify the factor interaction links, but also to graphically represent their directed structure. The results show that three out of seven factors have the strongest interrelation, namely, climate change, bioresources and technologies. This research can be complimented by further adding other factors that could be influencing for bioeconomy development, for example, financial resources, human health, well-being, and so on; therefore, to reach better understanding about influential factors and bioeconomy dependency on them; also, system dynamics approach could be used in order to fully uncover the factor interaction links.

Key words: bioeconomy, interpretive structural modelling, bioenergy, bioresources, climate change, production, pollution, biotechnologies, natural environment, infrastructure.

INTRODUCTION

Driven by the concerns of our major dependence on fossil fuels, their foreseen depletion and the search for alternatives, as well as such societal challenges as climate change, resource depletion and scarcity, environmental pollution and its negative impact on human health and lifestyle, the transition from current fossil-based economy to a knowledge-based bioeconomy (also known as bio-based economy) has become even more topical and important in recent years (European Commission, 2012, McCormick & Kautto, 2013).

Bioeconomy aims to manage bioresources in a way that allows to turn them into energy, goods, fuel, food and feed in a sustainable manner (European Commission, 2012). Within the bioeconomy concept, large attention is also given to valorisation of wasted bioresources (industrial co-products, by-products and waste) so that they can be used for production of other products or energy instead of treating them as wastes. Successful implementation of bioeconomy would result in reduction of CO_2 emissions released in the atmosphere, more sustainable resource management, increased food safety, reduction of waste and pollution as well as increased employment rate in bioeconomy sector (European Commission, 2011).

The Bioeconomy sector is advancing fast – the data shows a growing number of annually published bioeconomy related research papers, especially regarding biotechnology and applied microbiology, energy and fuels and environmental sciences (Bugge et al., 2016). In 2012, the European Union (EU) launched their Bioeconomy Strategy, followed by its member countries – Latvia, Finland, Germany, France, Spain, and Italy – to frame their national bioeconomy strategies (Lier et al., 2018). This fast-growing field is predicted to peak by 2030 (Koukios & Sacio-Szymańska, 2018), however the results so far show low development rate in the bio-product and chemical production sectors (Carus et al., 2016). This could be related to the deficient approach of practical bioeconomy implementation strategies despite the rapidly growing scientific research on bioeconomy. There is a lack of research accounting for the complex interrelated nature of the bioeconomy system and other factors related to it (Muizniece et al., 2018). Bioeconomy is affected by many multifaceted factors, therefore, one of the reasons for its slow development rate could be the lack of considering all those factors and the links between them (European Commission, 2011). Similarly, McCormick & Kautto (2013) stress the necessity to examine the key factors that influence bioeconomy development. Therefore, a research into those factors that affect the bioeconomy and the identification of their interlinkages and their quality would promote faster implementation of bioeconomy and increase sustainable use of bioresources.

In our previous study, the Nexus approach (i.e. identification and analysis of interaction links) has been suggested for the analysis of the multi-faceted factors that influence bioeconomy development (Muizniece et al., 2018). In this research, 22 factors were considered as selected from literature and by logical analysis: land, waste, welfare, climate change, bioresource, fossil resource, human resources/population, research and innovation, energy, education/knowledge, policy, health, behaviour, technologies, water, natural environment, consumption, financial resources, economic growth, food, production, and pollution.

To initiate an in-depth analysis of the interlinkages of the bioeconomy system, first, it is beneficial to reduce the number of factors for the initial analysis (due to time and resource constraints, as well as for more successful testing of the initial research concept). Bioeconomy researchers have reported various factors and their subsets that are assumed to be the most influential for further development of bioeconomy. Sillanpää & Nicbi (2017) identify biomass as the core of the bioeconomy; Gatzweiler & von Braun (2016) predict that agriculture will be the main constituent of bioeconomy. In another study, Finnish future environment professionals named climate change as the main driver towards the bioeconomy (Vainio, 2019). Koukios & Sacio-Szymańska (2018) researched bioeconomy value-based demand factors. Based on expert assessment and application of the radical technology inquirer tool, they named following factors as the 'hard core' of bioeconomy value chain: food, health, life, materials, goods, energy, governance, eco-systems. In their study, these factors accounted for 60% of the total weight of the bioeconomy value relevance.

Therefore, based on literature analysis, two sub-groups of factors are selected that are related to environmental and technological aspects of bioeconomy. Specifically, we focus on the biotechonomy or technology based bioeconomy concept by analysing following factors: bioresources, technologies, production, pollution, infrastructure, natural environment and climate change.

However, the mere identification of factor interaction links would not allow to explain the full extent and relationships of their impact on bioeconomy development. Therefore, the aim of this paper is to design a graphical representation of the structure of this biotechonomy subsystem by indicating its interlinked factors and the direction of their relationships (causal links). The methodology used in this research paper is supplemented with the use of Interpretive Structural Modelling (ISM) method to build a directed graphical description of this complex system.

MATERIALS AND METHODS

Interpretive structural modelling

The previous study (Muizniece et al., 2018) uses a simple graphical representation to describe the interlinkages between the factors that are influencing bioeconomy system. However, this approach gives only an initial insight into the structure of the system. After a more in-depth literature analysis of the links between each pair of bioeconomy influencing factors, the need for the use of structural modelling was evident.

ISM method, created by Warfield in 1973 (Azevedo et al., 2019), has been applied in wide variety of research to hierarchically represent the structure of complex systems to aid decision-making process (Sajid et al., 2017). Lately, Azevedo et al. (2019) performed analysis of countries' biomass related sustainability; Zhao et al. (2019) have used ISM to structure factors representing the development of renewable energy projects; Sajid et al. (2017) applied ISM to model risk factors in biodiesel systems; while Lim et al. (2017) applied it to investigate sustainable supply chain management. However, to the authors' best knowledge there is no previous study regarding the ISM of biotechonomy factors.

ISM is a theoretic causal mapping approach that is used to analyse the impact of one variable on another variable (Azevedo et al., 2019). Thus, ISM allows to identify the contextual relationships between analysed factors and organize those complex relationships in a directed structure (Wu et al., 2015). The inputs for the ISM model are the factor relationships that are identified through literature analysis, as well as expert judgement of the bioeconomy research team. Wu et al. (2015) note the ability to systematically incorporate expert knowledge as one of the advantages of ISM method.

The implementation of ISM method includes five sequential steps that are summarized in Fig. 1.

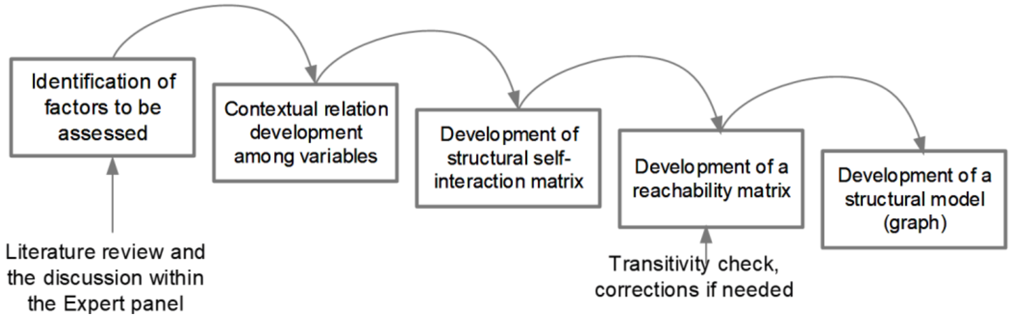

Figure 1. The sequence for implementation of interpretive structural modelling.

First, specific factors characterizing the structure of the studied system may be selected either by an expert panel or by literature review. In the current study, the most significant biotechonomy related factors are identified, defined and described based on literature analysis. After, the pair-wise contextual relationships between the studied factors are evaluated as neutral, influential or comparative, if there is a relation between the pair of factors it is designated with Y, while in case there is no relation between two factors, then it is designated with N (Sajid et al., 2017). Sequentially, within the third step of ISM method, the previously identified relations are further assessed regarding the contextual direction of the relationship. For a binary (adjacent) matrix (*i* x *j*) four different symbols are used to denote the type of relationship (Sajid et al., 2017):

V – factor *i* is linked to *j* but *j* does not link to *i*;

A – factor *j* is linked to *i* but *i* does not link to *j*;

X – when both factors are linked to each other;

O – when neither factor is linked to the other.

The fourth step includes transforming the structural self-interaction matrix into a binary reachability matrix (RM) and checking its transitivity. To create a RM following rules are applied (Majumdar & Sinha, 2019):

if (*i*,*j*) entry is designated with V, in RM this entry is designated with 1 and the (*j*,*i*) entry with 0;

and vice versa, for each relation designated with A, the (*i*,*j*) entry in RM is designated with 0 and the (*j*,*i*) entry with 1;

in case of X then both entries (*i*,*j*) and (*j*,*i*) are substituted with 1;

and for O – both entries become 0.

Simultaneously the ISM transitivity is checked by applying the rule that if a factor A is related to factor B and if factor B is related to another factor C, then factor A is also related to factor C (Sajid et al., 2017). Within the fifth step of ISM, the transitive links are removed and the reachability matrix is converted into a structural model, i.e., a directed graph (Azevedo et al., 2019).

RESULTS AND DISCUSSION

In order to build the structural model, the links between all the factors need to be identified, which was done through analysis of scientific literature and by considering experts' opinions to characterize of each particular link.

Prior to further evaluation, each factor is defined and clearly described to avoid any misinterpretation:

bioresources are renewable biological resources that can be obtained from water, land, air, as well as waste and co-products from industry (Blumberga et al., 2016);

technologies are methods, systems and equipment that have been created based on the knowledge and are being used for practical purposes (Collins Dictionary);

climate change is a change in the climate that is directly or indirectly linked to human actions that cause changes in the atmosphere and that is additional to natural change in the climate within the certain time of period (Kyoto Protocol, 1997);

production is rational, sequential, purposeful action system in order to provide products or certain services (Saksonova, 2010);

pollution – water, air, soil pollution that has negative impact on living organisms and surrounding environment. Pollution can present as chemical leakages, heat discharge, and physical pollution – radiation, noise, vibration, electromagnetic pollution (Harrison, 2006);

natural environment – all natural or by human affected living or non-living environment (Melecis, 2011);

infrastructure – simple physical and organisational structures and facilities (e.g. buildings, roads, power supplies) required to ensure the operation of a society or enterprise (Oxford Dictionary).

Interlinkages of Climate change factor

On one hand climate change is forcing people towards implementation of climate change mitigation measures, e.g., replacing fossil resources with bioresources, and thus increasing **bioresource** use. However, climate change also has a negative impact on bioresources, as changes in temperature or humidity are crucial for the growth of bioresources and the environment in which they grow. Therefore, if these parameters change, the bioresource distribution region may change (Gibbons et al., 2000). Climate change has contributed to the development and use of alternative **technologies** that are more environmentally friendly. These technologies – biotechnologies and climate technologies – have been designed to reduce the causes of climate change – greenhouse gas emissions. Biotechnologies are considered to be more environmentally friendly as they generate lower emissions (Hedenus et al., 2014). The use of such alternative technologies would lead to Climate change mitigation, whereas the technology lock-in, i.e., use of older technologies that are usually tied-up to fossil resource use would enhance Climate change. Climate change also affects the **natural environment**, where the natural development of bioresources is ensured, including food production. The greatest impact on the natural environment caused by climate change is the increase in the average ambient temperature; more frequent natural disasters (such as fires, storms, floods). Climate change and its consequences directly affect the natural environment (Liu, 2016), (EPA, 2016). On-going climate change is forcing **manufacturers** to improve their production technologies or evaluate production processes and their efficiency. Directives, as the directive on industrial emissions (integrated pollution prevention and control) are designed to reduce the environmental impact of industry (European Union, 2010). Climate change also has an impact on **production** through the raw materials needed in the production process. For example, climate change is predicted to reduce coffee bean productivity (Bunn et al., 2015). Climate change has a direct negative impact on the infrastructure stability, longevity and appropriateness to local conditions, i.e. climate change is responsible for floods and other disasters that affect infrastructure. The most affected would be the less developed areas, rural areas, coastal and mountainous regions (European Commission, 2013). The improvement of infrastructure resilience reduces its vulnerability to climate change effects (European Commission, 2013). Climate change does not directly affect pollution; it is however the consequence of environmental pollution.

Interlinkages of Bioresource factor

Bioresource use has an inverse effect (presented as an opposite direction link) on **Climate change** increase. Thus, the more fossil resources are substituted by bioresources, the lower are the society's generated non-renewable greenhouse gas (GHG) emissions because by replacing fossil resources with natural resources, the climate change will be decreasing (Gaurav et al., 2017). The demand for bioresource-based products promotes the need for **technologies** that can process those bioresources into a wide range of products. The European Union directs significant resources directly into research and innovation to promote the development of new biotechnologies (European Commission, 2018). The demand for bioresources contributes to the development of greener technologies (Engelmann, 2011) and the properties of the bioresources impact the complexity of the technologies. Bioresources are one of the most important products of the **natural environment**. Bioresource production provides oxygen, food and other primary and secondary important products for the society. The increase in bioresource demand would also increase the amount of oxygen produced and the amount of CO_2 attracted within the biomass, thus improving the natural environment (Rubene, 2011). The local bioresource availability, as well as, bioproduct manufacturing know-how, significantly impact the development of **production** facilities. The manufacturing industry has to become sophisticated in order to deliver as its core function the bioresource conversion into necessary bioproducts (European Commission, 2018). Various alternatives for replacing fossil resources by bio-renewable sources for the production of such products as various types of chemicals (Reddy at al., 2016), fuel (Behera & Ray 2019) and plastic alternatives, have already been invented (Sagnelli et al., 2017). Bioresource use may be the culprit for some environmental **pollution**, e.g., the use of biomass for energy production leads to emissions in air. Thus, increase of bioresource use would lead to pollution increase. On the other hand, the increased use of bioresources substitutes GHG emissions from non-renewable sources with ones that are from renewable sources, so the link between bioresource use and pollution is quite versatile. Bioresources do not have a direct impact on infrastructure as a whole.

Interlinkages of Technology factor

Technologies, especially their efficiency, have an impact on **climate change** (Salar-García et al., 2019). Technology improvements reduce environmental impact, and hence climate change. Technologies also have an indirect positive effect climate change through innovation and knowledge, as through the development of innovative technologies, bioresource use and substitution of fossil resource use can be increased. Technologies are used to turn raw **bioresources** into finished bioproducts. This is a very important and strong link (Loeffler et al., 2017). The impact of technology on the **natural environment** is indirect and exhibits through technology's link to pollution (Fernández-Dacosta et al., 2019). Technologies are an important part of the manufacturing process – it is a strong direct link. Technologies affect the amount of **pollution** generated – improving the efficiency of the technologies reduces their impact on environmental, thus this is an opposite direction link. Technologies can also be used to detect contaminants that are not easily detectable by the eye. For example, modern technologies allow to detect ozone pollution (Ripoll et al., 2019), thus leading to better environmental research and detection and monitoring of pollution. Technologies are required to ensure public technological **infrastructure**, as transport systems or sewerage, and relieve societal problems as environmental pollution (Aichholzer & Schienstock, 1994).

Interlinkages of the Natural environment factor

The environment is responsible for the natural regulation of **climate change**. However, as a result of human economic activity, those natural processes are hindered. One of the pathways is to mitigate climate change is to increase the area of forests, especially because young trees grow faster and attract carbon dioxide to a greater extent than the old trees can (Latvian State Forests). The natural environment has a strong direct impact on bioresources. The natural environment determines which **bioresources** can be grown and extracted in a particular area. The quality of bioresources is affected by a set of environmental conditions such as water regime, soil quality, rocks, climate, etc. Improper bioresource management (depletion of land, changes in water regime, reduction of biodiversity) can change the natural environment, which in turn affects the quality and quantity of potential bio-resources. By sustainably managing the natural environment, its quality will not be lost and, if necessary, nature will be able to self-clean and regenerate. The natural environment does not directly affect **technology**. However, some indirect effect can be transferred through the linkages between natural environment and bioresources and bioresource linkage to technologies. The natural environment affects **production** indirectly, for example because of the demand for resources (including bio-resources) whose production depends on the natural environment. However, in the current model this link is depicted with zero, as the explained connection is depicted by the natural environment and bioresource positive link. Natural environment has a strong direct connection to **pollution**. As the natural environment is the medium through which air, water and other pollution may be degraded (e.g., by microorganisms) or captured, thus the pollution level may be reduced. The natural environment has a direct impact on infrastructure, as the natural environment (e.g. terrain, climate, special nature areas) can be a limiting factor as to whether an infrastructure can or should not be realized.

Interlinkages of the Production factor

Similarly, as the applied technologies, the production has a significant impact on **climate change**. The production processes can be understood as a process where the raw materials are turned into the goods, energy or food and feed by using various processing methods. Most of the **pollution** that contributes to climate change comes from the production process, such as the processing of iron and the extraction and use of non-renewable resources. Renewable energy and bioresources are the environmentally friendly alternative that reduces productions impact on climate change (Handayani et al., 2019). **Bioresources** constitute an essential raw resource for production, especially in the context of sustainable development and bioeconomy. Considering current national and EU and global level legislation, it is envisaged that the use of bioresources for production will increase (European Commission, 2018). Production volumes, the used raw materials and legislation determine which **technologies** should be used in the particular production process (BREF). Production efficiency can determine how large and how dangerous the **pollution** will be (Ghaly et al., 2004). The manufacturing of bioproducts indirectly affects the **natural environment**, as it enhances the demand for bioresources (but this is conveyed by productions and bioresource positive connection). With constantly increasing number of population, larger amount of food and goods are required for the society, which means increased load on land and natural environment (The Conversation, 2015).

Interlinkages of the Pollution factor

Climate change is most affected by pollution resulting from agricultural activity and energy production. The intensification of agriculture has led to an increase in the use of synthetic fertilizers, pesticides, tractor equipment and energy (mostly produced from fossil resources) thus contributing to **climate change** (Landrigan et al., 2019). Pollutants such as nitrogen oxide (NO_2), sulphur dioxide (SO_2), ozone and particulate matter (PM) affect **bioresource** growth by impairing photosynthesis, altering plant structure and functions, and lowering production yields. Excessive heavy metal concentrations worsen seed germination and plant growth, resulting in reduced agricultural production (Sun et al., 2017). This indicates an opposite direction link between pollution and bioresources, larger pollution levels reduce bioresource production yields. Air pollution may be transferred to the **natural environment** through settling or precipitation. For example, acidous emissions containing sulphur and nitrogen can bond with water molecules and can be transferred to the earth through precipitation, sequentially leading to acidification of the soil and affecting plant growth (Sun et al., 2017). Agricultural activities (especially intensive agriculture) may lead to diffuse environmental pollution, e.g., when pesticide residues get into surface waters, or to point source pollution, e.g., when untreated sewage is introduced into the environment. Therefore, pollution has direct impact on the natural environment – the higher the pollution, the worse the condition of the environment will become. The direct effects of pollution and **technology** interaction are related to damage that the pollution can cause to agricultural and transport equipment, e.g., the acid rain causes corrosion of various metals, resulting in accelerated equipment failure (Sun et al., 2017). The additional connection of these factors is related to the fact that increased pollution levels and the problems they cause lead to development of new pollution treatment technologies. Therefore, this connection has two sub-links, a positive and a negative direction. The effects that the pollution has on infrastructure are reflected through its impact on technologies, and similarly, the impact of pollution on production reflects through the impact on bio-resources. No direct interaction of pollution on infrastructure and on bioresources was identified.

Interlinkages of the Infrastructure factor

Much of the infrastructure is energy intensive, thus impacting the demand for energy sources (including **bioenergy sources**) and generating pollution, that affects **climate change**. The efforts to reduce greenhouse gas emissions should also apply to infrastructure, especially energy and transport infrastructure. Thus, infrastructure improvements (and adjustment towards bioenergy use) would lead to reduction of the causes of climate change (Ingram & Brandt, 2005). The availability or lack of infrastructure can affect the development of **technological** innovations and, consequently, economic productivity (National Research Council, 1995). Infrastructure availability is an important aspect when choosing where to place or implement an economic activity, as water, wastewater and energy infrastructures are needed for production processes (Ingram & Brandt, 2005). The availability of infrastructure (both transport and utility) contributes to the development of **production** facilities in a particular area, while the lack of infrastructure hinders it, indicating a similar direction link. This applies to both the traditional industries and the development of the bioeconomy. Vice versa, the industrial development in a specific area attracts development of the necessary infrastructure. The infrastructure and **pollution** link is significantly related to infrastructure construction period, when both air, water and other emissions are produced (Moretti et al., 2018). On the other hand, some types of infrastructure are directed specifically towards pollution reduction, i.e., sewerage and wastewater treatment plants. For the structural model this factor is subdivided into two parts to show its dual nature. Infrastructure competes with the natural environment for land resources, but there is no direct link between the factors. The introduction of sustainable construction practices among other things, for infrastructure projects would lead to fewer disturbances to the **natural environment**, however this would manifest through reduction of primary resource and fossil-based energy consumption and through lowering the pollution (Georgopoulos et al., 2014).

Modelling of the identified links

According to the described ISM methodology, first, the structural self-interaction matrix is developed for all assessed factors (see Table 1). The information of factor interactions is based on previous in-depth literature analysis identifying the interactions and the direction between each pair of factors.

After, the structural self-interaction matrix is transformed into the reachability matrix; as well, the driver and dependence power is determined for each factor. The result can be seen in Table 2. In complement to the common ISM approach of denoting interactions in the reachability matrix with 0 and 1, we indicate the similar and opposite direction of the link, by also using value -1 (for opposite direction links).

Table 1. The structural self-interaction matrix

		1	2	3	4	5	6	7
1	Climate change							
2	Bioresources	X						
3	Technologies	X	X					
4	Natural environment	X	X	O				
5	Production	X	X	X	O			
6	Pollution	V	X	X	X	A		
7	Infrastructure	X	V	X	A	X	V	

Furthermore, this allows to also account for the different direction sub-links of factor interaction, and this information may be further transferred to the graphical representation. However, our approach does not affect the ISM calculation, as the absolute value of each interaction is considered for those calculations.

Table 2. Reachability matrix

		1	2	3	4	5	6	7	Driver power
1	Climate change	1	±1	1	-1	1	0	-1	6
2	Bioresources	-1	1	1	1	1	±1	0	6
3	Technologies	1	1	1	0	1	-1	1	6
4	Natural environment	1	1	0	1	0	1	-1	5
5	Production	1	1	1	0	1	1	1	6
6	Pollution	1	-1	±1	1	0	1	0	5
7	Infrastructure	1	1	1	0	1	±1	1	6
Dependence power		7	7	6	4	5	6	5	

The highest dependence power is for climate change and bioresources, but the lowest for natural environment. In addition, the evaluation for driver power divides factors in two groups – five factors has the highest driver power, but the rest of the factors – natural environment and pollution – have the lowest.

Table 3. Determination of levels

	Reachability set R(si)	Antecedent set A(si)	R(si) ∩ A (si)	Level
Climate change	1 2 3 4 5 7	1 2 3 4 5 6 7	1 2 3 4 5 7	1
Bioresources	1 2 3 4 5 6	1 2 3 4 5 6 7	1 2 3 4 5 6	1
Technologies	1 2 3 5 6 7	1 2 3 5 6 7	1 2 3 5 6 7	1
Natural environment	1 2 4 6 7	1 2 4 6	1 2 4 6	4
Production	1 2 3 5 6 7	1 2 3 5 7	1 2 3 5 7	3
Pollution	1 2 3 4 6	2 3 4 5 6 7	2 3 4 6	2
Infrastructure	1 2 3 5 6 7	1 3 4 5 7	1 3 5 7	3

Based on the developed reachability matrix, the reachability and antecedent factor sets are derived and after iteration, the factors can be assigned to various levels accordingly to its characteristic (see Table 3). The results divide assessed factors into four levels: three factors at the first level, one factor at the second level, two factors at the third level, and one factor at the fourth level. Lastly, by considering all the previously mentioned results, the structural model is designed by graphically representing the interaction links between all factors (see Fig. 2).

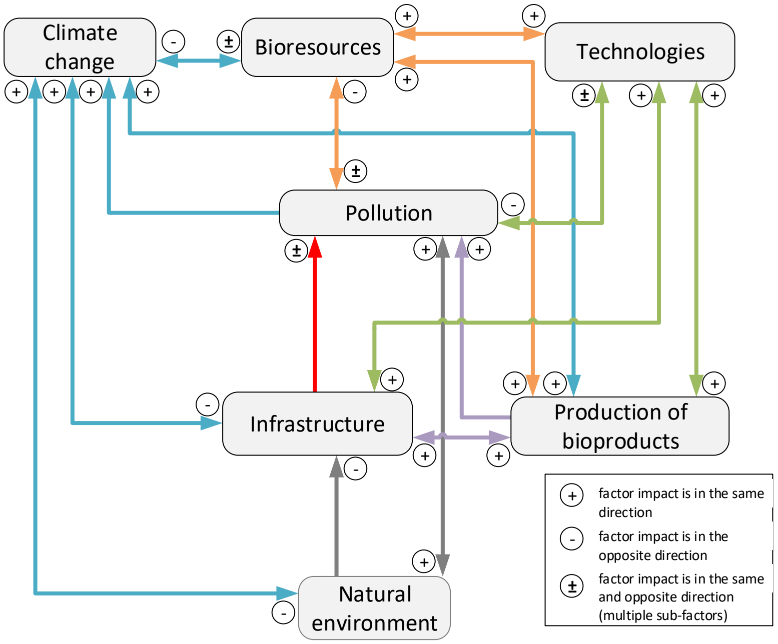

Figure 2. The levelized structure with links.

The obtained results show that the factors that are most connected to others are climate change, bioresources and technologies. These factors are also the main parts of biotechonomy itself, and are essential for bioeconomy's development. At the next level is pollution, which has high influence on other factors because of its effects on climate change; however, the reciprocal effect of how climate change is influencing pollution is an open question.

In addition, the plus and minus signs have been added to each link in the directed graph, in order to indicate whether the factor impact is in the same direction or opposite direction, e.g. bioresource use has an inverse effect on climate change increase (depicted by minus sign). This approach extends the current ISM practice and allows to indicate not only the direction of the links, but also cases when the impact may be in both directions (direct and opposite). However, due to the complex nature of the bioeconomy concept and interrelations between assessed factors, even with the foundation of literature analysis, some of the identified linkages are not unequivocal (including contrary effects as well as double effects in the same direction), thus leading to a need for further research that could account for this multifaceted nature of factors that affect the bioeconomy.

CONCLUSIONS

Stakeholders and decision makers could gain from a structured model that accounts for the multi-faceted and interrelated aspects that affect bioeconomy study field. To complement the bioeconomy research field, authors propose using ISM method to develop a directed graphical description of this complex system. The results obtained from this pilot study assessing seven important factors affecting biotechonomy development (e.g. bioresources, technology, infrastructure, climate change, production, natural environment, pollution) uncover the hidden levels of interaction between those factors and promotes further research into the modelling of the bioeconomy system.

This paper presents initial research regarding bioeconomy development, and can be further used as a carcass for the future researches where the wider list of essential factors within bioeconomy will be assessed. The additional factors in the future research would represent also social and economic factors, for example, behaviour, consumption, health, financial resources etc. Therefore, together with environmental and technological factors (that have been viewed in this paper) would cover the idea and requirements of sustainable development and would give comprehensive look at bioeconomy and related factors. This study proves that ISM approach is a valuable tool for designing the structure of the bioeconomy system. However, several limitations were recognized that affect the full uncovering of the structure and especially the subsystems and sub-connections between the bioeconomy influencing factors. We therefore propose that system dynamics modelling method could be used in further research to indicate positive and negative direction between the factor links and better explain the impacts of potential sub-factors. The results obtained within this study can be used by stakeholders for planning and evolving practical bioeconomy implementation strategies within the regional and national planning documents in order to accelerate the development of bioeconomy within the region.

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