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Transportation Biofuels in Latvia: A Life Cycle Thinking Approach

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***Abstract* – Transport consumes around one-third of Latvia's final energy demand being the largest sector that produces greenhouse gas emissions. In Latvia, in the year 2019, the share of renewable energy sources in the transport sector was only 4.8 % of the total gross consumption with a target of 7 % of not food-based biofuels by 2030. To tackle climate change problems, one significant task is reducing pollution in the transport sector by substituting fossil with biomass-based fuels. The goal of this study is to develop a methodology for evaluating biofuel production in Latvia considering economic, social, environmental, and technological aspects. A total of 16 specific criteria were selected for biofuel comparison. The methodology is based on a combination of two quantitative approaches, namely Life Cycle Assessment and Multi-Criteria Analysis. The proposed method aims to identify the most sustainable biofuel in Latvia according to a set of specific indicators.**

***Keywords* – biofuels; Life Cycle Assessment; Multi-Criteria Analysis; environmental aspects.**

1. INTRODUCTION

The world population reached 7.5 billion people, and it is still increasing [1]. An increased need for transportation of food, materials, and passengers required a higher demand for fuel with a rising tendency of CO_2 emissions level by 5.5 % of Latvia's road transport emissions in the period from 2016 to 2017 [2]. As climate change became an important topic worldwide, the demand for renewable energy use has grown in the energy sector as well as in the transport sector to decrease the use of fossils and mitigate the impact of climate change. Profound and strategic changes need to be introduced to reduce air pollution in the transport sector. Increasing the usage of transport biofuel is one the most promising way for CO_2 mitigation in the transport sector [3]. The use of renewable sources in the energy and transport sectors has a positive impact not only by reducing GHG emissions and minimizing air pollution but also by the use of biofuels, especially second and third-generation providing a positive result from a circular economy perspective. Moreover, involving small-scale producers would bring benefits for rural areas, in turn, increasing the independence and safety of the regional energy supply [4], [5].

Biofuels can be divided depending on the original feedstock. The first-generation biofuel's biomass is based on energy crops creating an ethical aspect of the use of the same crops within the food sector. The production of biofuels from first-generation raw materials competes with food production. The most available types of biofuels are bioethanol, biomethane, biobutanol,

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and biodiesel. The raw materials for the second-generation biofuels are agricultural and forestry waste streams and by-products or specially grown energy crops (fast-growing cultures like shrubs, and grass). This biomass is not used in the food sector, thus biofuels from this generation of feedstock are more sustainable because their use contributes to faster GHG emission reductions. This biomass is called lignocellulose biomass [6]. The third-generation biofuels are produced from cyanobacteria, microalgae and other microbes, their use is considered promising to help to cover growing energy consumption [7]. Algae needs light, carbon dioxide, and nutrients to grow in what is becoming a carbon sink also for other industrial carbon dioxide emissions. Another important advantage of this biomass generation is the ability to cultivate it throughout the year and its adaptability to different climates and growing conditions [8].

The fourth-generation biofuels are based on the latest, new, most unexplored technologies which use the intervention in gens of algae, sometimes also in gens of crops. Genetically modified algae are defined and used as an advanced type of biomass as a feedstock for advanced biofuels [9].

Nowadays, most of the used bioresources compete with the food sector. Advanced biofuels, especially the ones that are produced from biomass not used in the food sector, are promising to match the growing fuel demand [10]. The directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources sets the target to increase the total share of renewable energy in the final consumption in the transport sector by at least 14 % by 2030. The directive promotes the use of advanced biofuels reaching 3.5 % of modern biofuels in the transport sector. This threshold is also set in Latvia's National Energy and Climate Plan. According to the Directive, biofuels are liquid fuels for transport produced from biomass, but advanced (or modern) biofuels are biofuels produced from feedstock mentioned in Part A of Annex IX of Directive 2018/2001 [11].

Latvia has a high potential for the production of advanced biofuels, taking into account the wide range of available raw materials. Many ways of transforming raw materials into biofuels exists nowadays adopted in chemical, thermochemical, and biochemical technologies. Each of these methods consists of several transformation processes and stages like catalytic synthesis, hydrocracking, distillation, chemical treatment, and/or hydrogenation. Depending on the transformation processes, temperatures, pressures, and catalyst used, different types of biofuels can be produced [12].

Thermochemical technologies are considered to be the most perspective for the production of modern biofuels. Thermochemical transformation of biomass includes gasification, pyrolysis, hydrothermal processing or liquefaction, as well as hydrocracking. Many raw materials can be transformed by thermochemical technologies (i.e. lignocellulose-containing biomass, municipal residues, used cooking oil, fats, and vegetable oils) [13]. Gasification processes are widely used for different biofuel production. The main product of the gasification process is syngas. There are possibilities to transform syngas by Fischer-Tropsch (FT) process for dimethyl ether (DME) or biodiesel production. DME can be generated also from syngas by catalytic dehydration. Biohydrogen and biomethane can be produced by syngas upgrading too [14], [15]. During pyrolysis, in conditions of high temperature and lack of air, biomass is divided into several fractions - liquid, solid and gaseous. Liquid products, or bio-oil, can be used as biofuel for the transport sector with some specific limitations. However, typically bio-oil is transformed to DME by the FT process or purified to hydrogen [16]. The hydrothermal liquefaction process can be used for bio-oil production [17], but hydrogenation for hydrotreated vegetable oil production [18].

Biochemical processes include the use of microorganisms and enzymes for the treatment of biomass. Fermentation can be used for the conversion of different biological masses. It happens at relatively low temperatures and pressures compared to thermochemical processes. The most widely used biochemical processes are fermentation and anaerobic fermentation, where the final product is produced by a gaseous or liquid substance that can be improved to biofuel quality [12]. Anaerobic fermentation or digestion typically was used for biomethane production. Anaerobic digestion is a process of biodegradation of organic matter by bacteria in an environment without oxygen. The end product is biogas mostly a mix of carbon dioxide and methane, with traces of H_2, H_2S, N_2, and NH_3. It is possible to use 1st, 2nd, and 3rd generation biomass for biogas generation. Biomethane can be produced by biogas cleaning and further upgrading [19]. The process of fermentation can be used with a range of feedstock, classifiable into three types: 1) lignocellulosic, 2) starch-rich biomass such as maize, and 3) sugars-rich crops such as sugarcane or sugar beet. Bioethanol is the main product of fermentation [20], [21], however, also biohydrogen can be produced by the combined process of fermentation and absorption.

Technologies based on the chemical conversion of biomass are based on the use of chemicals to process the initial feedstock materials. The use of chemicals changes the molecular structure of biomass. There are several chemical processing technologies. Esterification and extraction are the two most widely used methods for the production of modern biofuels [22]. Esterification is a reaction between a fatty acid and an alcohol group for the production of an ester. Transesterification is the reaction used in the synthesis of polyesters and the production of biodiesel. Biodiesel, which is obtained via esterification is named fatty acid methyl ester (FAME) [23].

Biohydrogen has a wide perspective as fuel for the transport sector. Hydrolysis and electrolysis processes are used for biohydrogen production. Hydrolysis is a chemical reaction described as breaking molecules by using water. Electrolysis is the process of separating a matter by using an electric current. The main process of electrolysis is the exchange between atoms and ions by changing the molecular compounds [24], [25].

The choice of technologies for the production of modern biofuels depends on many factors such as the demand for the biofuel, characteristics of the biofuel to be used for vehicles, etc. [26]. One of the most important impacting aspects is the available raw materials and their characteristics. The goal of the study is an evaluation of available biofuels in Latvia taking into account economic, social, environmental, and technological aspects and the development of a methodology for the selection of the most sustainable biofuel.

2. METHODOLOGY

The identification of the most sustainable biofuel includes the analysis of several parameters. The developed methodology for this task consists of combined methods to determine the more promising biofuel in the transport sector taking into account technological, environmental, economic, and social factors. Firstly, a literature review is presented. Then an expert survey is used as a qualitative method to narrow the potential list of biofuels for deepening screening research. After it, five biofuels are selected to be explored deeper. The environmental parameters are evaluated by Life Cycle Assessment (LCA) [27] using the software SimaPro [28]. A tailored set of indicators is selected in line with the definition of the potential usage of biofuel in the transport sector. When all indicators are determined the multi-criteria analysis (MCA) is used as a ranking method. To make a final ranking of selected biofuels using the MCA method the TOPSIS (acronym from Technique

for Order Preference by Similarity to Ideal Solution) was also used [29]. Further in this chapter, all used methods are described.

2.1. Qualitative method

The qualitative method is used the methodology was presented in form of an expert survey as a focus group. The implementation of the qualitative method aims to get a provisional evaluation of selected nineteen biofuels after an in-depth literature review. The 10 experts who are specialists, researchers, and professors in the transport and energy field were interviewed. The list of 19 different transformation pathways of 6 different biofuels was provided in the survey with additional information about feedstock and transformation processes (see Table 1).

TABLE 1. LIST OF BIOFUELS IN THE EXPERT SURVEY

	Biofuel	**Transformation process**	**Raw material**	**Literature source**
1	Biodiesel – FAME	Esterification	Food crops - plant materials/oils	[23]
2	Biodiesel – HVO	Hydrogenation	Vegetable or animal fats and oils, waste oil	[18]
3	Biodiesel	Gasification + FT process	2nd generation biomass	[14]
4	Dimethyl ether	Gasification + FT process	2nd generation biomass	[15]
5	Dimethyl ether	Pyrolysis + FT process	2nd generation biomass	[16]
6	Dimethyl ether	Catalytic dehydration	Syngas	[14]
7	Bioethanol – Conventional ethanol	Fermentation	Sugar/Starch containing plants	[20]
8	Bioethanol – Cellulosic ethanol	Fermentation + absorption	Lignocellulose containing plants	[21]
9	Biooil	Hydrothermal liquefaction (HTL)	2nd generation biomass	[17]
10	Biooil	Pyrolysis	Oil crops, bio-residues	[16]
11	Biohydrogen	Pyrolysis	Biomass	[12]
12	Biohydrogen	Hydrolysis	Biomass	[12]
13	Biohydrogen	Fermentation + absorption	Biomass	[21]
14	Biohydrogen	Electrolysis	Wastewater	[24]
15	Biohydrogen	Gasification	Syngas	[14]
16	Biomethane	Gasification	2nd generation biomass	[14]
17	Biomethane	Anaerobic Digestion + upgrade	1st generation biogas	[19]
18	Biomethane	Anaerobic Digestion + upgrade	2nd generation biogas	[19]
19	Biomethane	Anaerobic Digestion + upgrade	3rd generation biogas	[19]

There were 6 parameters for the evaluation of the mentioned biofuels, namely: availability of a feedstock, status of technical development (at present time), innovation development potential (in the future), social factor (new workplaces, etc.), effect on climate change and an economic factor (biofuel production costs).

The request for the expert was integrated into a survey to make a ranking of each biofuel technology for each parameter, based on a grade from 1 (lowest rank) to 5 (highest rank). As ranking is based on subjective, personal opinion, this research type is considered qualitative,

thus based on the opinion and experience collected from the selected group of experts in the energetic and environmental field.

2.2. Life cycle assessment

LCA was part of the used methodology chosen for the evaluation of the environmental impact of biofuels. For this purpose, SimaPro software was used. Taking into account the context for environmental impact assessment, the functional unit (FU) needs to be defined. FU is a numerical expression of the function of the studied product which serves as a basis for calculations and comparison. The FU can be expressed as a unit of material, or product's physical values, i.e. – a kilogram of product, MWh of electricity, or can be expressed as a unit of service provided, i.e. – packaging of one device, or one pallet produced [30]. The FU was defined as 1 MWh embodied energy in the biofuel. The system boundaries were set as cradle-to-gate or well-to-tank. The boundaries were not taking into account the end-use of the product [31]. The life cycle impact assessment methodology IMPACT 2002+ was used within each study. It offers the implementation of the combined mid-point and damage approach [32].

2.3. Multi-Criteria Analysis

The second stage of the methodology included the use of an MCA approach [29]. The method is based on literature analysis and statistical data collection. For the MCA four main dimensions were defined: technological, economic, social, and environmental. Data for technological, economic and social parameters were collected from scientific literature, studies and assumptions. A total of 16 criteria of 4 parameters were defined (see Table 2).

The MCA was performed via the TOPSIS method. This method involves a comparison of different alternatives with each other and prioritizing them according to the highest average value of each criterion in total. To compare several parameters expressed in different units, the values must be normalized and weighted. Later, for each normalized and weighted value, the distance between the ideal and anti-ideal solution was calculated and used to define the closeness coefficient, which determines the distance of each alternative to the best. The closeness criteria (with normalized values from 0 to 1) were used to rank all alternatives from best to worst [29].

Different scenarios investigated by TOPSIS were considered to make a sensitivity analysis to assess the consistency of the ranking results:

- S1. All criteria categories were weighted equally (25.00 %);
- S2. Environmental criteria category was weighted by 50.00 %, but technological, economic and social – by 16.67 % each;
- S3. Economic criteria category was weighted by 50.00 %, but technological, environmental and social – by 16.67 % each;
- S4. Social criteria category was weighted by 50.00 %, but technological, environmental and economic – by 16.67 % each;
- S5. Technological criteria category was weighted by 50.00 %, but economic, environmental and social – by 16.67 % each;
- S6. Environmental and economic categories were weighted by 35.00 % each, but technological and social – by 15 %;
- S7. Environmental and social categories were weighted by 35.00 % each, but technological and economic – by 15.00 %;
- S8. Environmental and technological categories were weighted by 35.00 % each, but economic and social – by 15.00 %.

TABLE 2. LIST OF CRITERIA FOR MCA [12], [22], [33]–[36]

Dimension	Criteria	Indicator Type	Indicators
Economic	Feedstock price,	Quantitative	EUR/MWh
	Production cost,	Quantitative	EUR/MWh
	Cost of biofuel on the market	Quantitative	EUR per unit
	Price per certain covered distance	Quantitative	EUR/100 km
Social	New job creations	Qualitative	From 1 to 3 according to created new workplaces
	Raise of awareness	Qualitative	From 1 to 3 according to the impact of a particular technology on raising human awareness
	Inclusion of small-scale farmers/producers	Qualitative	From 1 to 3 according to a parameter that determines the involvement of small factories in the bioeconomy, human living conditions, etc. improvement
	Development of rural areas	Qualitative	From 1 to 3 according to improve regions, infrastructure, etc.
Technological	Status of technical development	Quantitative	Technological Readiness Level (TRL)
	Type of a feedstock	Qualitative	From 1 to 3 according to the generation of raw material used as a feedstock
	Average energy consumption	Quantitative	tank-to-wheel (TTW) in MJ/100 km
	Calorific value	Quantitative	MJ/kg (as received)
Environmental	Human health,	Quantitative	DALY* / kg
	Climate change	Quantitative	kg CO_{2eq}
	Ecosystem quality	Quantitative	PDF**/m^2 year
	Use of resources	Quantitative	MJ primary

* Disability Adjusted Life Years [37]
** Potentially Disappeared Fraction [37]

3. RESULTS

To find the most promising and prospective biofuel, the methodology described in the previous chapter was implemented. It contains the following methods: qualitative method (expert survey), LCA, quantitative method, MCA. The results for each of them are described below.

3.1. Qualitative method

Firstly, the results of the expert survey were summarized for determining the 5 most prospective biofuels to narrow the following research. As all parameters could be marked from 1 to 5 points, each biofuel in total could have a maximum of 30 points. By calculating the average value of each parameter and biofuel, the 5 biofuels with a higher amount of collected points in the transport sector in the Latvian context according to the examined group of 10 experts are shown in Fig. 1.

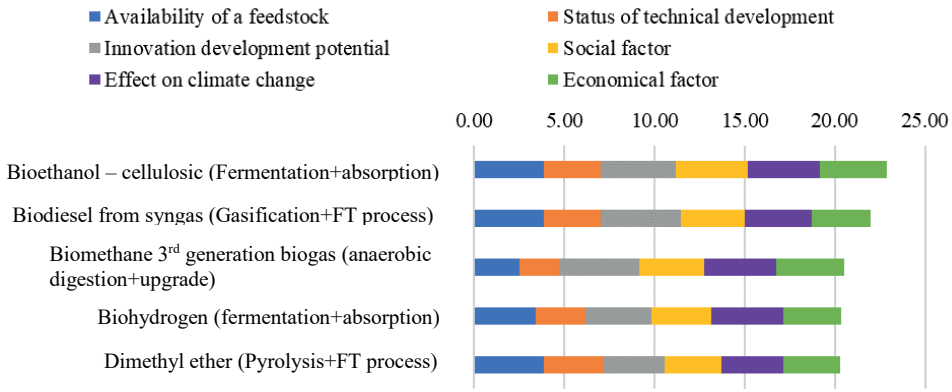


Fig. 1. Result ranking biofuels by the expert survey.

The five most promising fuels were determined as:

- Bioethanol - converted by a fermentation process from cellulosic feedstock;
- Biodiesel – obtained by improving syngas (via FT process), which is the end product of the gasification process;
- Biomethane – obtained by anaerobic digestion from 3rd generation biogas;
- Biohydrogen – as the end product of fermentation and absorption;
- DME – obtained in pyrolysis and FT process.

3.2. LCA and data inventory for LCA

The first step in evaluating more sustainable biofuels is to assess their impact on the environment. For the environmental parameter evaluation, the LCA approach was used. The data inventory for each biofuel is described below.

3.2.1. Bioethanol

Bioethanol obtained by fermentation was defined to be the most sustainable, promising fuel according to the results of the expert survey. The *Ecoinvent database* was directly used to define the environmental performances of the specific biofuel. The system also includes the treatment of waste streams. The data inventory of the bioethanol fermentation system is presented in Annex Table AI.

Since the FU used in the SimaPro is 1 kg of bioethanol, it was necessary to recalculate the existing values for the system with FU 1 MWh. Calculations were made using a lower heating value (LHV) of bioethanol. In the same way, other parameters were converted with values for the system referred to as the FU of 1 MWh. The product 'Ethanol, 95 %' was selected from the Ecoinvent database. The environmental burden of the plant construction was also included. All input values were readapted to the Latvian context.

3.2.2. Biodiesel

As in this scenario, biodiesel production includes syngas treatment via the FT process, existed system for syngas production was used from the Ecoinvent database. Data inventory for the FT process was taken from the existing study and was adjusted to the FU of 1 MWh, as it was done case of bioethanol. The used technology corresponds to indirectly heated, fluidized bed gasification, followed by a low-temperature wet gas treatment. As this syngas

product was used further in the FT process LCA as input data in Nm^3, no calculations for changing FU were made, but parameters, that were defined for other countries were changed to those, that were appropriate to Latvia. The resulting product – syngas, was used in the LCA of the FT process as input data. Data inventory for the FT process was taken from the study of D. Iribarren [38]. A cradle-to-gate approach is used in this paper, but FU is the use of 10 000 Nm^3 of syngas. For this study data from D. Iribarren's paper was modified by calculations. As in D. Iribarren paper from 10 000 Nm^3 syngas in the output 98.8 kg of biodiesel is declared, by using biodiesel LHV, which is 33 MJ/kg, all data was converted to the necessary system with FU 1 MWh. In Annex Table AII, all used and converted data is shown.

3.2.3. Biomethane

Data for biomethane LCA, as well as for bioethanol, was used from the SimaPro database. The system consists of two processes: biogas production and biogas upgrade to biomethane 96 %. The inventory of the last one is shown in Annex Table AIII.

3.2.4. Biohydrogen

Data inventory for biohydrogen was based on the study of Djomo S. N. [39]. An LCA was performed in a study to quantify the performances of hydrogen from three types of feedstock – wheat straw, sweet sorghum stalk and steamed potato peels. Data for the last one was used in this study. The following processes are included in a system: pre-treatment of feedstock, hydrolysis, fermentation, H_2 recovery and purification. Conversion of value was done through the LHV, which for biohydrogen is bigger than for other biofuels – 122 MJ/kg. The main inventory data of the biohydrogen via the FT process is shown in Annex Table AIV.

3.2.5. Dimethyl ester

The DME conversion process's first step of conversion is obtaining the syngas from wood chips via pyrolysis. Data inventory for syngas for further DME production can be processed from data of biodiesel LCA inventory due to the similarities of these two processes. For this purpose, it should be taken into account that the pyrolysis process is characterized by air avoidance, while gasification takes place in the presence of air. This also affects the amount of feedstock needed for obtaining the same amount of syngas by these two conversion technologies. The composition of syngas in both cases is also different. All these specific properties were considered for calculations for syngas data inventory necessary for DME processing via the FT process, as was done for biodiesel (Annex V).

The results of LCA, from the implementation in Simapro software, for all five biofuels, are presented in Fig. 2. Biomethane and bioethanol have a much lower impact in all categories. This fact makes these biofuels more promising and sustainable by environmental parameters. Results are presented at endpoints impact categories (i.e. Hulman Health, Ecosystem Quality, Climate Change and Resource use) as ecological points (i.e. Pt). A point corresponds to the average impact per capita per year. Such type of data display allows comparing all reached results better. However, it is important to note, that results are affected by data inventories, which were not equal among the different biofuels assessed because of different sources, and studies, where some data could be missed. It is suggested that more improvements and similar methods of data inventory must be applied for more accurate results.

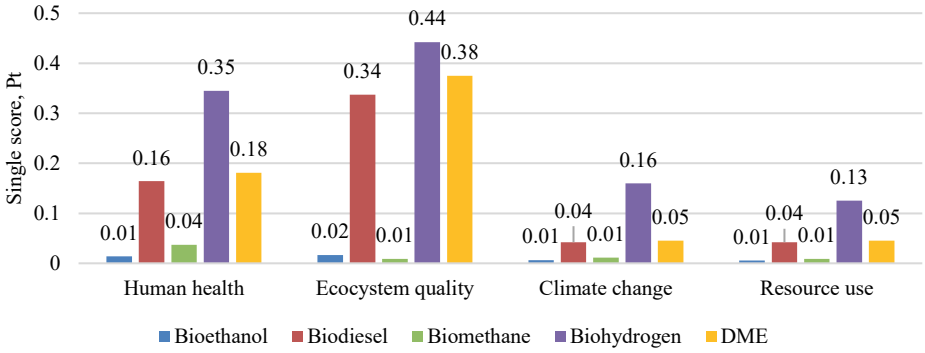


Fig. 2. LCA results by categories of impact.

Another conclusion is that it is not valuable to evaluate and compare biofuel sustainability and potential only by environmental parameters. Therefore, the results of LCA were used as environmental parameters in MCA, where they were evaluated together with other parameters. However, the impact on the environment is the main parameter that is used for assessing the biofuel sustainability parameter, because it is more described in climate plans and directives. For this reason, to assess and compare the consistency of the final ranking results a sensitivity analysis was used, wherein a few scenarios' environmental parameters have a bigger proportional value.

3.3. Quantitative method

Environmental parameters for the quantitative method were obtained from LCA while other parameters were based on a literature review including also statistical data from European Commission of European Union reports (Table 3).

TABLE 3. MCA DATA INVENTORY [9], [40]–[43]

Criteria category	**Criteria**	**Fermentation (cellulosic)**	**Gasification + FT process (wood)**	**Anaerobic digestion (3rd biogas)**	**Fermentation + absorption (biomass)**	**Pyrolysis + FT process (wood)**
		Bioethanol	Biodiesel	Bio-methane	Bio-hydrogen	DME
Economic	Feedstock price, EUR/MWh	11.5	15	40	40	15
	Production cost, EUR/MWh	94	107.5	80	60	75
	Cost of biofuel on market, EUR per unit	1.487	1.398	1.103	9.268	0.693
	Price per 100 km in EUR	9.81	6.906	5.768	6.6555	6.237
Social	New job creations (1–3)	2	3	1	2	3
	Raise of awareness (1–3)	2	3	2	3	2
	Inclusion of small-scale farmers/producers (1–3)	2	1	3	3	1
	Development of rural areas (1–3)	2	1	3	2	1

Technological	Status of technical development (TRL)	9	7	9	8	7
	Type of a feedstock	2	2	3	2	2
	Average energy consumption (tank-to-wheel TTW in MJ/100 km)	207	163	232	50	216
	Calorific value (CV) (MJ/kg)	27	33	44.4	121	28
Environmental	Human health, DALY/kg	0.0000969	0.00117	0.000263	0.00245	0.00168
	Climate change, kg CO_{2eq}	61.7	418	111	1.58E+03	450
	Ecosystem quality PDF/m^2 per year	225	4.16E+03	124	6.06E+03	5.14E+03
	Use of resources, MJ primary	896.00	6.45E+03	1300	1.89E+04	6.91E+03

Economic factors such as feedstock price, production cost, cost of biofuel on the market and biofuel price per 100 km were determined by deep analysis of scientific publications and other reliable sources. All the mentioned criteria aim to reach a lower value to define biofuel as more sustainable than others. The social parameters were assumed as in Table 3.

As the result of literature analysis and data collection, it was found, that some values diverge too much, for example, the feedstock price for anaerobic digestion is from 0 to 80 EUR/MWh, which is based on the type of feedstock – if is it waste or high-quality raw material. Therefore, all calculations were done with medium value, but different scenarios of MCA were considered to make sensitivity analysis to assess the consistency of the ranking results.

3.4. Multi-Criteria Analysis

In Table 4, the final ranking of biofuels (based on the closeness coefficient) in each scenario implemented in the sensitivity is presented. Scenarios are presented as letter S (scenario) with the number from the list above in chapter 'Methodology'.

TABLE 4. THE FINAL RANKING OF BIOFUELS IN EACH PROPOSED SCENARIO

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Bioethanol	2	2	3	2	3	1	1	2
Biodiesel	3	3	2	4	4	3	3	3
Biomethane	1	1	4	1	2	2	2	1
Biohydrogen	5	5	5	3	1	5	5	5
DME	4	4	1	5	5	4	4	4

In the first scenario, when all criteria categories were weighted the same, biomethane becomes a leading biofuel, but biohydrogen is estimated as the worst alternative.

The use of several scenarios constitutes a sensitivity analysis of the reliability and usability of the results obtained. As it is presented, none of the biofuels is ranked with 1 (as best) in all categories. This rules out the possibility of a possible TOSIS calculation error, which makes one type of biofuel many times better than the other in all categories. In the context of different scenarios, each biofuel changes its position, where 1 is recognized as the best, and

5 – is the worst, among others. To make this data usable, the probability of each biofuel being in the 1st, 2nd, 3rd, 4th and 5th place was assessed and results are presented in Table 5.

TABLE 5. RANKING PROBABILITY BASED ON THE WEIGHTING SENSITIVITY ANALYSIS

	Rank Position							
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
Bioethanol	25.0 %	50.0 %	25.0 %	0.0 %	0.0 %	25.0 %	50.0 %	25.0 %
Biodiesel	0.0 %	12.5 %	62.5 %	25.0 %	0.0 %	0.0 %	12.5 %	62.5 %
Biomethane	50.0 %	37.5 %	0.0 %	12.5 %	0.0 %	50.0 %	37.5 %	0.0 %
Biohydrogen	12.5 %	0.0 %	12.5 %	0.0 %	75.0 %	12.5 %	0.0 %	12.5 %
DME	12.5 %	0.0 %	0.0 %	62.5 %	25.0 %	12.5 %	0.0 %	0.0 %

Biomethane stays in the leading position with the criteria category of environmental weights with 50 %, which was proved in the LCA study. The worst scenario for biomethane is with economic criteria being the main parameter. This shows that biohydrogen is not economically justified.

According to the results of deep and wide multi-criteria analysis by TOPSIS method and LCA for environmental parameter evaluation, it was possible to make a list of more promising and sustainable biofuels in the context of Latvia is presented below, starting from the best one: 1) Biomethane; 2) Bioethanol; 3) Biodiesel; 4) DME; 5) Biohydrogen.

4. CONCLUSIONS

The Biofuel sustainability assessment methodology was developed, tested and approved. The qualitative method in form of a focus group was implemented. Ten experts from Riga Technical University evaluated 19 biofuel pathways by different parameters, and the most promising biofuels for Latvia were selected, among them are FT biodiesel and DME via gasification and pyrolysis respectively, biomethane via anaerobic digestion, bioethanol and biohydrogen via the fermentation process.

Results of LCA show that the production of biohydrogen has the most negative impact on the environment in total, but bioethanol – is the smallest one. In the category of an ecosystem, quality bioethanol has the lowest impact after biomethane, in the production of liquified wastes that can be used as a feedstock, that way decreasing the number of wastes with obtaining a biofuel.

MCA analysis was done by TOPSIS. Data for four categories were collected technological, environmental, economic, and social, creating a total of 16 criteria for MCA. Several scenarios were implemented with a different weighting of criteria categories. In the case of the same weights of all criteria categories, the first position takes biomethane, second – bioethanol, third – biodiesel, fourth – DME, and last one – biohydrogen. The same results are obtained from the final ranking of biofuels if all 8 scenarios are taken into account. It proves the reliability of the obtained results. Therefore, biomethane via fermentation is defined as a more sustainable and promising biofuel alternative in the case of Latvia.

The developed approach should be extended including in research more types of biofuels. As well as the LCA model should be better tailored to the Latvian context, excluding the use of data from Ecoinvent data basis or the adoption of scientific literature about cases abroad. Use of data specifically for Latvia, results will be more reliable and preventative. It is worthwhile to evaluate existing biofuel plants according to the developed methodology to

obtain results from real cases and to assess the potential of biofuels based on real and much wider data sets. The developed methodology has proven its effectiveness, so it is considered a good basis for more in-depth research to determine the best biofuel. The methodology can be used in cases of different countries and regions, but data adaptation is necessary.

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ANNEX

TABLE AI. MAIN INVENTORY DATA OF THE BIOETHANOL FERMENTATION SYSTEM (FU: 1 MWH)

Inputs	**Adapted data from the Ecoinvent database**
Electricity, kWh	0.67
Ethanol, 95 %, from fermentation, kg	134.8
Heat, natural gas, MJ	75.8
Outputs	
Wastewater, m^3	0.0037

TABLE AII. MAIN INVENTORY DATA OF THE BIODIESEL VIA FT PROCESS (FU: 1 MWH)

		Data inventory by D.Iribarren, FU = 10 000 Nm^3 syngas (or 98.9 kg FT biodiesel), (direct data from [38])	**Conversion midway, FU = 1 kg FT biodiesel, (adapted data from literature)**	**FU = 1 MWh biodiesel (adapted data from literature)**
		Inputs		
From the technosphere	Syngas, Nm^3	10 000	101.11	11 030.43
	WGS catalyst, kg	0.02	0.00020	0.0221
	FT catalyst, kg	0.27	0.00273	0.2978
	Water, kg	6380.07	64.51	7037.49
From the environment	Air, t	17.27	0.17	19.05
		Outputs		
		To the technosphere		
Products	FT biodiesel, kg	98.9	1	109.09
	FT biogasoline, kg	41.83	0.423	46.14
	FT biohydrogen, kg	0.34	0.003	0.375
	FT bioelectricity, MWh	1.21	0.012	1.335
Waste to treatment	Wastewater, kg	504.19	5.10	556.14
	WGS catalyst, kg	0.02	0.00020	0.0221
	FT catalyst, kg	0.27	0.00273	0.2978
		To the environment		

Emissions to water	Water, kg	1211.97	12.25	1336.85
Emissions to air	Biogenic CO_2, kg	5772.91	58.37	6367.77
	Water, kg	6478.66	65.51	7146.24
	Oxygen, kg	1813.20	18.33	2000.04
	Nitrogen, kg	19 650.86	198.69	21 675.73

TABLE AIII. MAIN INVENTORY DATA OF THE BIOMETHANE VIA ANAEROBIC DIGESTION (FU: 1 MWH)

	FU = 1 m^3 (LHV = 35.8 MJ/m^3) (direct data from Ecoinvent database)	**FU = 1 MWh (adapted data from Ecoinvent database)**
	Input	
Biogas, m^3	1.5	150,84
Electricity, kWh	0.5	50.28
	Output	
Carbon dioxide, kg	0.866	87.07
Hydrogen sulfide, kg	3.49E-06	3.51E-04
Methane, kg	0.02226	2.24
Sulfur dioxide, kg	5.52E-04	0.0555

TABLE AIV. MAIN INVENTORY DATA OF THE BIOHYDROGEN VIA FT PROCESS (FU: 1 MWH)

		S. N. Djomo study, FU = 460t H_2 (FU = 15588.88 MWh) (direct data from [39])	**FU = 1 MWh (adapted data from literature)**
General system parameters	Size of thermo-bioreactor	95	
	Size of photo-bioreactor, m^3	300	
	Plant capacity factor	0.92	
	Plant lifetime, years	20	
Input	Feedstock, kgfw/year	36 894 000	2366.69
	Chemical, NaOH, kg/year	129 000	8.28
	Enzyme, kg/year	253 000	16.23
	Water for reaction, kg/year	395 000 000	25 338.56
	Water as a solvent, kg/year	2 369 000 000	151 967.21
	Electricity, MWhe/year	4291	0.275
	Steam, MWh/year	3546	0.227
Output	Hydrogen, kg/year	460 000	29.51
	Protein residues, kg/year	403 0000	258.52
	Carbon dioxide, kg/year	505 3000	324.14
	Wastewater, m^3/year	236 9000	151.97

TABLE AV. MAIN INVENTORY DATA OF THE DME VIA THE FT PROCESS (FU: 1 MWH)

		FU = 10 000 Nm^3 syngas or FU = 98.9 kg FT fuel (direct data from Ecoinvent database)	**FU = 1 MWh FT fuel (DME) (adapted data from Ecoinvent database)**
		Inputs	
From the technosphere	Syngas, Nm^3	10 000	12 595.30
	WGS catalyst, kg	0.02	0.03
	FT catalyst, kg	0.27	0.34
	Water, kg	6380.07	8035.89
From the environment	Air, t	17.27	21.75
		Outputs	
		To the technosphere	
Products	FT biofuel (DME), kg	98.90	124.57
	FT biogasoline, kg	41.83	52.69
	FT biohydrogen, kg	0.34	0.43
	FT bioelectricity, MWh	1.21	1.52
Waste to treatment	Wastewater, kg	504.19	635.04
	WGS catalyst, kg	0.02	0.03
	FT catalyst, kg	0.27	0.34
		To the environment	
Emissions to water	Water, kg	1211.97	1526.51
Emissions to air	Biogenic CO_2, kg	5772.91	7271.15
	Water, kg	6478.66	8160.06
	Oxygen, kg	1813.20	2283.78
	Nitrogen, kg	19 650.86	24 750.84

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