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The Impact of RED III Directive on the Use of Renewable Fuels in Transport on the Example of Estonia

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***Abstract* – Over the past two decades, there has been an increasing use of biofuels worldwide, especially in Europe. The main objective is to reduce greenhouse gas emissions, particularly carbon dioxide (CO_2), from transportation. The regulation of fuels produced from biomass and other renewable sources at the EU level is primarily governed by the Renewable Energy Directive (RED). As of today, RED III directive has come into effect, significantly altering the EU fuel market by 2030. The main change involves an increase in the share of renewable fuels in transport and the non-use of first-generation fuels. Since all EU member states are obliged to comply with the RED III directive, it is essential to assess the current status of each member state in meeting the requirements for transport fuels. Therefore, the aim of this article is to analyse the impact of the RED III directive on the use of renewable fuels in the transport sector. Specifically, it provides an overview of various RED directives' requirements, analyses the shares of renewable fuels in fossil diesel in Estonia under different RED III compliance scenarios, and presents an overview of the situation regarding the use of renewable fuels in Estonia. The article is based on a literature review, and fuel share calculations are based on RED III directive calculation methodologies. The results of the study indicate that if the requirement for the share of renewable energy used in transport is 29 %, using only HVO (Hydrotreated Vegetable Oil) to achieve this goal would require replacing 30.3 % of diesel with HVO. In cases where there is a requirement to reduce the greenhouse gas emission intensity of fuels in the transport sector by at least 14.5 % by 2030, the volumetric share of HVO fuel must meet certain criteria based on the raw material. For example, fuel produced from residues must contain a minimal amount of biocomponents. In this context, biologically derived oil is initially used, such as in food preparation. Subsequently, after its use in food preparation, it is processed into fuel. The article also addresses cases where biogas is introduced as a renewable component in replacing diesel.**

***Keywords* – Biogas; biofuel proportion in fossil fuel; different biofuel proportions; GHG emissions; HVO; raw materials for fuel; Renewable Energy Directive; renewable energy politics in transport.**

1. INTRODUCTION

The introduction of biofuels in transport began a couple of decades ago, but their use remains limited today. This is due to several factors, such as sustainable feedstock utilization, engine compatibility, shelf life, climate conditions, technological, etc. [1], [2]. At the same time, they have a positive effect on the reduction of CO_2 emissions and, in a broader view,

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on the economy as well [3]. By now, the European Union has reached the RED III directive on biofuel legislation, which establishes the rules for biofuel use in member states, their environmental sustainability criteria, and future usage guidelines. The RED III directive is also in line with the Green Deal, and the goals outlined in them are practically the same [4]. The impact of previous directives, particularly RED I, has been discussed in scientific articles, analysing their share in fuels, studying their effects on transportation fuels, and evaluating compliance options for different biofuels [5]. As the biofuels market has undergone significant changes over the past decade, it is important to contextualize existing or widely used biofuels within the framework of the new RED III directive and examine under what conditions the requirements set out in the directive could be implemented. To narrow the analysis, the transportation fuels used in Estonia have been examined to assess which fuels are used and what fuel proportions could meet the requirements of the new RED III directive.

The aim of this article is to analyse the impact of the RED III directive on the use of renewable fuels in the transport sector. Specifically, it provides an overview of various RED directives' requirements, analyses the shares of renewable fuels in fossil diesel in Estonia under different RED III compliance scenarios, and presents an overview of the situation regarding the use of renewable fuels in Estonia. The article is based on a literature review, and fuel share calculations are based on RED III directive calculation methodologies.

2. RENEWABLE TRANSPORT FUELS FROM RENEWABLE SOURCES – GENERAL REGULATORY FRAMEWORK

At the EU level, the regulation of fuels produced from biomass and other renewable sources is primarily governed by the Renewable Energy Directive (RED) [6], [7], [8], [9]. The first version of the Renewable Energy Directive (2009/28/EC or RED I), adopted in spring 2009, established, among other things, a renewable energy target for transport, namely the obligation to achieve a situation by 2020 where the share of renewable energy in transport is at least 10 % in each Member State [7]. In Estonia, the renewable energy target for transport was set in three stages: initially at 3.1 % from 01.05.2018, then at 6.4 % from 01.05.2019, and finally at 10 % from 01.01.2020 [10].

In winter 2018, a revised version of the Renewable Energy Directive (2018/2001/EU or RED II) was adopted, which, among other updates, set new targets stipulating that by 2030, the share of renewable energy in transport should be 14 %. Additionally, the share of advanced biofuels was to increase significantly to at least 3.5 %, while the share of biofuels and biomass fuels produced from food and feed crops was to decrease significantly [8].

However, on 16.03.2020, Estonia decided to lower its renewable energy target for transport from 10 % to 7.5 % starting from 01.01.2022. Estonia utilized the option provided in the directive (RED II) to set a lower overall target for 2030 than 14 %, provided that the cap on the inclusion of food- and feed-based biofuels (otherwise a maximum of 7 %) is set lower. Specifically, starting from 2023, Estonia will not consider first-generation biofuels for meeting more than 2.5 % of the renewable energy target for transport, and from 2024, not more than 0.5 %. Consequently, in Estonia, biofuels predominantly made from waste or residues, including advanced biofuels, are already in use. Therefore, except for possible fraud, first-generation biofuels in Estonia are a thing of the past (see table 1). However, the demand for biofuels and biomass fuels from waste and residues is only expected to increase as the European Union's Green Deal and the accompanying European Climate Law (2021/1119) aim for significantly more ambitious greenhouse gas reduction targets (55 % by 2030 compared to 1990, instead of the previous 40 % by 1990), the European Commission proposed the Fit-for-55 package in July 2021, which includes substantial increases in climate targets, including in the transport sector. Regarding road transport and renewable fuels, Fit-for-55 will bring about significant changes in the Renewable Energy Directive (RED III), which, as of May 2023. Namely, (a) renewable energy must account for at least 42.5 % of total energy consumption in the EU by 2030 (the previous target was 32 %), and in transport, each Member State, including Estonia, must by 2030 either (a) reduce the greenhouse gas intensity of energy used in transport by 14.5 % or (b) ensure that the share of renewable energy in transport in that Member State (e.g., Estonia) is at least 29 % [6].

In the current context: (a) Estonia's renewable energy target for transport is 7.5 % (see RED II § 21 para. 1), and (b) there is an obligation to reduce greenhouse gas emissions by 6 % per energy unit over the life cycle of fuels (see RED II § 1231 para. 1).

The key principles, CO_2 calculation methodologies, and examples of opportunities to replace diesel fuel with biofuels in Estonia under the current directive, RED II, are described in the following text. Where reasonably possible, we also address the changes brought about by the new and significantly more ambitious targets for 2030 in the Renewable Energy Directive (RED III).

3. OVERVIEW OF DIRECTIVE (EU) 2018/2001 (RED II), REQUIREMENTS FOR TRANSPORT FUELS

The directive establishes requirements and goals for promoting the use of energy produced from renewable sources, which the EU and its member states must achieve by 2030. The directive addresses the use of renewable energy sources more broadly, including in industry, heating systems, energy, and transportation. However, here we will only address the energy sources used in transportation and the requirements placed on them.

As mentioned, in December 2018, RED II set a renewable energy target for transport of 14 % by 2030, but this is expected to increase significantly in the near future: the new target for 2030 is either (a) 29 % of energy used in transport from renewable sources or (b) a 14.5 % reduction in the greenhouse gas intensity of fuels.

Different generations of biofuels are used in transport. Biofuels can be roughly divided into four groups, where first-generation fuels are mainly produced from oilseeds, starches, and sugars, while second to fourth-generation fuels are produced from waste, residues, algae, or bacteria. In other words, first-generation fuels are those produced from food and feed crops, while subsequent generations are produced from waste and residues, which do not compete with human food sources [1].

At the EU level, since 2015, there has been a goal to reduce the share of first-generation biofuels, derived from food and feed crops, and increase the share of second-generation biofuels, derived from waste and residues.

The first of these goals, namely the reduction of the share of first-generation biofuels, has essentially been achieved in Estonia starting from 01.01.2024, they will account for only up to 0.5 % in meeting climate targets, with the share of biodiesel (FAME) in Estonia already practically zero by 2022 (see Table 1).

The directive stipulates that if a member state has restricted the consumption of biofuels and biomass fuels produced from food and feed crops to (usually) less than 7 %, then the member state may, to that extent, reduce the overall renewable energy target for transport set by the directive (14 %) by a maximum of 7 percentage points. As mentioned, Estonia has utilized this option [6].

TABLE 1. QUANTITIES OF FUELS REPORTED BY FUEL SUPPLIERS OR ALLOWED FOR CONSUMPTION BASED ON TOTAL ENERGY (DATA: MINISTRY OF THE ENVIRONMENT AND ENVIRONMENTAL BOARD)

The fuel allowed on the market	**2021**		**2022**	
	Energy, TJ	**The share of total energy, %**	**Energy, TJ**	**The share of total energy, %**
Fossil fuel – Total:	40 935	94.31	42 313	95.96
Gasoline	8805	20.29	8397	19.05
Diesel fuel	31 281	72.07	32 920	74.57
Gaseous fuels CNG, LNG, LPG	849*	1.95*	996*	2.28*
Renewable fuels – Total:	2400	5.53	1709	3.87
Biodiesel (FAME)	658	1.52	2	0.00
Bioethanol	171	0.39	78	0.17
Biogas	488	1.12	536	1.21
Hydrogenated vegetable oil (HVO)	1083	2.5	1094	2.48
Electricity	69	0.16	72	0.16
Total	43 404		44 095	

* Fossil gas fuels separately (2021): (i) LPG 501 TJ (1.15%), (ii) CNG 329 TJ (0.76 %), and (iii) LNG 19 TJ (0.04 %)
* Fossil gas fuels separately (2022): (i) LPG 583 TJ (1.32 %), (ii) CNG 394 TJ (0.89 %), and (iii) LNG 19 TJ (0.04 %)

The directive seeks to promote the wider use of second-generation biofuels through various means, such as (a) a general preference for biofuels produced from waste or residues or (b) setting a separate sub-target for certain specified raw materials, termed "advanced," listed in Annex IX Part A of the directive, with a lower target than the overall renewable energy target for transport [8].

Specifically, under the current RED III, the share of advanced biofuels in energy consumed in transport was supposed to be 0.2 % by 2022 (Estonia currently has a requirement of 0.5 %), 1 % by 2025, and 3.5 % by 2030. The overall renewable energy target for transport by 2030 is currently 14 %, but it will soon increase to 29 % [6].

An advantage of using advanced biofuels is that under the current rules, their energy content can be counted twice in meeting the renewable energy target for transport. This means that when using one kilogram of, for example, HVO produced from forestry waste or biomethane produced from sewage sludge, the energy of not one but two kilograms of HVO or biomethane is counted towards meeting the renewable energy target for transport. This bonus does not apply only to advanced biofuels. For example, the energy of biofuels produced from used cooking oil or from Category I and II animal fats can also be counted twice, although the use of these raw materials is limited to not more than 1.7 % in meeting the renewable energy target for transport. However, as agreed at the political level, amendments to the Renewable Energy Directive (RED III) foresee the disappearance of these multipliers, rendering them practically insignificant and ineffective in the perspective of 2025 and beyond.

Therefore, in the perspective of 2030, it is likely that (a) some part of renewable transport fuels should be advanced biofuels, both (RED II) and (RED III) regulations, (b) the share of food- and feed-based fuels is practically zero, (c) the use of biofuels produced from used cooking oil and animal fats is limited to 1.7 %, and their use may be insufficient, so (d) the vast majority of biofuels and biomass fuels used to meet the overall renewable energy target for transport are those produced from various and diverse waste and residues, with the pool constantly replenishing [6], [8].

As mentioned, the renewable energy target for transport by 2030 was currently 14 %, but today is it 29 %, almost doubling. However, an alternative method to meet the renewable energy target for transport is also emerging, based not on energy but on the greenhouse gas intensity of fuels, so as to reduce the greenhouse gas intensity of fuels by 14.5 %. Achieving both alternative targets largely depends on the use of biofuels and biomass fuels. This means that, for example, depending on the liquid renewable fuels used in transport, attention must be paid to their share in fuels to meet the condition described above. An overview of the development of the shares of liquid renewable fuels based on the requirements stated in the directive and their proposed amendments are provided below.

4. RESEARCH METHODOLOGY

To analyse the impact of directives on fuels used in Estonia, it is necessary to first map out which renewable fuels are currently in use and which fuels hold promise for the future. For this purpose, the fuels sold in Estonia in 2021 and 2022 have been analysed, and the most important alternative fuels have been identified as the basis for further analysis.

4.1. The share of renewable fuels in the transportation sector – the current situation in Estonia

Looking at the data on fuel and energy consumption in the Estonian transportation sector (Table 1), it becomes evident that the share of renewable fuels in the consumed energy is quite small, and the trend is heading in the wrong direction. The share of renewable fuels in the energy consumed in transportation was 5.5 % in 2021 and dropped below 4 % in 2022. These numbers are based on actual, not theoretical, energy content, meaning potential multipliers have not been taken into account.

As seen, in 2021, renewable fuels accounted for approximately 5 % of all fuels allowed for consumption in Estonia, of which roughly half (about 2.5 %) was hydrotreated vegetable oil (HVO), about a quarter (approximately 1.5 %) was fatty acid methyl ester (FAME), and about a fifth (around 1.12 %) was biogas. The share of bioethanol and renewable electricity was marginal. Specifically in terms of diesel fuel replacement, HVO and biogas together accounted for just over 5 %.

In 2022, renewable fuels accounted for less than 4 % of all fuels allowed for consumption in Estonia. Of this 4 %, over half (about 2.48 %) was HVO and approximately one-third (about 1.21 %) was biogas. The share of biodiesel (FAME) was virtually zero (about 0.0001 %). The share of bioethanol decreased by more than half (down to 0.17 %), while the share of renewable electricity remained the same compared to 2021 (0.16 %). In terms of diesel fuel replacement, HVO and biomethane continued to dominate, together accounting for just under 5 %.

From the analysis, it becomes evident that in the Estonian context, the future transportation fuels will likely be HVO and biomethane. Additionally, there is potential for electricity as a future option. Other so-called alternative fuels are already diminishing in the market currently.

4.2. The development of the share of renewables in transportation fuel

In this research, the calculation methodologies developed by Küüt, 2017 [5] have been used.

The RED II directive stated that the share of energy from renewable sources in the transport sector must be at least 14 % of the total final consumption by the year 2030. However, RED III raised this target and requirement to 29 %. To meet this requirement, it is necessary to know the energy content and density of the fossil fuel and renewable fuel used in the fuel blend. Using the above data, it is necessary to first determine the energy content of the added biofuel component E_{hb} from the consumed fuel, or the total fuel that meets the minimum requirements [5]:

$$E_{\mathrm{hb}} = \frac{B_{\mathrm{fr}} \cdot E_{\mathrm{hr}}}{1 - B_{\mathrm{fr}}}, \tag{1}$$

where

B_{fr} ratio of bio-component energy;

E_{hr} total amount of energy in fuel, J.

Total amount of energy in fuel can be calculated as follows:

$$E_{\mathrm{hr}} = V_{\mathrm{r}} \cdot \rho_{\mathrm{r}} \cdot E_{\mathrm{r}}, \tag{2}$$

where

Vr volume of fuel, l;

ρ_r density of conventional fuel, kg/l;

E_r energy content of conventional fuel, J/kg;

Ehr total amount of energy in fuel, J.

The minimum volume of the added bio component V_{ba} to the existing fuel can be found using the following equation:

$$V_{\mathrm{ba}} = \frac{E_{\mathrm{hb}}}{E_{\mathrm{b}} \cdot \rho_{\mathrm{r}}}, \tag{3}$$

where

E_b energy content of biofuel, J/kg;

ρ_r density of conventional fuel, kg/l;

To calculate the minimum volume amount of V_{be} (absolute value) of biocomponents in motor fuel, it is necessary to know the energy content of the substitute biocomponent. To find the substitutable energy amount V_{be}, the following relationship can be used [5]:

$$V_{\mathrm{be}} = E_{\mathrm{hr}} \cdot B_{\mathrm{fr}}. \tag{4}$$

The energy content of conventional fuel V_{re} in the total fuel can be calculated as follows:

$$V_{\mathrm{re}} = V_{\mathrm{hr}} \cdot V_{\mathrm{tr}}, \tag{5}$$

where V_{tr} is the ratio of conventional fuel component to total fuel in percentages can be calculated:

$$V_{\mathrm{tr}} = 1 - B_{\mathrm{fr}}. \tag{6}$$

Using the calculated energy content of the fuel component, V_{be} and V_{re}, it is possible to find the volumetric quantity of the bio-component V_{b1} and the volumetric quantity of the conventional fuel component V_{r1}.

$$V_{b1} = \frac{V_{be}}{E_{bv}}, \tag{7}$$

where E_{bv} is the volumetric-based energy content of the bio-component (J/L); where

$$E_{bv} = E_{b} \cdot \rho_{b}, \tag{8}$$

and

$$V_{r1} = \frac{V_{re}}{E_{rv}}, \tag{9}$$

where E_{rv} is the volumetric-based energy content of the conventional fuel (J/L), which is expressed:

$$E_{rv} = E_{r} \cdot \rho_{r}. \tag{10}$$

The volumetric-based energy content of conventional fuels and biofuels is established by RED II, Annex III. This is also referred to in the Energy Act, Section 324 (7), which in turn refers to Regulation No. 21 of the Minister of Economic Affairs and Infrastructure, based on Section 21 (6*), specifying the method for calculating total energy and the energy content of fuel and biofuel*.

The volumetric quantity of the total manufactured fuel, V_{t1} (L), is found using a formula that is primarily necessary for planning fuel storage volumes [5].

$$V_{t1} = V_{b1} + V_{r1} \tag{11}$$

The relative volumetric quantities of fuel components, V_{b1r} and V_{r1r} (%), can be found as follows [5]:

$$V_{b1r} = \frac{100 \cdot B_{fr} \cdot E_{hr}}{E_{bv} \cdot V_{r1} + B_{fr} \cdot E_{r} \cdot E_{hr}}, \tag{12}$$

and

$$V_{r1r} = \frac{100 \cdot E_{bv} \cdot V_{tr}}{E_{bv} - B_{fr} \cdot E_{bv} + B_{fr} \cdot E_{rv}}. \tag{13}$$

Since RED III provides for the possibility of achieving one alternative transport renewable energy target by reducing greenhouse gas emissions intensity by 14.5 %, and certain transport climate targets are already based on greenhouse gas emissions, it is important to know and consider the various biofuels' CO_2 reduction capabilities and shares.

To replace conventional fuel with biofuel, it is first necessary to find its default GHG values, E_{gr} and E_{gb}, and calculate the minimum energetic share of the bio-component. Then, formulas must be developed to find the relative values of the components in percentages and absolute quantities, as needed, either in kilograms or L. Default GHG values based on the biofuel production method and feedstock are specified in Annex V of RED II.

The minimum energy-based share of the bio-component V_{bfe} (%) in the fuel can be found as follows [5]:

$$V_{\mathrm{bfe}} = \frac{E_{\mathrm{g}} \cdot E_{\mathrm{gr}}}{\left(E_{\mathrm{gr}} - E_{\mathrm{gb}}\right)}, \tag{14}$$

where

E_{g} is the reduction of GHG, % (requirement min 14.5 %);

E_{gr} is the amount of GHG arising from the cultivation, processing, transport and distribution of traditional fuel, gCO_2eq/MJ (83.8 gCO_2eq/MJ);

E_{gb} the amount of GHG arising from the cultivation, pro-cessing, transport and distribution of biofuel, gCO_2eq/MJ.

The minimum quantity of the substitutable bio-component V_{b2} (L) can be calculated as follows:

$$V_{\mathrm{b2}} = \frac{E_{\mathrm{hr}} \cdot V_{\mathrm{bfe}}}{100 \cdot E_{\mathrm{bv}}}. \tag{15}$$

The maximum volumetric quantity of the conventional fuel V_{r2} (L) can be found as follows:

$$V_{\mathrm{r2}} = V_{\mathrm{r}} - \frac{V_{\mathrm{r}} \cdot V_{\mathrm{bfe}}}{100}. \tag{16}$$

The total fuel volume V_{t2} (L) can be found using the formula:

$$V_{\mathrm{t2}} = V_{\mathrm{b2}} + V_{\mathrm{r2}}. \tag{17}$$

The formula for calculating the minimum relative volumetric quantity of the substitutable bio-component, V_{b2r} (%), is as follows [5]:

$$V_{\mathrm{b2r}} = \frac{100 \cdot E_{\mathrm{g}} \cdot E_{\mathrm{gr}} \cdot E_{\mathrm{hr}}}{E_{\mathrm{g}} \cdot E_{\mathrm{gr}} \cdot E_{\mathrm{hr}} - 100 \cdot E_{\mathrm{gb}} \cdot E_{\mathrm{bv}} \cdot V_{\mathrm{r2}} + 100 \cdot E_{\mathrm{bv}} \cdot E_{\mathrm{gr}} \cdot V_{\mathrm{r2}}}, \tag{18}$$

and formula for finding the relative value of the maximum volumetric quantity of the conventional fuel, V_{r2r} (%), is as follows:

$$V_{\mathrm{r2r}} = \frac{100 \cdot E_{\mathrm{bv}} \cdot (100 \cdot E_{\mathrm{gb}} - 100 \cdot E_{\mathrm{gr}} + E_{\mathrm{g}} \cdot E_{\mathrm{gr}})}{100 \cdot E_{\mathrm{gb}} \cdot E_{\mathrm{bv}} - 100 \cdot E_{\mathrm{bv}} \cdot E_{\mathrm{gr}} + E_{g} \cdot E_{bv} \cdot E_{\mathrm{gr}} - E_{\mathrm{g}} \cdot E_{\mathrm{gr}} \cdot E_{\mathrm{rv}}}. \tag{19}$$

5. RESULTS AND DISCUSSION

One of the future biofuels to be used is HVO. It is important to note that HVO can be produced from various feedstocks, and RED directives regulate which feedstock-derived HVO is reasonable to use in the transportation sector. The environmental neutrality of this biofuel is also important, where the proportion of exhaust gases is lower or the same as when using fossil fuels [11]–[14]. Table 2 presents the greenhouse gas (GHG) reduction according to the feedstock as outlined in the RED II directive.

TABLE 2. SELECTION OF HVO FEEDSTOCKS [8]

Feedstock **Reference – (RED II, Appendix V)**	**GHG decreases, %**
Rapeseed oil produced from rapeseeds	47
Sunflower oil produced from sunflower seeds	54
Soybean oil produced from soybeans	51
Oil derived from used cooking oil residues	83
Oil derived from rendering of animal fats	77

Table 2 shows that the greenhouse gas (GHG) reduction rate of biofuel varies depending on the feedstock. However, the GHG reduction rates specified in the directive do not precisely describe the GHG emissions of the feedstocks used for fuel production. Fuel producers calculate the GHG reduction for each feedstock separately based on the methodology provided in the directive, which may result in GHG reductions exceeding 90 % for some feedstocks.

When considering the use of so-called advanced biofuels, which may account for double the energy share, the volumetric share of substitutable biofuels in diesel fuel decreases to approximately 7 % (if the target is 14 %) or around 15 % (if the target is 29 %), depending on the goal. This multiplier is not further analysed separately for clarity and simplicity.

The share of HVO produced from different feedstocks in diesel fuel, based on a 14 % requirement, is illustrated in Fig. 1.

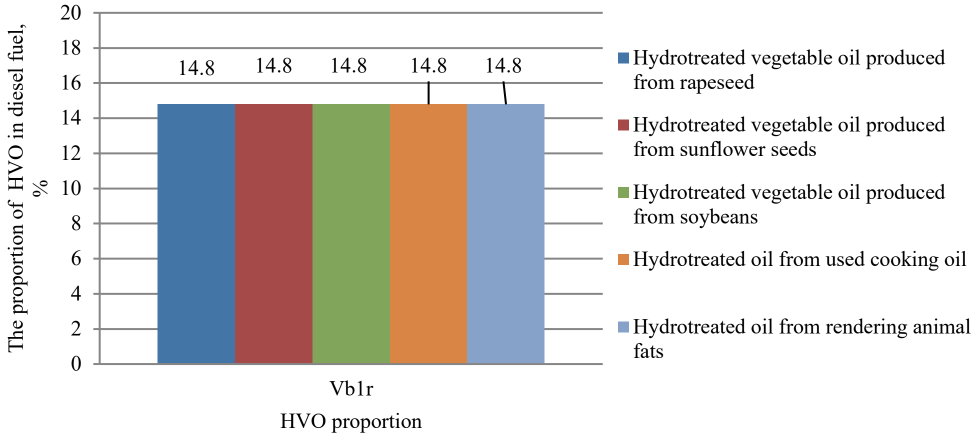

Fig. 1. The volumetric share of hydrotreated (HVO) fuel in diesel fuel in relation to the existing 14 % renewable energy share (RED II) requirement.

Fig. 2 illustrates the share of HVO produced from different feedstock in diesel fuel based on the new 29 % requirement.

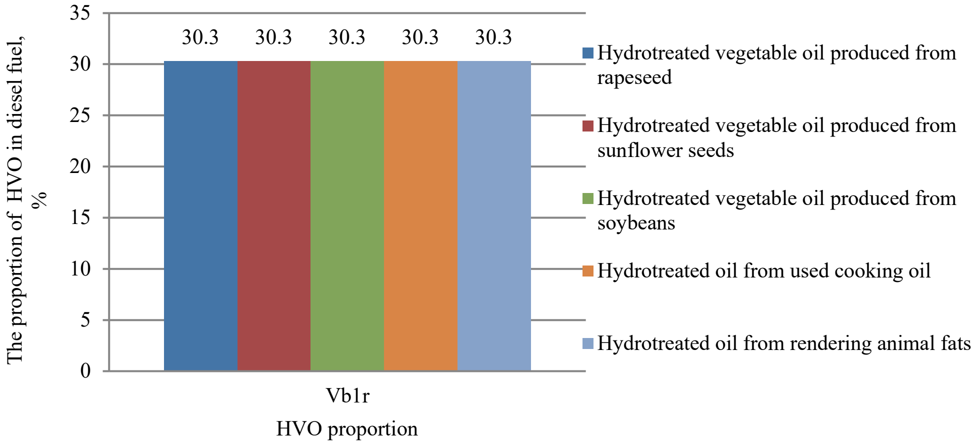

Fig. 2. The volumetric share of hydrotreated (HVO) fuel in diesel fuel in relation to the new 29 % renewable energy share (RED III) requirement.

If we consider that 14 % of the energy used in transportation is renewable, then to meet such a goal with HVO usage, approximately 14.8 % of diesel fuel should be replaced with HVO fuel. It is important that in such a replacement, the blend of fossil diesel fuel and HVO remains well within the limits of the quality indicators and standards for diesel fuel established by law. In other words, such a blend of diesel fuel and HVO can be used in a diesel engine vehicle just like regular fossil diesel fuel.

If the requirement for the share of renewable energy used in transportation is 29 %, then to meet this goal using only HVO, approximately 30.3 % of diesel fuel should be replaced with HVO. Does such a large quantity of HVO blended into fossil diesel fuel meet the standard for diesel fuel and the quality indicators established for it? The answer is yes, various scientific studies indicate that under these conditions, the fuel meets the EN 590 standard [1], [11].

Furthermore, the requirements for diesel fuel sold in Estonia have somewhat changed in a way that encourages a higher proportion of HVO blending in diesel fuel. Specifically, while the minimum density requirement for diesel fuel in the summer period was 820 kg/m^3 in 2018, today it is 815 kg/m^3. During the winter season, the minimum density requirement for diesel fuel remains 800 kg/m^3 [15].

Therefore, even diesel fuel containing 30.3 % HVO meets the quality requirements for diesel fuel. The use of such a fuel blend is equivalent to using fossil diesel fuel from an engine perspective.

Since the density of each specific blend depends on the specific diesel fuel and HVO used, i.e., the base fuels and their quality, it is essential to ensure that the base fuels also meet the quality requirements to guarantee the quality of the final blend. However, in this regard, diesel fuel, HVO, and their blend do not differ from any other fuel - a quality blend can only be achieved using quality input. Adding HVO to low-quality diesel fuel will not yield high-quality diesel fuel (blend), and vice versa. However, by adding up to 30.3 % quality HVO to quality diesel fuel, a fuel (blend) that meets the diesel fuel standard and quality requirements and is equivalent for engine use to quality (solely) fossil diesel fuel can be obtained.

Since the amendments to the Renewable Energy Directive proposed under the Fit-for-55 package (RED III) have been adopted and must be implemented no later than May 21, 2025, the requirements set out in Directive (EU) 2018/2001 will become stricter. Therefore, the possibilities for the use of the aforementioned biofuels must be considered more broadly, including from the perspective of reducing fuel GHG emissions.

For example, if the requirement to reduce fuel GHG emissions in the transport sector by at least 14.5 % by 2030 is implemented, the volumetric share of HVO fuel must meet at least the following requirements depending on the feedstock (see Fig. 3).

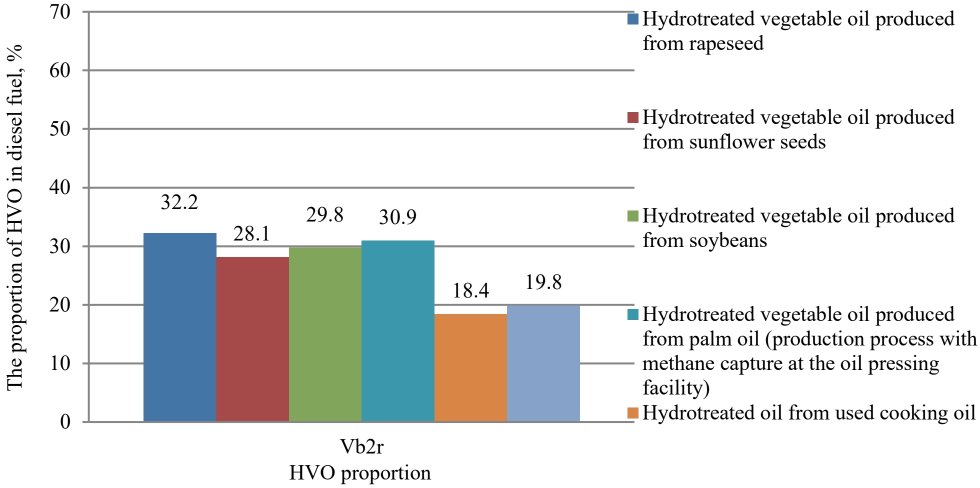

Fig. 3. The volumetric share of hydrotreated (HVO) fuel in diesel fuel to meet the 14.5 % reduction in greenhouse gas (GHG) emissions requirement.

From the graph, it is evident that the least amount of bio-component needs to be added in the case of waste-derived fuels. This means that, for instance, when biologically derived oil has been used first for cooking and then, after its use in cooking, processed into fuel, the minimum amount of bio-component needs to be added [6].

The proportions shown in Fig. 3 are the minimums required to meet the 14.5 % CO_2 reduction requirement. Comparing the proportions of fuels shown in Fig. 2 and Fig. 3, it can be observed that there is no significant difference in the proportion of bio-component (HVO) in diesel fuel when rapeseed, sunflower seeds, and soybeans are used to produce vegetable oils. However, when looking at feedstocks derived from waste (used cooking oil and animal fats), the proportion of HVO in diesel fuel may be one-third lower.

Based on the data provided in Table 1, 910 85 million L of diesel fuel were sold in Estonia in 2022. Therefore, using the data presented in Figs. 1–3 to align the quantity of diesel fuel sold in 2022 with the 14 % renewable energy requirement, it would be necessary to use 130 million L of HVO fuel. To align the same quantity of diesel fuel with the 29 % requirement, 276 million L of HVO fuel would be required.

Depending on the specific feedstock for HVO, to meet the 14.5 % greenhouse gas emissions reduction requirement using only HVO, for example, for the quantity of diesel fuel sold in 2022, one could use: 1) 264 million L of HVO based on rapeseed oil; 2) 150 million L of HVO based on used cooking oil residues; or 3) 132 million L of HVO based on animal fat residues.

5.1. The formation of the proportion of biomethane in the energy used in transportation

Using biomethane as a transportation fuel is promising and also reduces particulate matter emissions in diesel engines [14], [16], [17], [18]. Just like with liquid biofuels, various feedstocks are used to produce biomethane, some of which are listed in Table 3 along with their greenhouse gas reduction shares.

TABLE 3. SELECTION OF BIOMETHANE FEEDSTOCKS [8]

Feedstock for the production of biomethane used in transportation (RED II, Appendix VI)	**GHG decreases, %**
Biomethane from biogas, raw fermentation residue, exhaust gases are not burned	72
Biomethane from biogas, raw fermentation residue, exhaust gases are burned	94
Biomethane from biogas, closed fermentation residue, exhaust gases are not burned	179
Biomethane from biogas, closed fermentation residue, exhaust gases are burned	202
Biogas from whole maize plant, raw fermentation residue, exhaust gases are not burned	17
Biogas from whole maize plant, raw fermentation residue, exhaust gases are burned	39
Biogas from whole maize plant, closed fermentation residue, exhaust gases are not burned	41
Biogas from whole maize plant, closed fermentation residue, exhaust gases are burned	63
Biomethane from bio-waste, raw fermentation residue, exhaust gases are not burned	20
Biomethane from bio-waste, raw fermentation residue, exhaust gases are burned	42
Biomethane from bio-waste, closed fermentation residue, exhaust gases are not burned	58
Biomethane from bio-waste, closed fermentation residue, exhaust gases are burned	80

When considering the proportion of biomethane, we based it on the volume of diesel fuel (1000 L) and compared it to the mass of biomethane used for replacement (in kilograms).

If we take the current renewable energy target for transport, based on energy volume, which is currently 14 % but expected to increase soon, and consider the mass-based calculation and energy content of biomethane (50 MJ/kg), then the proportion of biomethane for diesel fuels to meet this target should be 101.1 kg per 1000 L of diesel fuel (refer to Fig. 4). Therefore, to align the energy share obtained from 1000 L with the 14 % requirement, one would need to use 860 L of diesel fuel and 101.1 kg of biomethane instead. In the case where the renewable energy target for transport based on energy volume is 29 %, the required proportion of biomethane increases to 209.5 kg per 1000 L of diesel fuel (refer to Fig. 5). In other words, to align the energy share obtained from 1000 L of diesel fuel with the 29 % requirement, one would need to use 710 L of diesel fuel and 209.5 kg of biomethane instead.

For context: According to data from Elering, Estonia produced 168 271 MWh or 605.8 TJ of biomethane in 2022 [19]. This would allow for replacing approximately 17.2 million L of diesel fuel based on energy volume, which accounts for about 1.8 % of the diesel fuel allowed for consumption by suppliers in 2022.

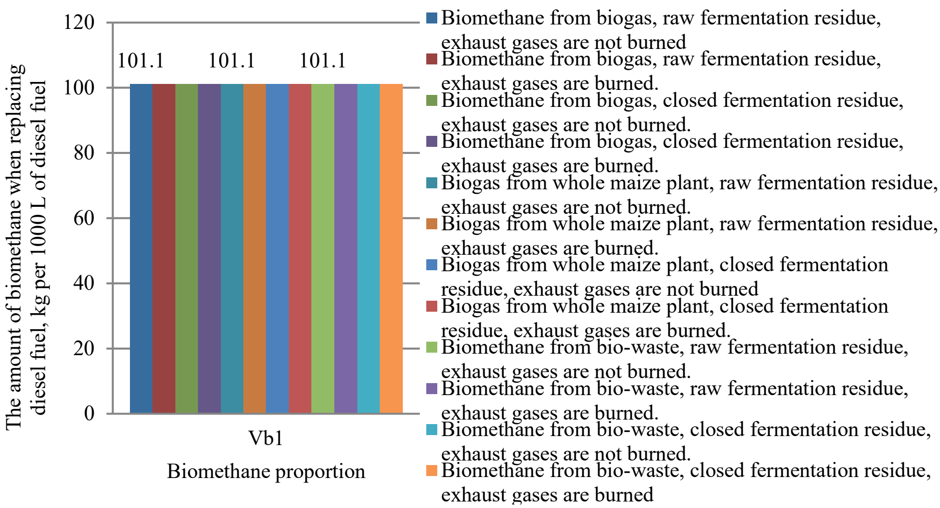

Fig. 4. Biomethane quantity when replacing 1000 L of diesel fuel to meet the 14 % renewable energy share requirement.

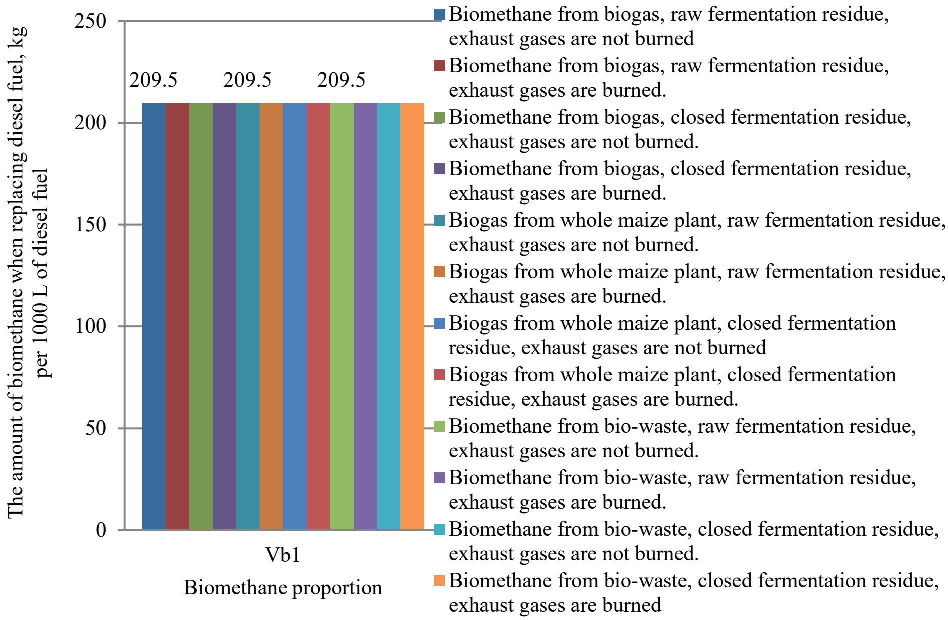

Fig. 5. Biomethane quantity when replacing 1000 L of diesel fuel to meet the 29 % renewable energy share requirement.

The amount of biomethane needed to replace fossil diesel fuel when the renewable energy target is based on greenhouse gas (GHG) emission reduction, such as 14.5 %, rather than an energy-based target, like 29 %, depends directly on the source and method of biomethane production.

To visualize the possibilities of meeting the 14.5 % CO_2 emission reduction target with biomethane, Fig. 6 has been prepared. From this figure, it can be seen that depending on the source and production method of biomethane, the requirement for reducing CO_2 emissions by 14.5 % can be fulfilled in various ways.

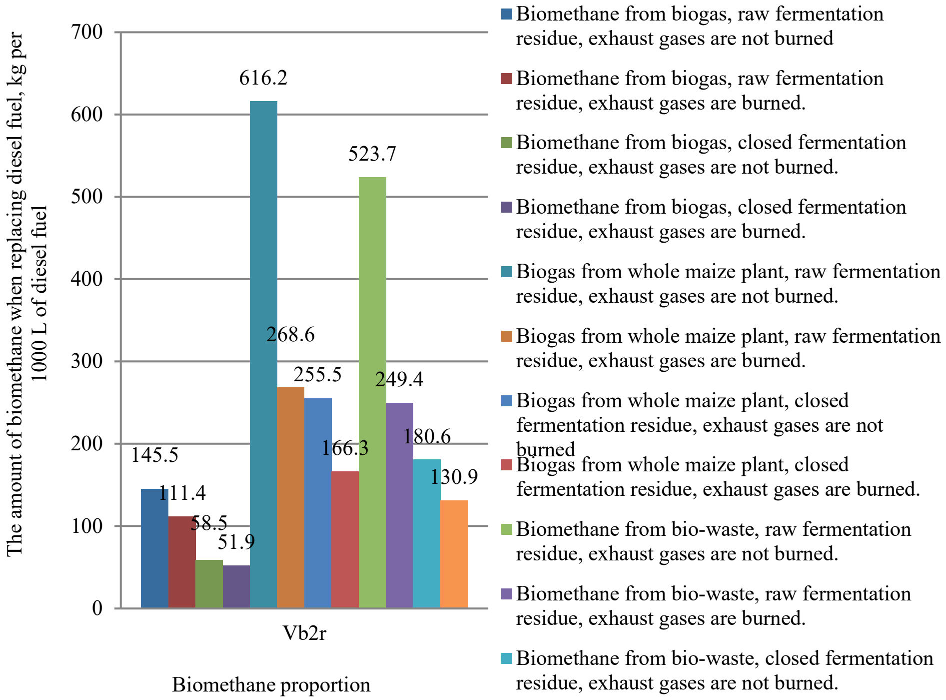

Fig. 6. The quantity of biomethane required to replace 1000 L of diesel fuel to meet the 14.5 % CO_2 emission reduction requirement.

For example, in the case of biomethane production through anaerobic digestion in a closed system without flaring, the 14.5 % requirement can be met with just 51.9 kg of biomethane. On the other hand, if biomethane is produced from biowaste instead of digestate using the same production method (i.e., in a closed system without flaring), then the required quantity of biomethane is 180.6 kg, which is roughly three times more.

Context: According to data from Elering, in Estonia, in the first nine months of 2023, 147 020 MWh of biomethane was produced, of which 48 083 MWh (33 %) originated from biowaste and 43 150 MWh (29 %) from animal manure.

The proportion of animal manure (including digestate) in domestically produced biomethane in Estonia is declining. In 2021, it accounted for 40 % (61 081 MWh out of 152 352 MWh), and in 2022, it was 32 % (54 397 MWh out of 169 074 MWh).

6. Conclusions

To reduce greenhouse gas emissions in transportation, including CO_2 emissions, renewable fuels have been widely adopted worldwide, especially in Europe. The advantage of biofuels over fossil fuels lies in their carbon cycle, which reduces the amount of CO_2 emitted into the environment. Generally, biofuels contain fewer other pollutants, such as particulate matter, nitrogen oxides, and sulphur dioxide, compared to fossil fuels.

The regulation of fuels produced from biomass and other renewable sources is mainly governed by the Renewable Energy Directive (RED) at the EU level. This directive sets targets, obligations, calculation methodologies, etc., crucial for reducing CO_2 emissions in transportation. RED I established targets for 2020, while RED II, introduced in 2018, set goals for 2030. Recently, RED III was adopted, imposing even more ambitious and challenging targets for 2030.

Looking at all three directives, it's evident that requirements for renewable transportation fuels are becoming stricter over time. RED I required a 10 % share of renewable energy in transportation energy consumption, while RED II increased this to 14 %, and RED III raises it to 29 % by 2030. Estonia's current renewable energy target for transportation is 7.5 %.

In addition to increasing renewable energy targets, requirements for renewable fuel feedstocks have also changed. Whereas RED I allowed any sustainably sourced biofuels, since 2015, the EU has been moving towards reducing food and feed-based biofuels and increasing the use of biofuels produced from various wastes and residues. This trend is also observed in Estonia.

Previously, Estonia mainly used Fatty Acid Methyl Esters (FAME) and ethanol as biofuels, but FAME has disappeared from the market, and ethanol use has decreased significantly in recent years. Currently, Estonia primarily uses Hydrotreated Vegetable Oil (HVO) and biomethane, with a gradual increase in renewable electricity's share in transportation.

The decrease in FAME and ethanol usage is due to practical issues with their storage, despite their safety for engines and compliance with environmental standards. HVO and biomethane are preferred because they pose no storage issues, maintain quality over longer periods, and are produced from feedstocks meeting sustainability criteria and environmentally friendly practices.

RED III also tightens requirements for reducing GHG emissions during the life cycle of transport fuels. Instead of solely focusing on renewable energy shares, countries can now opt to reduce GHG intensity by 14.5 %, placing greater emphasis on the choice of renewable fuel feedstocks.

For example, meeting the 14.5 % GHG reduction requirement with biomethane produced from closed-system anaerobic digestion without flaring would require 51.9 kg of biomethane per 1000 L of diesel. However, producing biomethane from biowaste instead of anaerobic digestion would require approximately three times as much biomethane.

Contextually, in 2023, Estonia produced 147 020 MWh of biomethane, with 33 % from biowaste and 29 % from animal manure. The share of animal manure in Estonian-origin biomethane production is declining, from 40 % in 2021 to 32 % in 2022.

In summary, to achieve the 2030 renewable energy targets, all available energy sources, including HVO, biomethane, and renewable electricity, must be actively promoted and utilized. This requires equal treatment of different renewable fuels and fair competition based on objective criteria such as energy content and GHG emissions. Supporting renewable fuel adoption through measures such as tax incentives can help accelerate progress towards sustainability goals.

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