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The whole world is trying to increase energy production from renewable energy sources. Biomass, mainly solid fuel (e.g. wood chips, sawdust, etc.), takes first place in Lithuania's efforts to increase energy production from renewables. There are a lot off studies about minimization of greenhouse gases (GHGs) during biomass combustion for energy production due to biogenic CO_2. Unfortunately, such aspects as biofuel production, including biomass collection in harvesting sites, delivery to special interim sites, processing, produced biofuel transportation to combustion plants is rarely estimated in this studies. A considerable amount of diesel fuel is used within these processes by various mechanisms (e.g., skidders, tractors, crushers, chippers, etc.); therefore woody biomass production and delivery processes have significant environmental impact to air quality and climate change due to air emissions (CO, NO_x, NMVOC, PM, NH_3) and GHGs (CO_2, N_2O, NH_4) from off-road and road mobile sources.

This paper presents the method of evaluation and results of analysis of material and energy flows of wood chips production from traditional raw materials – firewood and forest logging waste (residues). It was estimated that up to 0.038 toe of diesel fuel is used for one toe of produced woody biomass, incl. over 52% - for biofuel delivery to combustion plant; 0.293 kg of air emissions and over 22.5 kg of GHGs are emitted to the air during production of one tonne of wood chips. Results of comparison analysis show that in case of biofuel production from logging residues, volume of GHGs is 57% higher in comparison to wood chips are produced from firewood.

Several recommendations how to minimize significant environmental impact due to usage of logging residues to energy purposes are presented in article.

Received environmental indicators can be successfully used for further detailed life-cycle assessment of woody biomass production and usage for alternative energy.

Keywords: biofuel, biomass, forest logging residues, air emissions, greenhouse gases, production chain, renewable energy.

Introduction

Biomass carbon neutrality has been a long time debated issue. Considering that neutrality is reached by the fact that carbon returned to the atmosphere as a result of biomass burning and will again be absorbed by trees may lead to an error in accounting for carbon-based emissions (Haberl et al., 2012). An extensive and fascinating way to comprehend the accumulative impact and the grade of sustainability of a product like wood biofuels, which are supposed to decline the effect of energy use on the environment. At present, wood is commonly considered as a carbon-neutral resource. Heavy discussions in the science research changed the point of view on the government level. It was considered that if wood biomass is not managed properly it can lose it's name as carbon neutral by means of sustainable practices (Benoit, 2016).

In ensuring the overall greenhouse gases (GHGs) reductions, all stages in a biomass supply chain must be evaluated with respect on generated emissions. Using different methodologies and default values for calculating GHG balance and carbon sinks could lead to different conclusions rather than for example better understanding of changes in consumption and production in carbon footprint calculations (Van Dam et al., 2010, Levihn, 2014). Another point is that various biomass production scenarios may result in carbon footprint for wood products to vary widely (Newell & Vos, 2012).

The methodology for the evaluation of potential of biofuel production in Lithuania and the corresponding model was created by the researches from Regional Energy Development Laboratory of the Lithuanian Energy Institute. They evaluated both volume of wood fuel harvesting and forest logging residues (unused portion of wood and bark left on the ground after trees' feeling, e.g. tops, broken pieces, and unmerchantable

species). The simulation showed that in case of increasing use of potential logging residues by approx. 10%, production volume of chopped wooden biomass chips could increase by approx. 1 mil. m^3 per year, and thus, volume of produced wooden chips will be increased twice as much compared to 2013 (Dzenajaviciene et al., 2013). It was evaluated that up to 4.25 mil. m^3 per year of different wood waste can be used for biofuel production in Lithuania, incl., up to 18% - forest logging residues, 39% - firewood, and 43% - balance wood, which is commonly used for chipboards and paper production (it can be used for energy purposes in case of absence of another demand or due to economic aspect) (Dzenajaviciene et al., 2013).

Wood fuel can be divided into two main categories: processed (e.g. wood briquettes, pellets, etc.) and unprocessed (e.g. traditional firewood, pressed forest residues, wooden chips and sawdust). Unprocessed fuel is a wood fuel, which was only cut (crushed) and packed during processing, but its other properties don't change.

Several environmental risks are associated with the removal of logging residues from forest and use as a biofuel, e.g., biodiversity loss, physical damage to forest soils (due to stumps removal), and air pollution (from mobile and stationary sources) (Giuntioli, et al., 2015). Earth and stones are often taken along with the forest logging residues and can broke shredders and crushers. Besides, efficiency of combustion process decreases volume of ashes increases due to usage such type of biofuel.

Evaluating the carbon neutrality, the most effective forest cleaning method is the one when minimally fulfils the requirements, in other words, the one which shows equal or slightly higher carbon reserves compared to

harvesting residue in non-use mode (Repo et al., 2015).

The main technological processes of wood chips production from the firewood or forest logging residues are the follows: collection with special mechanisms (tractors, skidders, and forwarders) and delivery to special storage place (within or near the forest), chipping with mobile chippers (crushers) (disc, drum or screw), wood chips transportation to biofuel combustion plant for energy production (Vares et al, 2007).

It was evaluated that chipping is the most expensive and at the same time the most negative environmental impact creating action across the wood supply chain (Spinelli, 2009). Another crucial importance is calculation of capturing market adjustments and a large geographic scope when measuring the carbon implications of biomass energy policies (Daigneault et al., 2012).

Evaluation of air emissions and GHGs during wood chip production and delivery to energy production company is one of the essential condition for the environmental impacts assessment (EIA) and comparison of different types of energy production (Eero at al., 2014). Therefore, it's necessary to carry out a number of analyses for the evaluation of inputs and outputs flows and calculation of relative environmental indicators for every wood chips production and supply chain.

Environmental impact of wood chip production depends on the used raw materials (firewood or forest logging residues), mechanism (skidders, tractors, chippers, crushers, etc.), trucks, characteristics of produced biofuel, etc. For example, fraction size of chipped material is very important from environmental impact point of view. Researcher from Belgium evaluated that if the diameter of produced chips increases from 4 to 16 cm (by factor 4), CO_2 emission per 1 MWh of energy production decreases by factor 7 (Van Belle, 2006). One of the main forestry tasks in area of production of biofuel or raw materials for biofuel is to select most proper conditions for different types of biofuel production (locality, climate, relief, etc.) and forestry planning. Most of this has been done in northern Europe, where it is better accessible wood stocks and a well-developed forestry system (Eero at al., 2014).

There are little specific studies, made in Lithuania, about harvesting wood for energy, for example, what kind of machinery is using for delivery, chipping of forest logging residues, environmental impact of such activity. Biomass producers inform that mainly the same tractors are used both for log and forest logging residues delivery out of tree feeling to log wood storage areas (tractors with self-loading trailers and forwarders (skidders). Forwarders use more fuel in comparison with tractors, in this case, cost-price increases significantly. Tractors with self-loading trailers are the most optimal machinery.

Logistics is a crucial aspect for the evaluation of energy balance of biofuel production and combustion processes. Fuel (energy) consumption for the delivery of wood residues or/and wood chips depends on particle size of biofuel, density of chips and technical characteristics of track.

Briefly, there are a lot of studies from area of forest CO_2 absorption, extraction of GHGs, CO_2 from biomass combustion plants were made, but there is a lack of researches and information about life-cycle-assessment (LCA) of energy production from different types of biomass (both log wood and forest logging residues). The main goal of this investigation firstly is to evaluate air emissions and GHGs during woody biomass production, used widely applied mechanisms in Lithuania, and to make comparative analysis for the usage of 2 types of raw materials: traditional firewood (from log wood) and forest logging residues. Received environmental indicators will be used for further evaluation step – LCA.

Materials and methods

The analysis was done, evaluating main material and energy flows of wood chips production within ordinary Lithuanian biofuel Production Company. In 2015, about 43.2 thousand m^3 of firewood and forest logging waste were used for wood chips production within this company.

Environmental impact assessment (EIA) was focused on the evaluation of significant environmental aspects – consumption of diesel fuel and direct impact to air due to emissions and GHGs from stationary and mobile sources during biofuel (wood chips) production processes, incl., log wood delivery to log wood storage site, forest logging waste collection and delivery

to the same storage site, raw materials chipping, and produced wood chips transportation to the combustion plant for heat energy production.

Monitoring of used machineries, incl. evaluation of its technical data was the first step of analysis with purpose to evaluate inputs and outputs of technological processes and to create material and energy flows diagram. Received absolute environmental indicators (e.g. diesel fuel consumption (liters hour^{-1} or tonnes year^{-1}), volume of air emissions (tonnes year^{-1}), volume of GHGs (tonnes year^{-1})) were used for the evaluation of relative environmental indicators (EI$_r$), which are usually used for the comparison analysis. EI$_r$ were calculated according to the following two equations (Kliopova et al., 2016):

$$EI_r = X_i(t) \times P_b(t)^{-1} \qquad (1)$$

$$EI_r = X_i(t) \times R(t)^{-1} \qquad (2)$$

where

i is input or output flow; $X_i(t)$ is the quantity characteristic of this input or output flow per analyzed period, e.g. amount of diesel fuel (tonnes year^{-1}); $P_b(t)$ is the volume of produced biofuel (wood chips) per analyzed period, e.g. tonnes year^{-1} or $P_b(t)$ is the energetic volume of produced biofuel (wood chips) in tonnes oil equivalents per analyzed period (toe year^{-1}); R(t) is the amount of consumed raw materials per analyzed period, e.g. m^3 year^{-1} or tonnes year^{-1}.

Evaluation of air emissions during wood chips production (collection, delivery to storage site, and chipping) and produced biofuel transportation to energy production company was carried out according to the method, presented in EMEP/EEA air pollutant emission inventory guidebook - technical guidance to prepare national emission inventories (EMEP/EEA, 2016). Air emissions from the combustion and evaporation of fuel in all types of mobile sources could be evaluated according to the following equation:

$$E_p = FC \times EF \times 10^{-6} \qquad (3)$$

where

E_p - emission of pollutant (CO, NMVOC, NOx, TSP or PM, NH$_3$), tonnes; FC – diesel fuel consumption, kg per year, EF – specific emission factor for off-roan machinery or road transport, g kg^{-1} of used diesel fuel (see Table 1).

Methodology for the evaluation of GHGs from the combustion and evaporation of fuel is presented IPCC Guidelines for National Greenhouse Gas Inventories. Volume of GHG is calculated according to the following equation (IPCC, 2006):

$$GHGs = FC \times Q \times EF \times 10^{-6} \qquad (4)$$

where

GHGs: CO_2, CH^4 or N_2O, while burning various fuels, tonnes; FC – fuel consumption, tonnes; Q – Low heating value of fuel (GJ tonne^{-1}), in case of diesel

Table 1

Specific emission factors for evaluation of air emissions during biomass wood chips production and transportation to energy production company, g kg^{-1}

Specific emission factors	CO	NMVOC	NOx	TSP or PM	NH$_3$
1	2	3	4	5	6
[1]Off-roan machinery	7.673	1.997	28.471	0.943	0.008
[2]Road transport	7.58	1.92	33.37	0.94	0.013

Information sources:

[1]EEA/CORINAIR, 1.A Combustion, 1.A.4 Non road mobile machinery 2016, Tables 3.1, fuel – diesel, sector – Forestry.

[2]EEA/CORINAIR, 1.A Combustion, 1.A.3.b.i-iv Road transport 2016, Tables 3.5 – 3.7, category - HDV.

fuel – 43.07 GJ tonne^{-1}; EF – specific emission factor (g GJ^{-1} of fuel) (see Table 2).

Table 2

Specific emission factors for evaluation of air emissions during biomass wood chips production and transportation to energy production company, g GJ^{-1}

Sector:	CO_2	CH_4	N_2O
1	2	3	4
Road transport	74 100	3.9	3.9
Off-road machinery	74 100	4.15	28.6

Information sources:

[1]IPCC, 2006, Volume 3 "Energy", chapter 3 "Mobile combustion", tables 3.2.1 – 3.2.2 (fuel type – diesel, sector - road transport.

[1]IPCC, 2006, Volume 3 "Energy", chapter 3 "Mobile combustion", table 3.3.1 (fuel type – diesel, sector - off-road sources - Forestry).

Results and discussion

The initial environmental assessment aggregated information about the company's environmental impact. For this purpose, the most suitable way is to analyse material and energy flows and to create materials and energy balance. Energy production from wood chips material and energy flows are presented in Fig.1. Four cycles are presented in this diagram: extraction of main raw materials (forest harvesting), wood chip production from firewood and/or forest logging residues, produced wood chip transportation to biofuel combustion plant and biofuel combustion for energy production.

Monitoring of wood chips production

Technical information about widely used machinery within woody biomass production, incl. evaluated El_r in area of diesel fuel consumption is presented in Table 3.

In analysed company, tractor MTZ-82 is used both for the log wood and forest logging residues delivery from the harvesting site to the temporary log wood storage site (e.g., the access road). From the economic point of view, maximum distance for log wood delivery to storage site could be less than 1 km.

Two chippers are used for biomass chipping and chips wood production: rather new one - Pezzolato PTH 900/1000 and old one - Doppstadt AK 421 (see Table 3).

Fig. 1

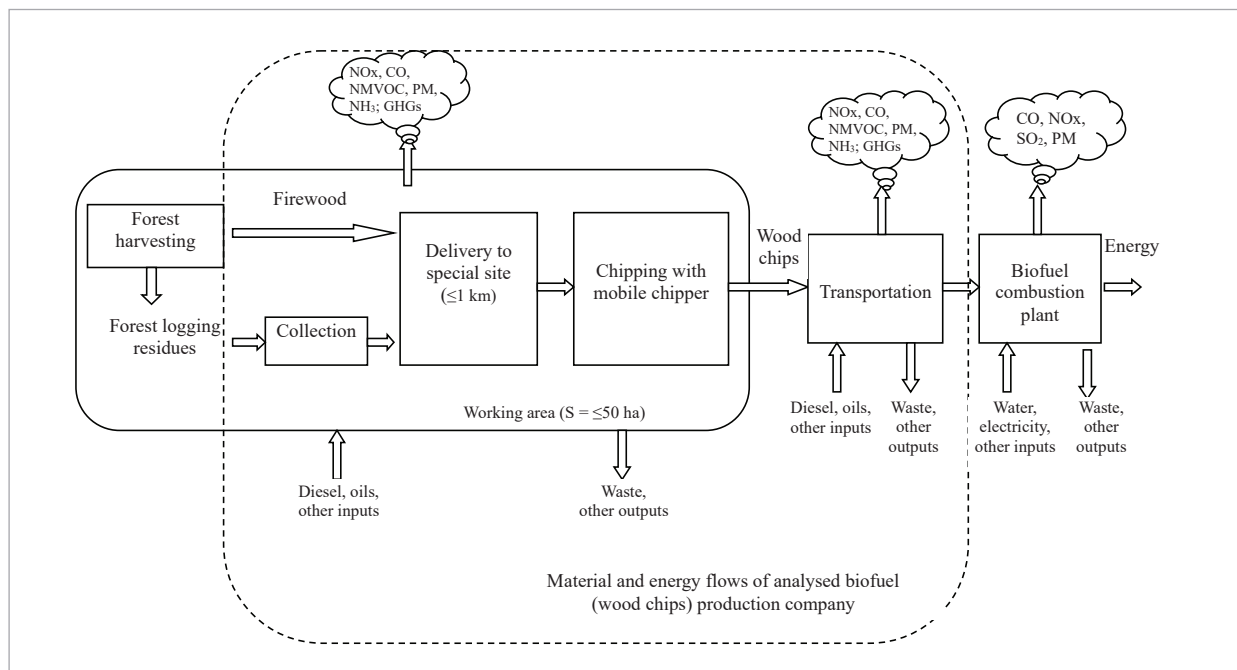Energy production from forest residues: material and energy flows diagram

Table 3

Technical data of machinery, used in analyzed company for wood chips production and delivery

Machinery	Model	Comments	Diesel fuel consumption (*El$_r$ was evaluated using equation 2*)
1	2	3	4
Tractor	MTZ-82	Maximum distance of wood haulage way (a forest track) – 1 km	[1]0.57 liters for 1 m^3 of firewood; [2]up to 2.286 liters for 1 m^3 of logging residues
Drum chipper	Pezzolato PTH 900/1000	Capacity – up to 300 m^3 of log wood per hour	[1]1.5 liters for 1 m^3 of firewood; [2]1.143 liters for 1 m^3 of logging residues
Chipper	Doppstadt AK 421 (1998)	Capacity - 36 m^3 of lops, logging residues, etc. per hour	[1]1.58 liters for 1 m^3 of firewood; [2]1.143 liters for 1 m^3 of logging residues
Truck with special hydraulic trailers (5 units)	Volvo FH-12	Capacity (V) - 36 m^3 of biofuel	[1]40 liters per 100 km

Information sources: [1]Company's data; [2]Dzenajaviciene et al., 2013.

Volvo FH-12 trucks with special hydraulic trailers with capacity 36 m^3 of biofuel (wood chips) or approx. 28 tonnes per trailer are used for biofuel transportation to combustion plant. From the economic point of view, maximum distance for produced biofuel delivery to combustion plant could be less than 100 km.

The following produced biofuel characteristics were evaluated in the Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry and were used for further evaluation of El$_r$:

_ density of wood chips is 0.78 tonnes m^{-3};

_ low heating value of wood chips made of firewood is 0.158 toe m^{-3}, or 6.63 MJ m^{-3}, or 8.52 MJ kg^{-1};

_ low heating value of wood chips made of forest logging residues is 0.142 toe m^{-3}, or 5.93 MJ m^{-3}, or 7.62 MJ kg^{-1}.

According to the company's data, the price of wood chips is distributed as follows:

_ Cost-price of raw materials (log wood) – 60-70%;

_ Cost-price of production (collection, delivery, processing) – 10-20%;

_ Cost-price of transportation to combustion plant (-s) – 10-20%;

_ Profit – 5-10%.

Price varies depending on type of log wood, the distances, the market price, etc. In 2015, average market price of biofuel (wood chips) in Lithuania during heating period was 147.78 Eur toe^{-1}, excl. VAT (Baltpool 2016). Variation of biofuel (wood chips and woof pellets) market price in Lithuania during 2016-2017 heating period is presented in Fig. 2.

Material and energy flows

In analysed company in 2015, 31.92 thousand tonnes of wood chips were produced from 21.6 thousand m^3 of firewood and the same volume of forest logging residues. The energetic volume of produced wood chips – 258350.4 GJ or 6171.77 toe. Over 268 thousand tonnes of diesel fuel (≈ 9703.8 GJ or 231.82 toe) were consumed, incl., over 52% - for biofuel transportation to combustion plants, approx. 25% - for biomass chipping and rest amount - for biomass delivery to special site.

Using experimental monitoring data and data of company's annual financial report, it was evaluated how much diesel fuel was used exactly for wood chips production made of firewood, incl. transportation (the results are presented in Fig. 3) and how much - for wood chips production made of logging waste
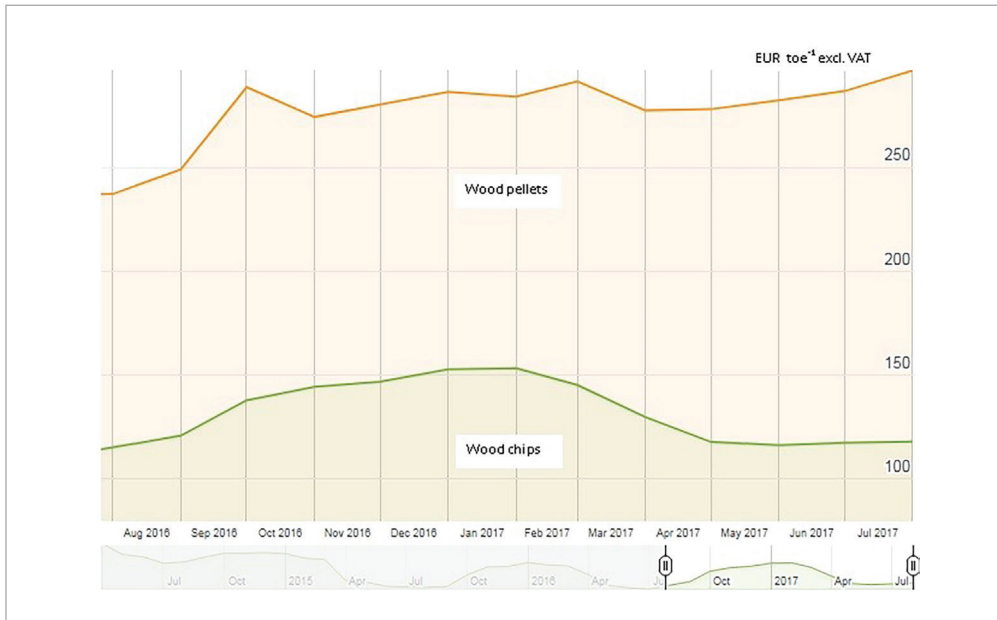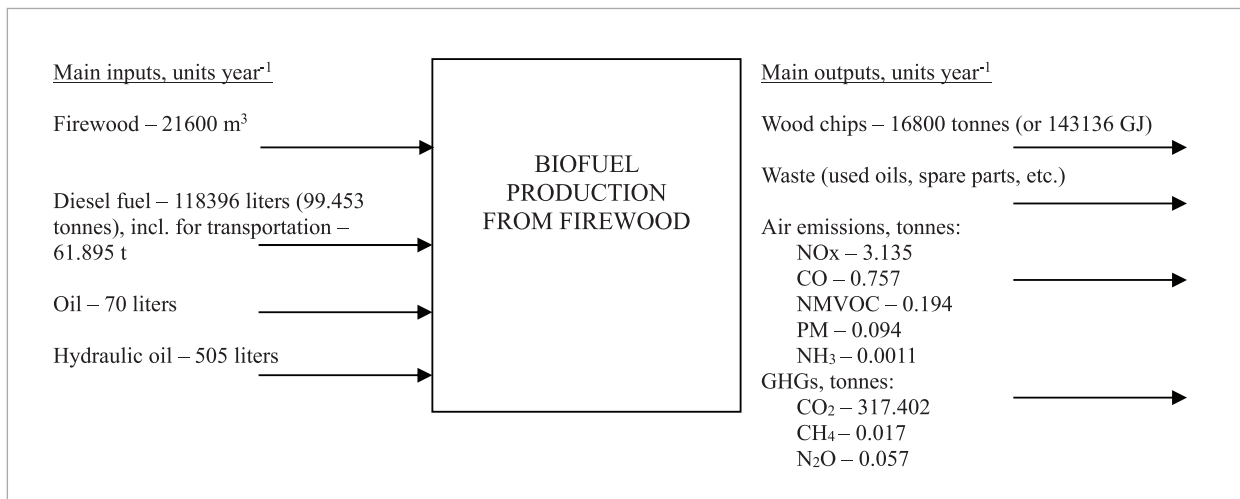
Fig. 3

Material and energy flows of wood chips production from firewood and transportation to combustion plant (-s), units year^{-1} (company's data, 2015)

(see Fig. 4). Fig. 4 Material and energy flows of analysed wood chips production from forest logging residues and transportation to combustion plant (-s), units year^{-1} (company's data, 2015)

Air emissions from mobile sources due to diesel fuel consumption for firewood and logging residues collection, delivery by tractor and chipping by mobile chippers were evaluated using equation 3 and specific emission factors for off-roan machinery (forestry). It was evaluated that 4.21 tonnes of emissions (CO, NO$_x$, NMVOC, PM, NH$_3$) are emitted to the air during these processes.

Air emissions from mobile sources due to diesel fuel consumption for manufactured biofuel transportation

Fig. 4

Material and energy flows of analysed wood chips production from forest logging residues and transportation to combustion plant (-s), units year^{-1} (company's data, 2015)
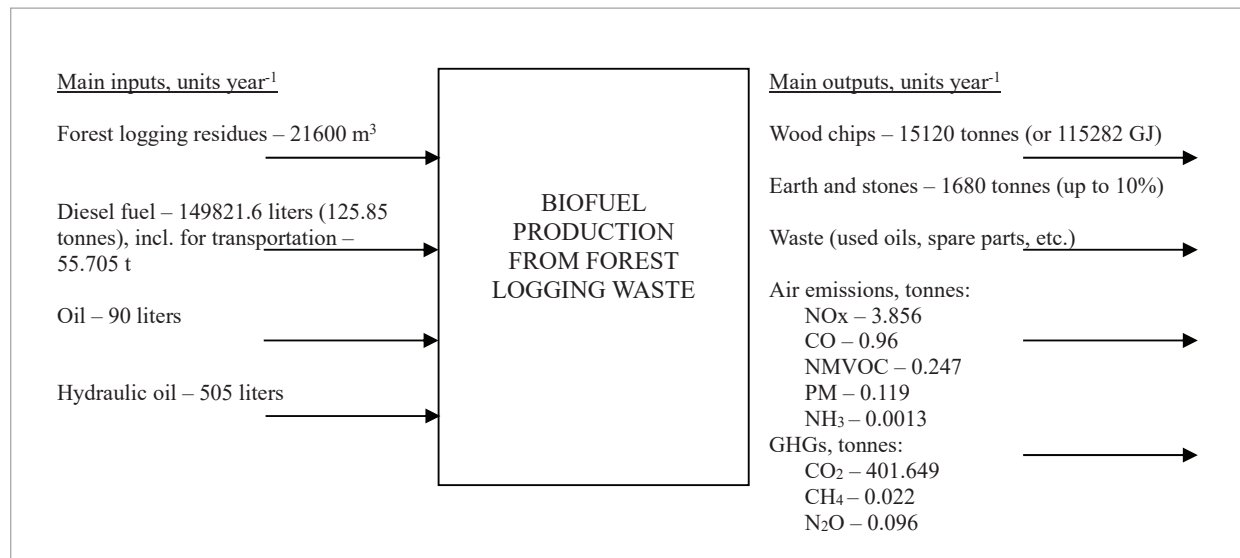

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Main inputs, units year^{-1}

Forest logging residues – 21600 m^3

Diesel fuel – 149821.6 liters (125.85 tonnes), incl. for transportation – 55.705 t

Oil – 90 liters

Hydraulic oil – 505 liters

BIOFUEL PRODUCTION FROM FOREST LOGGING WASTE

Main outputs, units year^{-1}

Wood chips – 15120 tonnes (or 115282 GJ)

Earth and stones – 1680 tonnes (up to 10%)

Waste (used oils, spare parts, etc.)

Air emissions, tonnes:
    NOx – 3.856
    CO – 0.96
    NMVOC – 0.247
    PM – 0.119
    NH$_3$ – 0.0013
GHGs, tonnes:
    CO$_2$ – 401.649
    CH$_4$ – 0.022
    N$_2$O – 0.096

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were evaluated using equation 3 and specific emission factors for road transport. It was evaluated that 5.154 tonnes of emissions (CO, NOx, NMVOC, PM, NH$_3$) are emitted to the air during wood chips transportation.

GHGs were calculated using equation 4 and specific emission factors from Table 2. It was obtained that 719.051 tonnes per year of CO$_2$, 0.039 tonnes of CH$_4$ and 0,152 tonnes of N$_2$O are emitted to the air. The global warming potential (GWP) of CH$_4$ is over 25 times bigger in comparison to CO$_2$ equivalent (eq.), N$_2$O gases is by 298 times bigger. Therefore, GWP of evaluated GHGs from wood chips production and transportation to combustion plant is 765,448 tonnes of CO$_2$ eq. per year or over 124 kg per toe of energetic volume of produced wood chips.

Results of comparison analyses

Relative environmental indicators were calculated using equation 1 and 2. Comparison of such indicators for wood chips production from firewood and forest logging residues are presented in Table 4. The results of comparison analysis show that:

– in case of evaluation of produced wood chips in mass units (in tonnes), producer consumes over 11% more biomass for biofuel production from forest logging

residues in comparison to biofuel production from firewood (up to 1.429 m^3 per tonne of wood chips), over 40% more diesel fuel (up to 8.323 kg per tonne of wood chips); approx. 37% more emissions (up to 0.343 kg per tonne of wood chips) and over 40% more GHGs are emitted to the atmosphere;

– in case of evaluation of energetic volumes of produced wood chips (in toe), producer consumes over 24% more biomass for biofuel production from forest logging residues in comparison to biofuel production from firewood (up to 7.848 m^3 per toe of wood chips), over 56% more diesel fuel (up to 0.047 toes per toe of wood chips); approx. 54% more emissions (up to 1.883 kg per toe of wood chips) and over 57% more GHGs are emitted to the atmosphere.

The main reasons are following: usage unfit machinery for forest logging residues' collection, old and worn-out equipment for biomass delivery to special site, usage of old chippers, less low heating values in comparison with wood chips from firewood, etc.

Possibilities to minimize environmental impact

Volume of diesel fuel and thus environmental impact to the air can be minimized by applying Cleaner Production (CP) prevention methods for forest logging waste

Table 4

EI$_r$ of wood chips production from firewood and forest logging residues

Relative environmental indicator	Dimension	Firewood	[1]Forest logging residues
1	2	3	4
Biomass consumption for biofuel production	m^3 tonne^{-1}	1.286	1.429
	m^3 toe^{-1}	6.317	7.848
Diesel fuel consumption for biofuel production	kg tonne^{-1}	5.920	8.323 *(7.662)*
	toe toe^{-1}	0.030	0.047 *(0.043)*
Total air emissions (CO, NOx, NMVOC, SP, NH$_3$) during biofuel production and transportation	kg tonne^{-1}	0.249	0.343 *(0.317)*
	kg toe^{-1}	1.223	1.883 *(1.741)*
GHGs (CO$_2$, CH$_4$, N$_2$O) during biofuel production and transportation	kg tonne^{-1}	18.897	26.572 *(24.460)*
	kg toe^{-1}	92.845	145.971 *(134.367)*

Comments:

[1]Figures in brackets are the evaluated indicators of disel fuel consumption, volume of air emissions and GHGs in case of the implementation of CP options for wood chips production from forest logging residues.

[2]Q of wood chips made of firewood is 0.158 toe m^{-3}; Q of wood chips made of forest logging residues is 0.142 toe m^{-3}.

collection and for collected biomass chipping chines (Virbickas, 2015). Applying methodology of CP implementation within production companies (Staniškis at al., 2010), the feasibility analysis of CP proposals was carried out. It was evaluated that using special head for skidder with purpose to collect forest logging residues will allow increasing efficiency of this process by 5-10 %, thus minimizing diesel fuel consumption per by 5% (till 2.172 litters per m^3 of biomass). Besides, electronic engine control of new modern skidders and forwarders ensures low energy losses, while enhancing fuel economy. The implementation of new modern chipper for wood chips production from forest logging residues will allow minimizing diesel fuel consumption within this technological process by 22-27% (depends on model) (till 1.143 litters per m^3 of biomass).

The implementation of suggested CP proposals will allow decreasing total volume of diesel fuel consumption for wood chips production from forest logging waste by approx. 8.5% (till 0.043 toe per toe of wood chips), in this case air emissions will decrease by 7.5% (till 1.741 kg per toe of wood chips), GHGs – by 7.9% (till 134.367 kg per toe of wood chips). Nevertheless, environmental impact to the air will remain much higher than in case of wood chips production from traditional firewood (see Table 4).

Conclusions and recommendations

The results of literature analysis show that Lithuania has a big potential of biofuel production from forest logging residues: up to 780 thousand m^3 year^{-1} of logging waste could be used for the production of wood chips with approx. 111 thousand toe of energetic value. Environmental risks due to removal of logging residues from forest and use as biofuel associate with the biodiversity loss, physical damage of forest soils, and air emissions from mobile and stationary sources on all woody biomass production chain.

Main results of the evaluation of material and energy flows of wood chips production in ordinary Lithuanian biofuel production company:

‒ optimal distance for delivery forest logging residues to special interim sites must be ≤ 1 km;

‒ optimal distance for transportation of woody biomass to combustion plant must be < 100 km;

_ density of wood chips is 0.78 tonnes m^{-3};

_ low heating value of wood chips made of forest logging residues is over 10% lower in comparison with wood chips made of traditional firewood and amounts 0.142 toe m^{-3}, or 7.62 MJ kg^{-1};

_ diesel fuel consumption for off-road purposes is up to 3.374 kg tonne^{-1} of produced wood chips;

_ diesel fuel consumption for wood chips transportation to combustion plant – up to 3.684 kg tonne^{-1} of produced wood chips and this indicator depends on distance to combustion plant;

_ amount of air emissions due to diesel fuel consumption is 0.293 kg tonne^{-1} of wood chips (or 1.517 kg toe^{-1});

_ GWP due to emitted GHGs from mobile sources is up to 765.448 tonnes of $CO_{2\,eq.}$ year^{-1} or 124.024 kg of $CO_{2\,eq.}$ toe^{-1} of wood chips.

Comparison analysis of material and energy flows of wood chips production determined that diesel fuel consumption within all stages of biofuel production from forest logging residues and transportation to combustion plant, exceeds diesel fuel consumption for biofuel production from firewood in average by 56.7% or by 43.3% in case of applying CP options. Equipment optimization or modernization will allow decreasing diesel fuel consumption from 0.047 toe toe^{-1} of wood chips to 0.043 toe toe^{-1} and thus decreasing volume of air emissions and GHGs by over 7.5%.

Recommendations for wood chips production from forest login residues:

_ It is necessary to properly assess the amount of logging residue in the harvesting site before their collection and usage for biofuel production, to evaluate economic and environmental aspects of this decision, especially in case of situation when distance between harvesting site and interim biomass processing site is ≥ 1 km.

_ It is necessary to find an optimal scenario of power and energy consumption within used machinery (equipment), to optimize the work and to carry out a detailed life-cycle assessment of usage forest logging waste for energetic purposes. Received environmental indicators could be successfully used for further evaluation step – LCA.

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Išmetamų oro teršalų ir šiltnamio efektą sukeliančių dujų analizė medienos biomasės gamybos grandinėje

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Visam pasauliui didinant energijos gamybą iš atsinaujinančių energijos išteklių, pirmauja biomasės - kietojo kuro gamyba. Straipsnyje apžvelgiama esama situacija Lietuvoje, galimas biomasės potencialas. Medienos skiedros gamybos procesų monitoringas, nustatant žaliavos, energijos sąnaudas produkcijos vienetui (m^3 medienos skiedros) atliktas 2015 metais įmonėje, kuri užsiima medienos skiedrų gamyba iš malkinės medienos ir kirtimo atliekų ir pardavimu katilinėms Kauno regione.

Naudojant monitoringo duomenis, straipsnyje analizuojama ar tikrai Lietuvoje naudojamo atsinaujinančioji kietojo biokuro energija yra tokia „žalia" aplinkai, kaip pateikta daugumoje tyrimų, teigiančių, kad deginant medieną į aplinką išsiskiria šiltnamio efektą sukeliančių dujų (ŠESD) kiekiai, kurie yra absorbuojami augalams augant. Tačiau visuose tyrimuose yra mažai vertinamas toks aspektas kaip biokuro gamybą, įsk., biomasės paruošimą, surinkimą, gabenimą iki tarpinių aikštelių, smulkinimą ir transportavimą iki biokurą deginančių įrenginių. Visų šių procesų metu sunaudojamas dyzelinis kuras, į aplinkos orą iš mobilių taršos šaltinių išmetami oro teršalai (CO, NOx, NMLOJ, KD, NH$_3$) ir ŠESD (CO$_2$, N$_2$O, CH$_4$). Šio klausimo aktualumas didėja, kai vertinama skiedrų gamyba iš miško kirtimo atliekų, pasižyminčiu mažesne žemutine šilumingumo verte.

Tyrime atlikta lyginamoji analizė, vertinant medienos skiedrų gamybos iš tradicinės malkinės medienos ir kirtimo atliekų poveikį aplinkos orui dėl dyzelinio kuro sąnaudų visoje biomasės gamybos grandinyje. Medienos akiedrų gamybos ir transportavimo metu, biokurui naudojant miško kirtimo atliekas į aplinką išskiriama net 57 % daugiau ŠESD (iki 145.971 kg per tne (tona naftos ekvivalento) biokuro) nei naudojant malkinę medieną. Apibendrinus tyrimo rezultatus matyti, kad norint turėti kuo mažesnį poveikį aplinkai ir pelningai vykdyti veiklą, biokuro gamyba iš miško kirtimo atliekų turi būti gerai pasverta ir organizuota, galbūt net papildomai remiama, persvarstant miško kirtimo atliekų panaudojimo strategiją. Būtina tęsti tyrimus ir atlikti pilną būvio ciklo analizę medienos biokuro gamybos ir naudojimo energijai gauti procesuose, nes tai itin svarbu šalims, kuriose biokuras yra populiariausia atsinaujinančios energijos rūšis.

Raktiniai žodžiai: biokuras, biomasė, miško medienos atliekos, oro emisijos, šiltnamio dujos, gamybos grandinė, atsinaujinanti energija.