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Life Cycle Inventory for winter and spring rapeseed production in Northern Europe

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ABSTRACT

Rapeseed is currently cultivated as an industrial crop in Latvia as a source of oil rich biomass to contribute to renewable energy goals of the European Union. However, rapeseed oil can also be used as a feedstock biobased polyurethane production. Latvian State Institute of Wood Chemistry have developed polyols based on rapeseed oil and have developed biobased and volatile organic compounds-free polyurethane coatings.

The main aim of this study was to present a Life Cycle Inventory of spring and winter rapeseed produced in Northern European country Latvia based on primary data of agricultural practices used in this region. The study was carried in accordance with ISO 14040 and ISO 14044. Data were collected from a large crop company in Latvia to ensure a specific and accurate data collection for the definition of the complete supply chain. The reference unit of this study was defined as 1 ha, time horizon 2008–2016, stages from the raw materials production to the seed harvesting were considered. The data presented will add to and expand the existing knowledge of rapeseed production in other European countries.

Lastly, this paper is the first in a series of papers that will result in a complete Life Cycle Assessment for these develop polyurethane coatings based on rapeseed oil polyols to avoid black box unit process and provide transparent results.

1. Introduction

Oil crops are an attractive raw material for the polymer industry and have been studied intensively by both, academia and industry, to find more sustainable feedstock for the industry. Different vegetable oils, such as castor (Mutlu et al., 2010), soybean (Petrovic et al., 2007), palm (Markovich et al., 2017), jatropha (Saalah et al., 2015) and rapeseed (Zieleniewska et al., 2015; Stirna et al., 2014) have been studied as a biobased feedstock for polyurethane (PU) materials. PU is synthesized in a reaction between isocyanate moiety containing isocyanate groups (-NCO) and polyol components containing hydroxyl groups (-OH) (Ionescu, 2005). Due to its versatility, PU is one of the most widely used polymers. The global biobased PU market is expected to reach ~ USD 38 million (Jan 2015) by 2020. The global biobased market was 1634.0 tons in 2013 and is expected to jump to 2546.6 tons by 2020. The building industry is mentioned as the largest end-use industry for the biobased PU market and accounted for 35% of total volume in 2013 (Biobased polyurethane market analysis, 2015).

Furthermore, oil crops are an attractive renewable energy resource even if some are the first generation type of biofuel. Despite being first generation feedstock, different oil crops are intensively used for biodiesel production. Depending on the region, different oil crops are the main feedstock for biodiesel production – in Europe it is rapeseed, which is grown throughout Europe; in the US it is soybean; and palm oil in the Asian region. From 2007 to 2012, EU biodiesel production grew 57%. In 2015, the production of biodiesel reached 11,067,800 tons in 28 member states of the European Union (EU-28), with the majority of production coming from Germany with 2,765,400 tons, followed by France with 2,139,100 tons. Latvia produced 65,700 tons of biodiesel according to Eurostat (2017a). Rapeseed oil is the main feedstock for biodiesel production in the European Union (EU), accounting for 49% of total production in 2015 (EU Biofuels Annual, 2016).

Rapeseed (*Brassica napus*) is a widely cultivated crop around the world due mainly to its oil rich seeds. It is the second largest source

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of vegetable oil in the world with production of 70.19 million metric tons; the first largest source is soybean with 312.81 million metric tons in 2015/2016. In EU-28, in 2015/2016, the production of rapeseed oilseed came to 22,195,000 tons and 198,000 tons of rapeseed oilseeds were imported. Domestic consumption of rapeseed oil reached 10,050,000 tons, from which 71.1% is for industrial (biodiesel, lubricants, other), 28.4% for food consumption (cooking, frying, as an ingredient), and 0.5% as a feed (USDA, 2017). Rapeseed is a widely cultivated crop also in Latvia. Since 2000, the amount of land devoted to rapeseed cultivation has increased vastly. In 2000, 8400 ha were used for rapeseed cultivation; by 2016 it reached 101,000 ha ha (CSB, 2017) from which 75,100 ha (74.3%) was winter rapeseed and 26,000 ha (34.6%) was summer rapeseed (CSB, 2017). Land used for rapeseed cultivation was 8.3% of the total sown area of agricultural crops (1223.9 thousand ha) in Latvia in 2016 (CSB, 2017). One of the reasons for this rise is rapeseed cultivation was the EU's Sugar policy which began in 2006. As a result of major reforms, two Latvian sugar refineries - the Liepaja Sugar Refinery in western Latvia and the Jelgava Sugar Refinery in central Latvia - were closed in 2007 (Ermsone, 2010). Approximately 14,000 ha were used for sugar beet cultivation in 2000–2006. Another reason for the increase in rapeseed cultivation was increased demand for rapeseed due to increase in biodiesel production.

However, since intensive agricultural practices are used for rapeseed cultivation and there has been an exponential growth of rapeseed production, the sustainability of rapeseed production is questioned due to emissions from biodiesel cultivation and indirect land use change (iLUC). The EU has acknowledged this in its Directive (EU) 2015/1513 (2015), the "iLUC Directive," which amended Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Now the contribution of biofuels produced from "food" crops (to the 10% renewables in transport target) is capped at 7% (Directive (EU) 2015/1513). However, now biodiesel is the most important biofuel in the EU and, on an energy basis, represents 80.6% percent of the total transport biofuels market in 2014 (Biofuels barometer, 2017).

Also, as mentioned above, food and energy crops are also attractive sources of feedstock for the polymer industry to produce more added value products. The polymer industry is also using first generation feedstock as a potential replacement for petroleum based products. There are already several biobased polyol plants up and running in Europe where different vegetable oils are used as a feedstock for polyol production. Given this situation, sustainability is becoming an important facet to be deeper explored. However, there has been little assessment of sustainability through the use of quantitative tools such as Life Cycle Assessment (LCA). There are few published LCA studies of biobased polyols. There is a need for in-depth research regarding the environmental sustainability of biobased PU materials.

Latvian State Institute of Wood Chemistry have developed polyols based on rapeseed oil and have developed biobased, spray applied and 100% volatile organic compounds-free PU coatings (Fridrihsone-Girone et al., 2016). This paper is the first in a series of papers (Fig. 1) that will result in a complete LCA for these develop PU coatings based on rapeseed oil polyols.

According to the LCA methodology developing the Life Cycle Inventory (LCI) part is the most difficult and time-consuming aspect of the whole study. In fact, LCI is a key aspect dealing with the quantification, definition and gathering of a specific in- and out-data set. In this case a process-based LCI method has been selected in order to create a specific inventory for the analyzed system within the considered regions. At the LCI stage the scientific hypothesis it is essentially lying on the novel inventory created within the research work.

This study aims to define a LCI for both winter and spring rapeseed production using primary data sources that are actual agricultural practices used in Latvia as Northern European country. This paper will expand knowledge concerning rapeseed production with respect to regionalized LCI studies. Data were collected from a large crop company in Latvia to ensure a specific and accurate data collection for the definition of the complete supply chain.

2. Methods

The study is carried out according to the ISO Standard 14040 (2006) and ISO Standard 14044 (2006).

2.1. Goal and scope definition

The goal of this study is to carry out a cradle-to-gate LCI of rapeseed (both spring and winter) production in Latvia, to be further involved in a cradle-to-grave LCA for biobased PU using polyol from rapeseed. The starting point is cradle-to-gate perspective – from raw materials production to seed harvesting. The inventory has been carried out to identify and quantify the inputs and outputs associated with the production of oilseed rape in the Zemgale region of Latvia.

2.2. Functional unit

The functional unit (FU) for this study was set as 1 ton of rapeseed. The reference flow selected for this study was 1 ha. It should considered that on average, 1 ha produces 3.5 tons of winter rapeseed and 2.5 tons of spring rapeseed.

2.3. System boundary

The system boundary of oilseed rape production is presented in Fig. 1. Rapeseed cultivation includes soil preparation, fertilization, sowing, weed control and harvesting. The system boundary of the LCI study was chosen in order to show comprehensively inputs and outputs for rapeseed cultivation unit process and to avoid black box unit processes and provide transparent, reproducible results. The selection of the foreground system was based on cut-off criteria approach in fact excluding unit processes contributing less than 1% of the whole life cycle. The product system represented in Fig. 1 is based on actual agricultural practices in the region of the study.

2.3.1. Geographical boundaries

Oilseed rape is grown in the Zemgale region in a cereal and oil seeds production company. The Zemgale region is located in the central part of Latvia and in the central part of the Zemgale plain (Fig. 2). Zemgale has very high proportion of arable land and the most fertile agriculture land of Latvia (Melece and Lakovskis, 2014); it also has a developed agriculture and agricultural processing industry. Zemgale is known as Latvia's granary (SIF, 2017).

All of the components needed for rapeseed production are produced outside Latvia and are imported.

2.3.2. Time horizon

The goal of this study was to use as recent data as possible. Data on the rapeseed growing/production are from actual numbers from 2008 to 2016.

Data about spring oilseed rape production is from 2008 to 2014. For winter rapeseed, the data is from time period 2008–2016.

2.3.3. Data requirements

The goal has been to be as accurate as possible and avoid assumptions as much as possible. The LCI data for the foreground

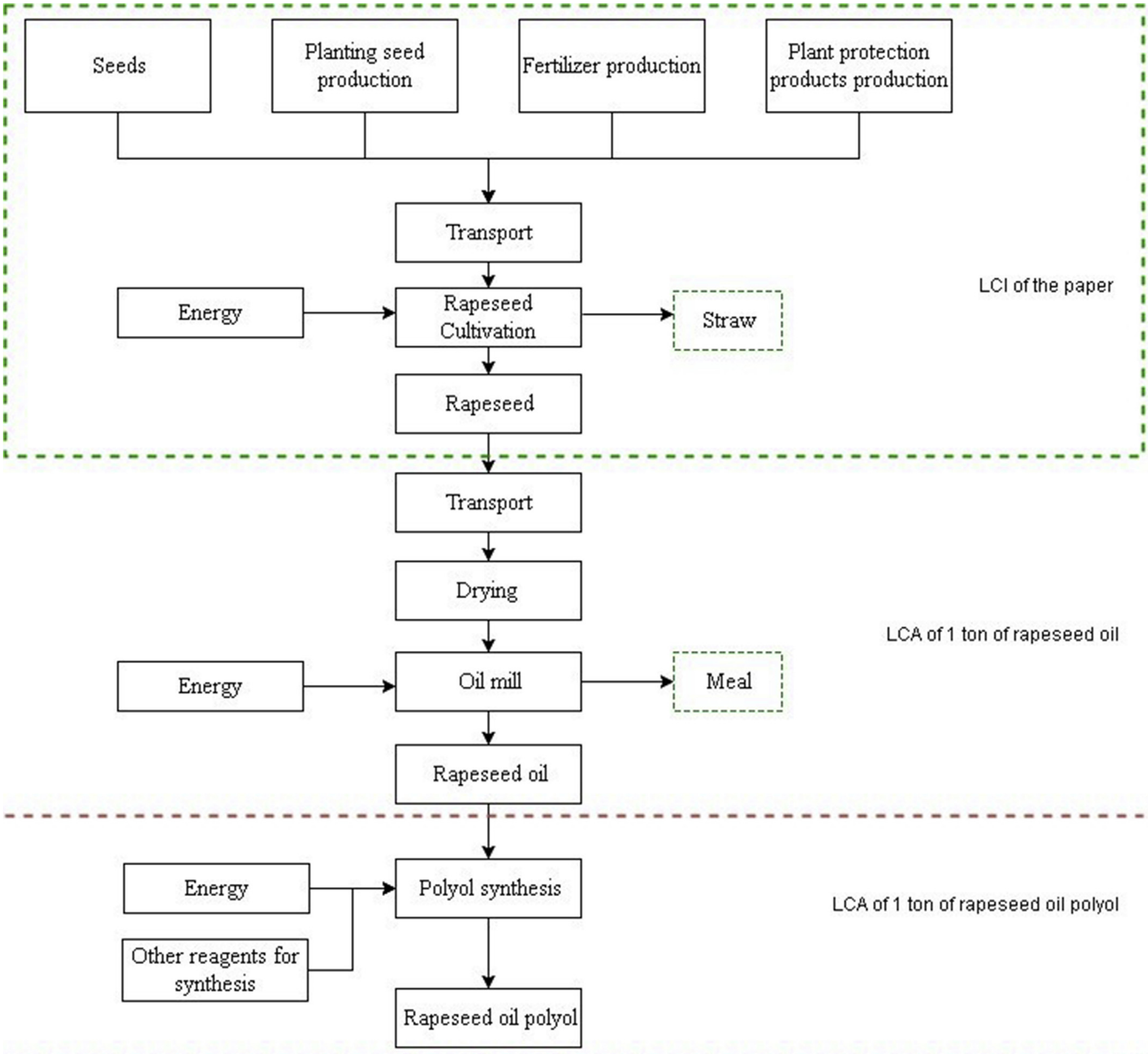

Fig. 1. The system boundaries of LCI of the paper and rapeseed oil polyol production

system (data about yield, use of plant protection products, fertilizers, seeds, the kind of agriculture machinery used and other data related to agricultural practices used) were collected from the lead agronomist at one of the largest agricultural companies in Latvia.

Data about fertilizers, plant protection products and the seed supply chain - from factory/warehouse to farming company—were collected from distributors/importers in Latvia. If data about the complete supply chain or a specific element was not available, a consistent assumption was made. Assumptions will be discussed in sections where the LCI data will be described. Cut-off rules have not been applied. The goal was to be as accurate as possible.

2.3.4. Data provider

The agricultural company providing the data is one of the largest crop farming companies in Latvia. In 2015, the company had 5742 ha of land from which 1083 ha (18.9%) is used for winter rapeseed cultivation in (Katanenko, 2017). In 2015, the average total land area per agricultural holding was 35.9 ha, of which agricultural area was 24.3 ha. In 2016, Latvia had 82,400 agricultural holdings (CSB, 2017).

3. Results and discussion

In LCI information and data are reported with reference 1 ha, it should considered that from 1 ha an average of 3.5 tons of winter rapeseed and an average of 2.5 tons of spring rapeseed are obtained.

3.1. Land

The lead agronomist reported that the average organic matter content of soil is 3.4% and pH is 7.4. The soil has a normal humidity

Fig. 2. Location of Zemgale in Europe.

regime being sandy loam or loam sod-calcareous soil. The soil is not limed (Katanenko, 2017). In this study, a transformation from arable to arable land is taking place because rapeseed is being cultivated on existing local agricultural land. No artificial irrigation is applied on rapeseed fields, only natural irrigation (rain).

3.2. Winter and spring rapeseed yields

Yields of winter and spring rapeseed produced in Zemgale, Latvia are depicted in Fig. 3a and b. The average yield for winter rapeseed was 3.5 t/ha. The average yield for spring rapeseed was 2.5 t/ha in during the period 2008–2014. In 2014, a harsh winter and unusual freezing conditions caused a large acreage of winter rapeseed to freeze, and the company was forced to plant spring rapeseed in spring and that resulted in an increase in spring rapeseed cultivation. After 2014, the company discontinued spring rapeseed cultivation due to attacks of flea beetles. Spring oilseed rapeseeds can't be treated because of bees, and thus crop fields have to be sprayed all the time (Katanenko, 2017).

In Europe, rapeseed is mainly grown as a winter crop as it generates the highest seed and oil yield of oil seed crops (Singh, 2013). The average yield of rape and turnip rape yield of EU-28 is 3.4 t/ha as reported by Eurostat (Eurostat, 2017b). However, rapeseed yield varies across Europe depending on soil type, climatic conditions, agricultural management practices, time of planting and other factors and also information about yield differs from source to source. The highest yields typically are harvested in Central and Eastern Europe (Singh, 2013). In 2014, in Germany the average yield of rapeseed was 4.5 t/ha, in France it was 3.7 t/ha (Faostat, 2017). Grau et al. (2013) reported a yield of 2.3 kg/ha for rapeseed cultivated in the Mediterranean region where yield is lower than in middle Europe wet lands. According to Faostat (2017), the average yield for Northern Europe is 2.8 t/ha in 2014; the best performer was Denmark with 4.3 t/ha followed by UK and Ireland with 3.6 t/ha, Sweden – 3.4 t/ha. The yield below 2.5 t/ha was for remaining countries in the region – Estonia, Finland, Latvia, Norway. However, in other sources yield differs as for France the reported yield is 3.3 t/ha Ademe (2010), Dalgaard et al. (2008) describes a yield of 2.8 t/ha for rapeseed cultivation in Denmark. Faostat (2017) reports very low rapeseed yield for Latvia in 2014, but according to CBS (2017) the winter rapeseed yield has increased since 2014 with 3.0 t/ha in 2015 and 2.5 t/ha in 2016.

3.3. Materials

Materials for rapeseed production include planting seed, pesticides and fertilizers.

3.3.1. Planting seed material

The agricultural company in the Zemgale region in Latvia is effectively using only hybrid seeds for rapeseed breeding and production. Hybrid varieties can be used only for one year without

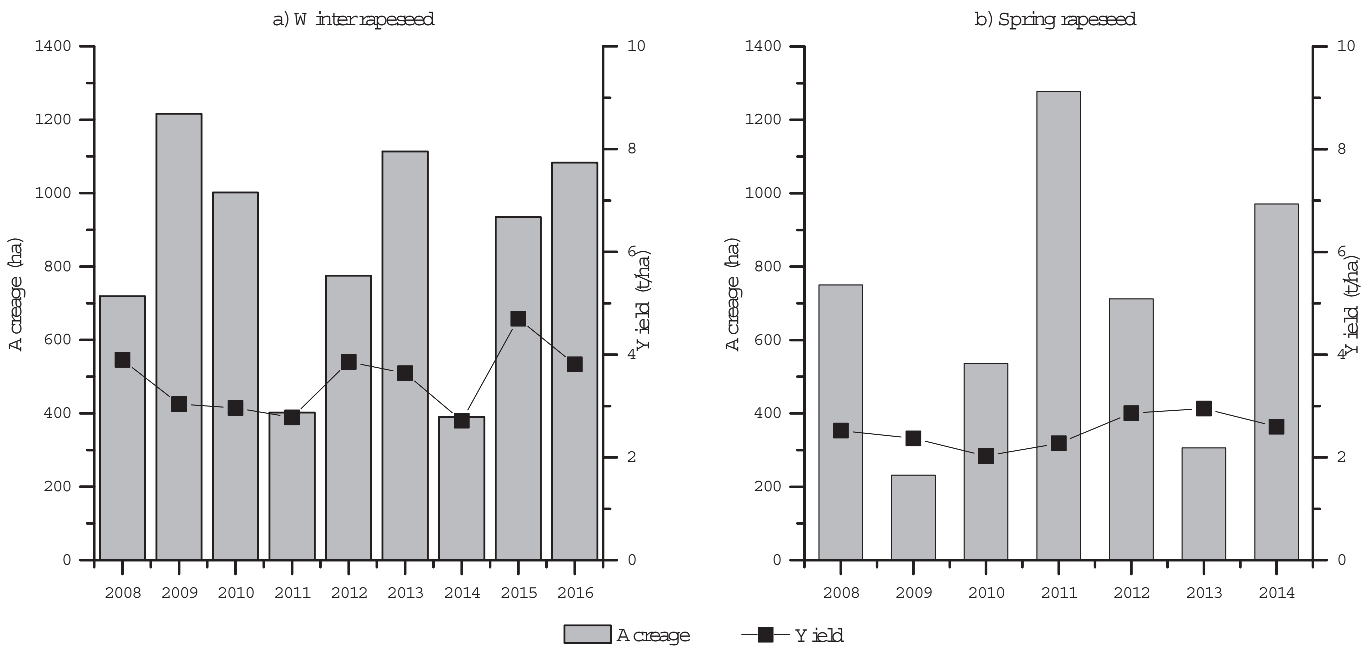

Fig. 3. Yield of winter (a) and spring (b) rapeseed produced in Zemgale, Latvia.

changes in the properties, because the next generation of plants from those hybrids will not have the uniform characteristics of their parental lines. Rape plants are not uniform, they ripen unevenly and are unevenly prolific (Katanenko, 2017). Thus, the agricultural company buys new seeds every year. Other papers mostly do not report and specify what kind of seed is used – hybrid or open pollinated seeds. However, in terms of cultivation, there is a trend towards an increased use of hybrids in all major canola and oil seed rape-growing areas worldwide. In Germany, Great Britain and France, from 50 up to70% of rapeseed acreage uses hybrid seeds (Singh, 2013; Ropelewska et al., 2017).

The agricultural company uses several (five) winter rapeseed breeds from different breed selectors with planting seed input ranging from 3.6 to 6 kg/ha to achieve the desired plant density. Seeds are delivered from Sweden, Germany and Denmark. Germany was chosen as a country of origin as it is the farthest point from Latvia. For spring rapeseed, the company used two different breeds from a company located in Sweden. The average planting seed input needed for winter and spring rapeseed is presented in Table 1.

3.3.2. Fertilizers

Fertilizers used for rapeseed cultivation include nitrogen, potassium, sulphur and phosphorus. The need for fertilizers depends on whether the crop is winter or spring rapeseed, as well as on soil type and climate, the previous crop (Schmidt, 2007); thus fertilizer use differs for rapeseed cultivation in different countries.

The lead agronomist reported a standard fertilizing scheme the company uses for winter and spring rapeseed (Table 2). The yearly dosage can change ±10% depending on various factors. The company does not take into account nutrients from the previous crop

Table 1
Planting seed input for 1 ha of winter and spring rapeseed.

Type	Average planting seed input (kg/ha)
Winter rapeseed	4.8
Spring rapeseed	4.0

Table 2
Fertilizer application rates.

Applied fertilizer product	Applied nutrient	Winter rape	Spring rape
		Value (kg/ha)	
NPKS 4-16-34-2S	Dosage	380.0	380.0
	Nitrogen	15.2	15.2
	P_2O_5	60.8	60.8
	K_2O	129.2	129.2
	Sulphur	7.6	7.6
Ammonium nitrate	Dosage	300.0	220.0
N34.4	Nitrogen	103.2	75.7
Ammonium sulphate	Dosage	180.0	160
N21 + S24	Nitrogen	37.8	33.6
	Sulphur	43.2	38.4
KAS N25 + S3	Dosage	260.0	250.0
	Nitrogen	65.0	62.5
	Sulphur	7.8	7.5
Total	Nitrogen	221.2	187.0
	Sulphur	58.6	53.5
	P_2O_5	60.8	60.8
	K_2O	129.2	129.2

and the standard fertilizing scheme is not adjusted to this factor. At times, the company also uses pig slurry; however since the amount and area applied varies significantly, this factor was not taken into account. The difference between dosage and applied nutrient is due to other compounds/additives present in the fertilizer to make it mechanically and chemically stable. Most of the additive is calcium sulfate.

The total nitrogen fertilizer application rate reached 221.2 kg N/ha for winter rapeseed and 187 kg N/ha for spring rapeseed. Schmidt (2007) reported N-norm of 171 kg N/ha with 3.6 t/ha yield for winter rapeseed on mixed sand and clay soil (52% of Denmark's agricultural soil). The nitrogen level for winter rape recommended in Germany is up to 250 kg N/ha; for spring rape the recommended level is up to 180 kg N/ha (El Bassam, 2010). Dutch cultivation practices give an application of 200–250 kg N/ha for rapeseed cultivation representing two case studies with a yield of 3.9 and 4.0 t/ha (Marinussen et al., 2012).

Table 3
Micronutrient application rate.

Type	Micro-nutrient	Dosage (L/ha)	Active ingredient content (g/L)	Active ingredient (g/ha)
Micro-element-1	Nitrogen	2.0	80	160
	Magnesium		90	180
	Sulphur		80	160
	Boron		50	100
	Manganese		90	180
	Molybdenum		4	8
Micro-element-2	Nitrogen	3.0	350	1050
	Magnesium oxide		47	141

The total P_2O_5 application reached 60.8 kg/ha. The recommended P_2O_5 level for winter and spring rape cultivated in Germany is 80–100 kg/ha, respectively (El Bassam, 2010). Marinussen et al. (2012) gives a value of 55 and 70 kg P_2O_5 for the two case studies, representing a yield of 3.9 and 4.0 tonnes of rapeseed/ha.

Concerning potassium, K_2O fertilizer 129.2 kg/ha are applied for both winter and spring rape. German standards report up to 120 kg/ha for spring rapeseed and 180–220 kg/ha for winter rapeseed (El Bassam, 2010). The average use of K_2O for rapeseed cultivated in France and Germany was 82 kg/ha (Marinussen et al., 2012).

Other fertilizers are also used. Sulphur is reported in Table 2 as it is applied in complex fertilizer together with macro-nutrients (N, P, K). The company also uses micronutrients as reported in Table 3.

If a micronutrient producer has allowed to make the mixtures, few of the plant protection products are applied together with micronutrients, the mixtures are made. The company uses this practice to save time and fuel.

3.3.3. Plant protection products

During cultivation of rapeseed, plant protection products, commonly referred to as pesticides, are used to destroy pests and prevent diseases. Detailed data about the quantity of plant protection products used and active ingredients in those products for winter and spring rapeseed production is given in Table 4. The formulas and active ingredients in plant protection products were obtained from the State Plant Protection Service that publishes the List of Registered Plant Protection products in the Republic of Latvia every year (SPPS, 2016). Plant protection products are sprayed on the fields and thus they are diluted with water. Plant protection products without active ingredients also contain other ingredients. Water for dilution and other ingredients present in plant protection products were ignored.

The total of plant protection products used reached 5 L/ha for winter rapeseed and 6.6 L/ha for spring rapeseed.

Overall data about plant protection product use and their representation is a "grey zone" in LCA papers. Other authors report total pesticide use per hectar without giving details about specific pesticides or their active ingredients; yet others report kg of active ingredients per hectar.

3.4. Rapeseed straw

Rapeseed straw is a by-product of rapeseed production. There is a large amount of rapeseed straw generated from the harvest of rapeseed. Different straw to seed ratios are reported by different authors. The agricultural company reported that their straw to seed ratio is 2:1 (Katanenko, 2017). Graef et al. (1995) reported a straw to seed ratio of 1.7 to 1. The agricultural company located in Zemgale implements an agricultural management practice type where the remaining biomass generated (stalks, pods and leaves) is left on the field and incorporated back into the soil. Rapeseed straw was incorporated back into soil at a depth of 10–12 mm using disc cultivators. The above mentioned agricultural management practice presents several benefits, namely enhances the organic content of the soil, which is beneficial for the next crop as a soil nutrient, and improves the structure of the soil and prevents soil erosion (Desroches et al., 2012; Börjesson and Tufvesson, 2011).

Table 4
Plant protection products used for winter and spring rapeseed production expressed per ha.

Type of plant protection product	Active ingredient name and CAS#	Dosage (L/ha)	Active ingredient content (g/L)	Active ingredient (g/ha)	Comments
Herbicide-1	Metazachlor 67129-08-2	2.5	333	832,5	
	Quinmerac 90717-03-6		83	207,5	
Herbicide-2	Propaquizafop 111479-05-1	1.0	100	100	Winter rape only
Insecticide[a]	λ-Cyhalothrin 91465-08-6	0.2	50	10	
Fungicide applied as growth regulator	Metconazole 125116-23-6	0.7	90	63	
Fungicide-1[a]	Deltamethrin 52918-63-5	0.1	50	5	
Fungicide-2[a]	Cyproconazo 94361-06-5	0.6	80	48	
	Azoxystrobin 131860-33-8		200	120	
Desiccant	Diquat dibromide 85-00-7	2.5	150	375	Summer rape only

[a] Plant protection product applied together with micro-elements reported in Table V.

3.5. Agricultural machinery

Fuel consumption for each field work process has been well documented by the lead agronomist of the company. The agricultural machinery, diesel consumption related to cultivation of rapeseed and operation per year is shown in Table 5. Fuel consumption is referred to diesel fuel consumption.

It is meaningless to compare diesel consumption for different countries, as it varies depending on the soil type and on the condition of the agricultural machinery, its age, model type and horsepower.

3.6. Transport

The transport of input materials – planting seeds, fertilizers and plant protection products – has been defined as accurately as possible, in terms of mode and distance. The transport of goods related to the agricultural stage for rapeseed, both spring and winter types, are depicted in Table 6. Information was gathered from the producers and/or distributors of the products. The origin is specified: some distribution chains start at the producer, some at the distributor. In the case of the latter, most often local distributors were able to give information only about the last distribution chain link. The transported amount of input materials needed for the production of rapeseed in regards to the reference flow is considered. For plant protection products and micro-elements, to calculate mass instead of volume per ha, the density provided in safety

Table 5
Specific diesel consumption for different fieldwork process.

Field work process		Diesel consumption (L/ha)		Operations per year
		Winter rapeseed	Spring rapeseed	
Tilling	Tilling – turn over the soil	0	27.0	1
	Disc cultivation	7.5	7.5	1
	Drag harrowing	0	8.6	1
Sowing	Sowing	16.2	9.6	1
Fertilizing	Application of fertilizer	1.1	1.1	2 -3 times, depending on the need
Spraying	Application of plant protection products	0.83	0.83	4-7 times, depending on the need
Harvesting	Combine harvesting	20	20	1
	$Total_{min}$	49.2	78.2	
	$Total_{max}$	52.8	81.8	

Table 6
Transport of goods related to the agricultural stage for rapeseed.

Input material	Type[a] W or S	Amount per ha, kg	From	To	Distance, km	Mode, size	From	To	Distance, km	Mode, size
Seed	W	5.8	Producer in DE	Storage in LV	1600	Truck, 24 t	Storage in LV	Company warehouse	65	Truck, 10t
	S	4.0	Producer in SE	Port in Riga	900	Ship, no info	Port in Riga - Storage in LV	Company warehouse	120	Truck, 10t
Fertilizer NPKS 4-16-34-2S	W, S	380	Producer in BY	Storage in LV	600	Truck, 24 t	Storage in LV	Company warehouse	70	Truck, 24 t
Fertilizer - Ammonium nitrate	W S	300 220	Producer in LT	Storage in LV	210	Truck, 24 t	Storage in LV	Company warehouse	45	Truck, 24 t
Fertilizer - Ammonium sulphate	W S	180 160	Producer in LT	Company warehouse	280	Truck, 24 t	–	–	–	–
Fertilizer – KAS N25 + S3	W S	260 250	Producer in LT	Storage in LV	210	Truck, 24 t	Storage in LV	Company warehouse	45	Truck, 24 t
Herbicide-1	W, S	2.8	Port in DK	Port in LV	1100	Ship, no info	Port in LV	Company warehouse	80	Van
Herbicide-2	W	1.0	Producer in IL	Storage in LT		Truck, 24 t	Storage in LT	Company warehouse	–	–
Insecticide	W, S	0.2	Storage in PL	Company warehouse	600	Truck, 24 t	–	–	–	–
Fungicide as growth regulator	W, S	0.7	Port in DK	Riga port	1000	Ship, no info	Port in LV	Company warehouse	80	Van
Fungicide-1	W, S	0.1	Port in DK	Riga port	1000	Ship, no info	Port in LV	Company warehouse	80	Van
Fungicide-2	W, S	0.7	Storage in PL	Company warehouse	600	Truck, 24 t	–	–	–	–
Desiccant	S	2.9	Storage in PL	Company warehouse	600	Truck, 24 t	–	–	–	–
Micro-element-1	W, S	3.1	Port in UK	Port in LT	2500	Ship, no info	Port in LT	Company warehouse	270	Van
Micro-element-2	W, S	3.0	Producer in PL	Company warehouse	600	Truck, 24 t	–	–	–	–

DE – Germany, LT-Lithuania, LV – Latvia; DK – Denmark; UK – United Kingdom; PL- Poland; IL- Israel; BY-Belorussia; Sweden - SE.
The transport of goods for spring and winter rapeseed is summarized in Table 7.
[a] Type: Winter rapeseed – W; Spring rapeseed - S.

data sheets was taken. The type of the ship is not known, so an assumption will have to be made in the next LCA paper. It was not possible to obtain more detailed information about the transportation of micro-nutrient 2 other than it is delivered from Poland.

Table 7
Summary of transport in the agricultural stage for winter and spring rapeseed.

	Winter	Spring
Transport mode	Ton-kilometer	
10 t truck	0.4	0.5
24 t tuck	462.3	421.5
Ship	11.6	15.2
Van	2.9	2.9

3.7. Emissions

3.7.1. Emissions of the application of plant protection products

Pesticide emissions occur during and after the application of plant protection products in agriculture. The rate and extent of emissions are affected by many factors, including the properties of the pesticides, soil and crop type, application method and environmental variables (wind, temperature, soil moisture content, soil type and structure). Due to the increased use of pesticides over the last decades and due to their toxic nature and potentially adverse health effects, the use of plant protection products and emissions have caused great public concern (Berg et al., 1999; Sarigiannis et al., 2013). It is reported that on average, 25% of all pesticide used is released into the air (EMEP/EEA, 2016).

Emissions data related to the application of pesticides were estimated according to the method proposed by the Air pollutant emission inventory guidebook by EMEP/EEA (2016). To calculate emissions, it is necessary to know the applied quantity and pesticide vapor pressure. The emissions factors (EFs) are derived from the vapor pressure of the pesticides. The amount of active

Table 8
Emissions from plant protection products to air.

Type	Active ingredient	Vapor pressure, mPa[a]	EF	Air emissions (kg/ha)
Herbicide-1	Metazachlor	9.3E-02	0.05	0.042
	Quinmerac	1.0E-07	0.01	0.002
Herbicide-2 (only winter rape)	Propaquizafop	4.4 E-07	0.01	0.001
Insecticide	λ-Cyhalothrin	2.0E-04	0.01	0.0001
Fungicide applied as growth regulator	Metconazole	2.1E-05	0.01	0.00063
Fungicide-1	Deltamethrin	1.24E-05	0.01	0.0001
Fungicide-2	Cyproconazo	2.6E-02	0.05	0.0024
	Azoxystrobin	1.1E-07	0.01	0.001
Desiccant (only summer rape)	Diquat dibromide	1	0.15	0.05625

[a] IUPAC PPDB, 2017.

ingredients applied is given in Table 4. Results are summarized in Table 8.

3.7.2. Heavy metal content in fertilizers

Elemental contaminants, known as heavy metals, are present in the fertilizers. Heavy metals are toxic elements that may express their pollutant potential directly on soil organisms, due to the availability to plants in phytotoxic levels. They also have the ability to transfer to the food chain through the plants or by contamination of soil and water resources (Gonçalves et al., 2017). To date, there is very little reporting on heavy metal content in fertilizers and their impact in oilcrops' LCAs. Information about heavy metal content in fertilizers and harvested crops and residues of crops is scattered among sources, in time and locations. Schmidt (2007) reported on heavy metal emissions from rapeseed cultivation and carried out a sensitivity analysis where he found that heavy metals constitute only a minor share (0.065%) of the total contribution to ecotoxicity. For these reasons, heavy metal emissions from fertilizers are not included.

3.7.3. Nitrous oxide emissions

Nitrous oxide emissions are produced from natural and human sources. The use of synthetic fertilizer in agriculture is a major source of nitrous oxide emissions and is of great concern (Iriarte et al., 2010). The use of nitrogen-containing fertilizers creates direct emissions that come from fertilized agricultural soils and manure and indirect emissions from runoff and leaching of fertilizers.

Cultivation of rapeseed is characterized by high greenhouse gas emissions, which is associated with high nitrogen (N) demands for plant growth (Queiros et al., 2015). Nitrous oxide emissions from the cultivation of winter and spring rapeseed were calculated using the Global Nitrous Oxide Calculator (GNOC) - an online tool to estimate soil N_2O emissions from the cultivation of biofuel crops (Köble, 2014). The emissions calculations are based on IPCC (2006) combining TIER1 and TIER2. Soil organic matter content, pH and other environmental conditions (provided by the company) were taken into account and parameters were adjusted accordingly in GNOC online tool. Calculated NO_X emissions are shown in Table 9.

To convert N_2O–N emissions into kg emission per ha instead of kg N/ha, Following conversation is used:

$$N_2O = N_2O - N \cdot 44/28$$

Total N_2O emission for spring rapeseed is 2.4 kg N/ha and for winter rapeseed is 3.1 kg N/ha. There are several methods to estimate N_2O from agriculture but they all present a degree of uncertainty, and N_2O emissions remain a topic for debate. Soils with organic C contents of >3% have significantly greater NO emissions than soils with <3% organic C. Good drainage, coarse texture and neutral pH promote NO emissions EMEP/EEA (2016).

3.7.4. Emissions related to phosphorus

Emissions related to the phosphorus cycle were calculated according to Schmidt (2007). Phosphorus emissions contain no emissions to air. Phosphor binds tightly to soil particles, phosphate leaching was specified as 2.9% of the surplus of phosphorus. The remaining is accumulated into soil.

The content of phosphorus in the harvested crop is 6.2 g per kg of rapeseed and 0.77 g per kg of straw (fresh weight basis) (Schmidt, 2007). The applied amount of fertilizer P_2O_5 is 60.8 kg/ha for winter and spring rapeseed (Table 2), which corresponds to 26.5 kg of phosphorus. The phosphorus surplus can be calculated by applying the reported yield of rapeseed (spring- 2.5 t/ha, winter 3.5 t/ha), straw production with a straw to seed ratio of 2:1 (all the straw remains on the field) and planting seed input as reported in Table 10.

3.8. Not included

The human labor load was excluded, as this was intensive farming. Capital goods and overhead, which include means of production, i.e. buildings and machinery, electricity and energy for administration buildings, were not included since it was not possible to obtain detailed data on these factors.

4. Conclusions

The Life Cycle Inventory developed in this study in accordance with ISO 14040 (2006) and 14044 (2006) allowed to present a regional Life Cycle Inventory study of rapeseed oil crops cultivated in Latvia as there is a lack of regionalized Life Cycle Inventory studies. Comprehensive primary data collection allowed avoiding the assumptions in the LCI stage. The methodology used for Life Cycle Inventory building resulted in an in-depth inventory out resembling as closely as possible the actual agricultural practices used for rapeseed production in Latvia, which is an essential for the quality of future Life Cycle Assessment.

Table 9
Nitrous oxide emissions calculated by GNOC.

Type	Summer rapeseed	Winter rapeseed
	Value (kg N_2O-N/ha)	
Direct N_2O emissions from fertilizer application N_2O	1.3636	1.7356
Indirect N_2O emissions produced from atmospheric deposition of N volatilised N_2O	0.1870	0.2212
Direct N_2O emissions from N in crop residues N_2O	0.0005	0.0007
Total soil N_2O emissions	**1.5511**	**1.9575**

Table 10
Phosphorus field balance and leaching calculation.

	Winter	Spring
Input (kg P/ha)		
Seed	0.036	0.025
Fertilizer	26.51	26.51
Total P input	26.54	26.53
Output (kg P/ha)		
Harvested rapeseed	21.7	15.5
Straw	remains on the field	remains on the field
Total P output	21.7	15.5
Balance (kg P/ha)		
P surplus	4.84	11.03
P leaching 2.9%	**0.14**	**0.32**

The rapeseed cultivation inventory identified that the average yield of winter rape in Latvia is in line with the average yield of rape and turnip rape yield of EU-28. The use of fertilizers is similar in respect to other EU member state practices. This study reported the use of micronutrients for rapeseed cultivation which haven't been fully reported elsewhere. The study was addressed to actual rapeseed cultivation strategy within the analyzed region thus identifying and highlighting a lack on the use of agricultural leftovers. The use of rapeseed straw for different applications and avoided impact scenarios can be modeled and exploited in further Life Cycle Assessment studies aiming to assess the environmental strategies maximizing the overall environmental performances.

The results of the present study are valuable to add and expand the existing knowledge of rapeseed production in North European countries. Moreover, the results are relevant to be implemented in any Life Cycle Assessment software database representing the state-of-art in term of rapeseed cultivation for the Latvian context. The LCI study is beneficial for others LCA practitioners to evaluate on which quantitative extend would be possible to move towards the use of the agro-feedstock (i.e. rapeseeds) not only for biodiesel production but as potential feedstock for the polymer industry to produce more added value products within the light of a more sustainable bioeconomy.

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References

Biofuels Barometer, 2017. EUROBSERV'ER. Final report. https://www.eurobserv-er.org/biofuels-barometer-2017/.
Ademe, 2010. Life cycle Assessments Applied to First generation biofuels Used in France. Final report.
Bio-Based Polyurethane (PU) Market Analysis By Product (Rigid Foams, Flexible Foams, CASE), by End-Use (Furniture & Interiors, Construction, Automotive, Footwear) And Segment Forecasts to 2020: new report by Grand View research, Inc., 2015. https://globenewswire.com/news-release/2015/01/12/696610/10114872/en/Bio-Based-Polyurethane-PU-Market-Analysis-By-Product-Rigid-Foams-Flexible-Foams-CASE-By-End-Use-Furniture-Interiors-Construction-Automotive-Footwear-And-Segment-Forecasts-To-2020-N.html. (Accessed 29 April 2017).
Börjesson, P., Tufvesson, L.M., 2011. Agricultural crop-based biofuels – Resource efficiency and environmental performance including direct land use changes. J. Clean. Prod. 19 (2–3), 108–120. https://doi.org/10.1016/j.jclepro.2010.01.001.
CSB-Central Statistical Bureau, 2017. Collection of Statistics. Agriculture of Latvia, p. 72. ISBN 978-9984-06-507-6.
Dalgaard, R., Schmidt, J., Halberg, N., 2008. LCA of soybean meal. Int. J. Life Cycle Assess. 13, 240–254. https://doi.org/10.1065/lca2007.06.342.
DIRECTIVE (EU) 2015/1513, 2015. http://eur-lex.europa.eu. (Accessed 29 April 2017).
El Bassam, N., 2010. Handbook of Bioenergy Crops: A Complete Reference to Species, Development, first ed. Earthscan, UK.
EMEP/EEA, 2016. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016. (Accessed 6 July 2017).
Ermsone, D., January 2010. National Seminar – Latvia national Background paper Anticipating and managing restructuring Latvia. European Commission Employment, Social Affair and Equal opportunities, p. 39.
EU Biofuels Annual, 2016. Biofuels Annual. The Hague.EU 28 6 29 2016. USDA GAIN reports. GAIN report number: NL6021.
Eurostat, 2017a. http://ec.europa.eu/eurostat/statistics-explained (Accessed 29 April 2017).
http://ec.europa.eu/eurostat/statistics-explained (Accessed 29 April 2017).
Faostat, 2017. Available at: http://www.fao.org/faostat/en/#home (Accessed 12 July 2017).
Fridrihsone-Girone, A., Stirna, U., Misāne, M., Lazdiņa, B., Deme, L., 2016. Spray-applied 100% volatile organic compounds free two component polyurethane coatings based on rapeseed oil polyols. Prog. Org. Coat. 94, 90–97. https://doi.org/10.1016/j.porgcoat.2015.11.022.
Gonçalves Jr., C.A., Nacke, H., Schwantes, D., Coelho, G.F., 2017. Heavy metal contamination in Brazilian Agricultural soils due to Application of fertilizers. In: Hernandez-Soriano, M.C. (Ed.), Environmental Risk Assessment of Soil Contamination. https://doi.org/10.5772/57086.
Graef, M., Vellguth, G., Krahl, J., Munack, A., 1995. Fuel from sugar beet and rape seed oil - mass and energy balances for evaluation. In: Biomass for energy, environment, Agriculture and Industry: Proceedings of the 8th European Biomass Conference, Vienna, Austria, 3-5 October 1994, vol. 2. Pergamon Press, Oxford; New York, pp. 1159–1164.
Grau, B., Bernat, E., Rita, P., Jordi-Roger, R., Antoni, R., 2013. Environmental life cycle assessment of rapeseed straight vegetable oil as self-supply agricultural biofuel. Renew. Energy 50, 142–149. https://doi.org/10.1016/j.renene.2012.06.031.
Ionescu, M., 2005. Chemistry and Technology of polyols for polyurethanes. Smithers Rapra Technology, Shrewsbury.
IPCC (Intergovernmental Panel on Climate Change), 2006. IPCC guidelines for national greenhouse gas inventories. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), Ch. 11: N2O Emissions from Managed Soils and CO2 Emissions from Lime and Urea Application. Prepared by the National Greenhouse Gas Inventories Programme, vol. 4. Institute for Global Environmental Strategies, Japan.
Iriarte, A., Rieradevall, J., Gabarrell, X., 2010. Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions. J. Clean. Prod. 18 (4), 336–345. https://doi.org/10.1016/j.jclepro.2009.11.004.
ISO 14040, 2006. Environmental Management -Life Cycle Assessment – Principles and Framework. ISO copyright office, Geneva (Switzerland).
ISO 14044, 2006. Environmental Management -Life Cycle Assessment - Requirements and guidelines. ISO copyright office, Geneva (Switzerland).
IUPAC PPDB - Pesticides Properties DataBase 2017 http://sitem.herts.ac.uk/aeru/iupac/index.htm. (Accessed 06 July 2017).
Katanenko, S., 2017. Personal Communication With Lead Agronomist of Uzvara lauks, Ltd.
Koble, R., 2014. The global nitrous oxide calculator. GNOC. Online Tool Manual, v.1.2.4. JRC Technical Reports, Ispra, May. http://gnoc.jrc.ec.europa.eu/. (Accessed 6 July 2017).
Marinussen, M., van Kernebeek, H., Broekema, R., Groen, E., Kool, A., van Zeist, W.J., Dolman, M., Blonk, H., 2012. LCI data for the Calculation tool Feedprint for Greenhouse Gas Emissions of Feed Production and Utilization Cultivation Oil Seeds and Oil Fruits. Crushing Industry, p. 66.
Markovich, N.E., Kuranska, M., Prociak, A., Malewska, E., Kulpa, K., 2017. Open cell semi-rigid polyurethane foams synthesized using palm oil-based bio-polyol. Ind. Crops Prod. 102, 88–96. https://doi.org/10.1016/j.indcrop.2017.03.025.
Melece, L., Lakovskis, P., 2014. Impacts of bioenergy on Agricultural land use changes in Latvia. Econ. Rural Dev. 10 (1), 39–46. https://doi.org/10.15544/erd.2014.005.
Mutlu, H., Meier, M.A.R., 2010. Castor oil as a renewable resource for the chemical industry. Eur. J. Lipid Sci. Tech. 112 (1), 10–30. https://doi.org/10.1002/ejlt.200900138.
Petrović, Z.S., Guo, A., Javni, I., Cvetković, I., Hong, D.P., 2007. Polyurethane networks from polyols obtained by hydroformylation of soybean oil. Polym. Int. 57 (2), 275–281. https://doi.org/10.1002/pi.2340.
Queiros, J., Malça, J., Freire, F., 2015. Environmental life-cycle assessment of rapeseed produced in Central Europe: addressing alternative fertilization and management practices. J. Clean. Prod. 99, 266–274. https://doi.org/10.1016/j.jclepro.2015.03.016.
Ropelewska, E., Zapotoczny, P., Budzyński, W.S., Jankowski, J.K., 2017. Discriminating power of selected physical properties of seeds of various rapeseed (Brassica napus L.) cultivars. J. Cereal Sci. 73, 62–67.
Saalah, S., Abdullah, L.C., Aung, M.M., Salleh, M.Z., Biak, D.R.A., Basri, M., Jusoh, E.R., 2015. Waterborne polyurethane dispersions synthesized from jatropha oil. Ind. Crops Prod. 64, 194–200. https://doi.org/10.1016/j.indcrop.2014.10.046.
Sarigiannis, D.A., Kontoroupis, P., Solomou, E.S., Nikolaki, S., Karabelas, A.J., 2013. Inventory of pesticide emissions into the air in Europe. Atmos. Environ.75 6–14. https://doi.org/10.1016/j.atmosenv.2013.04.003.
Schmidt, J., 2007. Life Cycle Assessment of Rapeseed Oil and Palm Oil: Ph.D. thesis, Part 3: life Cycle Inventory of Rapeseed Oil and Palm Oil. Department of Planning and Development, Aalborg University, Aalborg.

Singh, B.P., 2013. Biofuel Crop Sustainability. Wiley-blackwel. ISBN: 978-0-470-96304-3.
SPPS, 2016. List of Registered Plant Protection Products in Latvia. Valsts augu aizsardzības dienests, Riga, 2016, 352 pp, ISBN 9984–679–79–9.
Stirna, U., Fridrihsone-Girone, A., Yakushin, V., Vilsone, D., 2014. Processing and properties of spray-applied, 100% solids polyurethane coatings from rapeseed oil polyols. J. Coat. Technol. Res. 11 (3), 409–420. https://doi.org/10.1007/s11998-013-9545-8.
USDA- United States Department of Agriculture, April 2017. Oilseeds: world Markets and Trade. https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf. (Accessed 29 April 2017).
Van den Berg, F., Kubiak, R., Benjey, W.G., 1999. Emission of pesticides into the air. Water Air Soil Pollut. 115 (1–4), 195–218. https://doi.org/10.1023/A:1005234329622.
Zieleniewska, M., Leszczyński, M.K., Kurańska, M., Prociak, A., Szczepkowski, L., Krzyżowska, M., Ryszkowska, J., 2015. Preparation and characterisation of rigid polyurethane foams using a rapeseed oil-based polyol. Ind. Crops Prod. 74, 887–897. https://doi.org/10.1016/j.indcrop.2015.05.081.