Polish Journal of Agronomy
2017, 28, 12-18

Life cycle assessment of winter rape production in large-area farms with intensive cultivation system

Radosław Dąbrowicz, Jerzy Bieńkowski, Małgorzata Holka, Janusz Jankowiak

Institute for Agricultural and Forest Environment (IAFE) of Polish Academy of Sciences in Poznań
ul. Bukowska 19, 60-809 Poznań, Poland

Abstract. The European Union places great emphasis on the use of renewable energy sources in the energy industries. The share of bio-components in liquid fuels consumption is expected to reach 10% by the end of 2020. A consequence of this regulation is the increased cropping area of rapeseed in Poland. The aim of the study was to quantify the environmental impact associated with winter rape production along the life cycle stages. The method used to calculate the overall environmental profile of rapeseed was the Life Cycle Assessment (LCA). Analysis was based on the case study of two large-area farms in the Wielkopolska region carried out in the years 2011–2013.

Our study showed that fertilizer operation was the largest contributor to the environmental impact categories, representing almost 99 percent of the acidification potential and 77 percent of the global warming potential. Among the components of fertilizing operations, field application of nitrogen fertilizers generated the highest load of greenhouse gas emissions.

It is concluded that the data obtained characterizes the conventional type of rapeseed production in the Wielkopolska region and can be used as source material for extending the LCA to the rapeseed processing industry which receive the material from the local suppliers.

Keywords: winter rape, life cycle assessment, impact category, environment, agriculture

INTRODUCTION

Regulations of the Directive 2009/28/EC, which promote the use of renewable energy sources, require that the share of energy from renewable sources in all forms of transport in 2020 must increase to 10% of the final consumption of energy in transport (EU, 2009). This aim is to be achieved mainly through biofuel production from oil plants. These actions have led to a constantly growing demand for the rapeseed oil ester in Poland and in Europe. Over the last few decades the rape sown area in Poland doubled and at the moment it equals nearly 1 mln ha (CSO, 2013). While at the same time the cultivated area of rye and potatoes decreased by half. Consequences of changes in crop patterns are clearly visible in farms of intensive cultivation system. In their present crop structure, the rape occupies a prominent place.

The cultivation of rapeseed crops is associated with the use of large amounts of mineral fertilization and the frequent use of plant protection products (Williams et al., 2006; Rudko, 2011). These field operations require the increased use of agricultural tractors, machinery and fossil fuel consumption. Higher number and intensity of operations might incur additional burden to the environment. The recognition of these environmental effects linked to the rapeseed production technology is still insufficient in Poland.

The comprehensive analysis of the impact of rapeseed production on the environment can be assured by the life cycle assessment methodology, LCA (Goedkoop et al., 2013; Rebitzer et al., 2004). This method was especially developed as an analytical tool to identify and evaluate potential effects of the product manufacturing on various environmental aspects. The environmental assessment method of products and services includes the entire life cycle of product, from the extraction of raw materials to waste management, i.e. "from cradle to grave".

The aim of this study was to assess the potential impact of winter rape production on the various environmental aspects over the life cycle, beginning from upstream through the core processes of crop cultivation until the delivery of seeds to the distributor, i.e. – "from cradle to client". Thus, such assessment could be the base for extending further research on life-cycle environmental effects of post-farm processed products, originating from rapeseed grown in both similar cultivation system and soil, and climatic con-

Corresponding author:
Jerzy Bieńkowski
e-mail: bjerzy@onet.pl
tel.: 61 8475603, fax: 61 8473668

ditions. Later stages of industrial seed processing were however outside the scope of the undertaken analysis.

MATERIAL AND METHODS

The life cycle assessment of winter rape was performed based on the data from two farms belonging to the Długie Stare Agricultural Company Ltd., a subsidiary of the state Treasury. The company is included in the pool of strategic agricultural companies responsible for the diffusion of innovation techniques in production practices. The company farms 3100 hectares of agricultural land and is located in the Wielkopolska province (Poland). Another important reason for choosing this company for our study was its intensive way of farming, both in plant and livestock production systems. In both farms, winter rape is grown in two cropping rotations. Crop sequence in the first rotation pattern is maize, winter cereal, winter rape, winter cereal, and in the second one – manured sugar beets, winter wheat, winter rape, winter wheat.

Results presented in this study constitute the 2-year average for Farm 1 (Długie Stare Farm), covering the period from 2012 to 2013, and 3-year average for Farm 2 (Trzebiny Farm), with time span from 2011 to 2013 (Table 1). For the analysis, a detailed documentation of all producing inputs from both farms was used, i.e. fertilizers applied, plant protection products, tractor and machine work hours, the dates and time in which operations were carried out, as well as the cultivation technology applied. Both farms use intensive production systems, as evidenced by a high level of mineral fertilization which is twice as much as the average for Poland (CSO, 2013). The two farms are of similar size but they differ in terms of the soil quality index which affects the choice of suitable crops and their productivity. The surveyed farms, despite belonging to the same agricultural company, were different with respect to several essential characteristics, namely the soil quality indicator, the cropping pattern, the level of fertilization and the intensity of equipment used. The above characteristics may have affected the potential use of the natural soil productivity. In Farm 1 the winter rape had been cultivated in a much larger area where the indicator of the soil quality was nearly two times higher than in Farm 2.

A life cycle assessment was carried out according to the methodology documented in the ISO standard 14040 (PN-EN ISO 14040, 2006). This includes following the scheme under which four phases were defined: 1) definition of the goal and scope, 2) analysis of the essential input and output data, 3) life cycle impact assessment, 4) interpretations on inventory and impact category levels (results and discussion). The results have been presented for two functional units: 1 ha of winter rape crop and 1 Mg of winter rape seeds.

Various life cycle inputs and outputs were quantified for each stage of rape production (phase 2), which were taken into account in the system boundary and were assigned into one of three process stages: upstream, core and downstream (Fig. 1). The input data which were

Table 1. Characteristic of the surveyed farms (average from the years 2011–2013).

Characteristics	Unit	Farm 1	Farm 2
Area of agricultural lands	ha	516.2	506.7
Livestock density	LSU ha^{-1}	0.72	0.66
Winter rape yield	$dt \cdot ha^{-1}$	36.4	26.2
Basic cereals yields	$dt \cdot ha^{-1}$	57.6	50.2
Soil quality indicators	-	1.2	0.7
Fertilization NPK	$kg \cdot ha^{-1}$	269.8	245.9
Crops structure			
- Cereals	%	51.9	61.1
- Root plants	%	12.1	7.9
- Oilseeds	%	15.0	12.9
- Annual feed crops	%	10.6	13.4
- Perennial feed crops	%	10.5	4.7

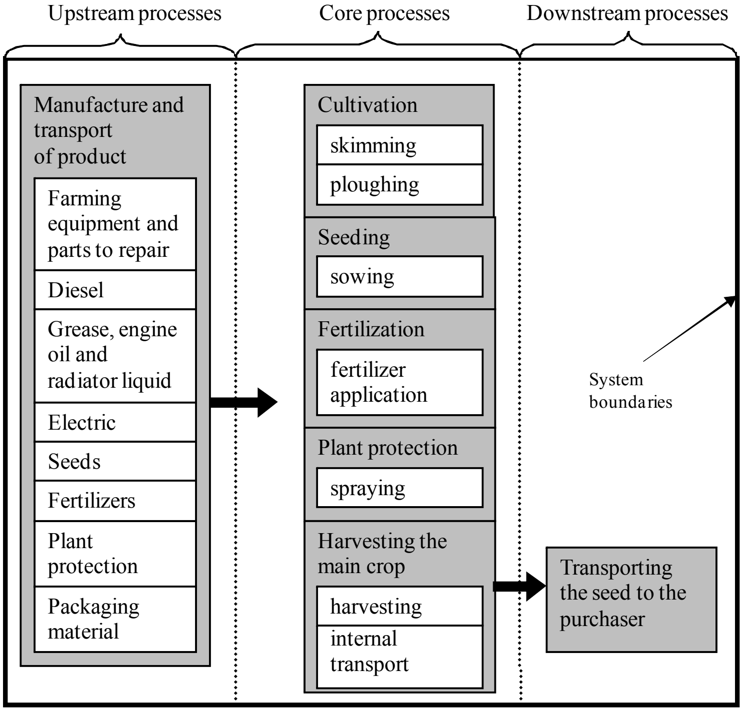

Figure 1. Scheme of processes for the winter rape production.

assigned to the upstream processes included all the energy and materials inputs utilized in the field production ranging from fertilizers, plant protection products, packaging materials to machines and tractors, from the beginning of manufacturing until the moment they enter the farms. The data sources for these processes were the published data and the Agribalyse database (Harasim, 2002; Nemecek et al., 2004; Audsley et al., 2009; IPCCa, 2006; Colomb et al., 2013). The core stage in relation to field cultivation included the following technological operations: skimming, ploughing, sowing, fertilizing, spraying, harvesting and internal transport. For these processes, actual data was collected from farms using their record keeping documents which detailed records of each operations, farm accountancy data, as well as technical documentation of the farm equipment and interviews with managers. Downstream stage of the LCA analysis, which follows the core stage, included the transport of seeds to the to the oil industry facility located in the Wielkopolska region (i.e. Szamotuły oil & margarine plant) which in our analysis was the final "gate" of the analyzed system.

The life cycle impact assessment (phase 3) was carried out according to the CML methodology, based on midpoint approach (Guinée et al., 2002) and IPCC report (IPCC, 2006b). It considered several categories of impacts such as: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), abiotic and fossil fuel resources depletion potentials (ADP mineral and ADP fossil fuel respectively). The impact categories included in the assessment covered all important types of environmental effects related to the analyzed product system. Their choice was justified in relation to the goal of the study.

In the final stage of the analysis, normalization of indicators calculated for the distinguished impact categories was undertaken according to the formula:

$$NIR = \frac{IR_p \cdot P_{Europe}}{IR_{Europe}}$$

NIR – normalized impact category indicators,
IR_P – average impact category values for the rape production of the surveyed farms per 1 Mg of seeds,
P_{Europe} – the size of the rape production in Europe, measured in tonnes (data year 2005),
IR_{Europe} – the value of the impact category reference indicator in Europe for the year 2005.

The normalization procedure unifies impact indicators by dividing by their reference values in order to be able to compare the respective environmental effects. For references in this analysis, indicators of the different categories of impacts for Europe have been chosen (Sleeswijka et al., 2008).

RESULTS AND DISCUSSION

The inventory of all inputs used in rape production, revealed higher levels of mineral fertilization and plant protection products being applied in Farm 1 (Table 2). Though, it did not result in noticeable differences in the amounts of fuel consumed and the equipment utilized. Less use of tractors and non-road mobile machinery in this farm, expressed in kg machine mass per hectare, indicated more efficient utilization of the equipment employed. Such features of described characteristics allowed to get high rapeseed yields, but on the other hand they could have had an adverse impact on the environment induced by high amounts of mineral fertilizer and pesticides inputs.

A comprehensive life cycle assessment of winter rape production showed marked differences of environmental effects between both farms with regard to defined functional units of 1 ha and 1 Mg of main crop. In Farm 1, the values of nearly all analyzed impacts per 1 ha of crop were higher than in Farm 2 (Table 3). These effects were the direct result of higher inputs incurred during rape production in Farm 1. However, due to differences in productivity, the environmental effects per functional unit of 1 Mg showed the distinctively higher burden on the environment in Farm 2. In relative terms, there were no major differences between farms for the analyzed impact categories.

The results of this study, compared to published values, indicate a smaller environmental impact potential for the

Table 2. Inventory of inputs in relation to functional unit of 1 ha for winter rape production in the analyzed farms (average from years 2011–2013).

Inputs	Unit	Farm 1	Farm 2
Seeds	kg	3.84	2.78
Fertilizers			
- nitrogen (N)	kg	216.4	181.8
- phosphate (P_2O_5)	kg	17.5	15.8
- potassium (K_2O)	kg	161.3	153.4
Plant protection product			
- fungicide (a.i.)	kg	1.03	0.58
- herbicide (a.i.)	kg	2.03	1.26
- insecticide (a.i.)	kg	0.30	0.30
Tractors and non-road mobile machinery	kg	8.8	16.8
Machines	kg	6.4	6.3
Replacements and materials for repair	kg	4.8	7.2
Diesel	l	91.8	93.6
Transmission fluid	l	0.8	0.7
Engine oil	l	0.6	1.0
Radiator fluid and other liquids	l	0.3	0.4
Polyethylene mesh	m^2	212.0	139.3
Polypropylene bags	kg	1.7	1.6
Cardboard bags	kg	0.07	0.05

Table 3. Impact category indicators for the rape production in the analyzed farms (average from years 2011–2013).

Impact category	Farm 1		Farm 2	
	per 1 ha	per 1 Mg	per 1 ha	per 1 Mg
Global warming potential (GWP100), kg CO_2 eq.	2613.7	718.1	2355.0	898.9
Acidification potential (AP), kg SO_2 eq.	44.6	12.3	36.4	13.9
Eutrophication potential (EP), kg PO_4^{-3} eq.	11.4	3.1	9.5	3.6
Photochemical ozone creation potential (POCP), kg C_2H_4 eq.	0.60	0.16	0.52	0.20
Abiotic depletion potential (ADP mineral), kg Sb eq.	0.02	0.01	0.02	0.01
Fossil fuel resources depletion potential (ADP fossil fuel), kg Sb eq.	4.0	1.1	3.7	1.4

rape production process in the analyzed farms. The studies conducted in Great Britain presented twice as high potential of eutrophication (EP), abiotic depletion (ADP) and global warming potential (GWP) quantified per functional unit of 1 Mg for the product (Williams et al., 2006). While, compared to the analyzed farms, the British data showed lower indicator values for the acidification impact category. The analysis of the environmental effects of rape production in Chile, from the life cycle perspective, also showed higher values of EP, ADP, as well as acidification potential (AP) per 1 Mg of seeds, while the GWP indicator remained on the same level like in the surveyed farms (Iriarte et al., 2010).

Mineral fertilization was the most influential factor in accounting for the impact values from among all technological operations that were specified (Fig. 2). Technological processes related to fertilization were responsible for contributing of up to 77% toward GWP and up to 99% toward AP, and EP impacts. Similar results for rapeseed were obtained by Iriarte et al. (2010), Gasol et al. (2012) and Krzyżaniak et al. (2013). A study of Iriarte et al. (2010) indicated that mineral fertilization was a dominant process in developing the size of the impact for 10 out of 11 environmental effect categories. Results of Krzyżaniak et al. (2013), in turn, showed a relatively high importance of fertilization in 8 out of 10 investigated impact categories. Fertilization constituted a contributory impact on the GWP for the rapeseed with the share ranging from 63% to 93% (Iriarte et al., 2010; Gasol et al., 2012). The analysis showed, that the operation of applying fertilizers on winter rape field contributed the most to the final value of the GWP and was responsible for the emission of above 390 kg CO_2 eq. per 1 Mg (Fig. 3), that was twice as much as in the production stage of fertilizers. These effects were mainly due to the N_2O direct emissions of and its indirect emissions as a result of the depositions of NH_3 and NO_x emitted earlier during the application of nitrogen fertilizers on the field.

The analyzed impact categories of the environmental profile were internally differentiated in terms of mutual relations of the various life cycle stages (Fig. 4). The upstream stage of winter rape production had a major con-

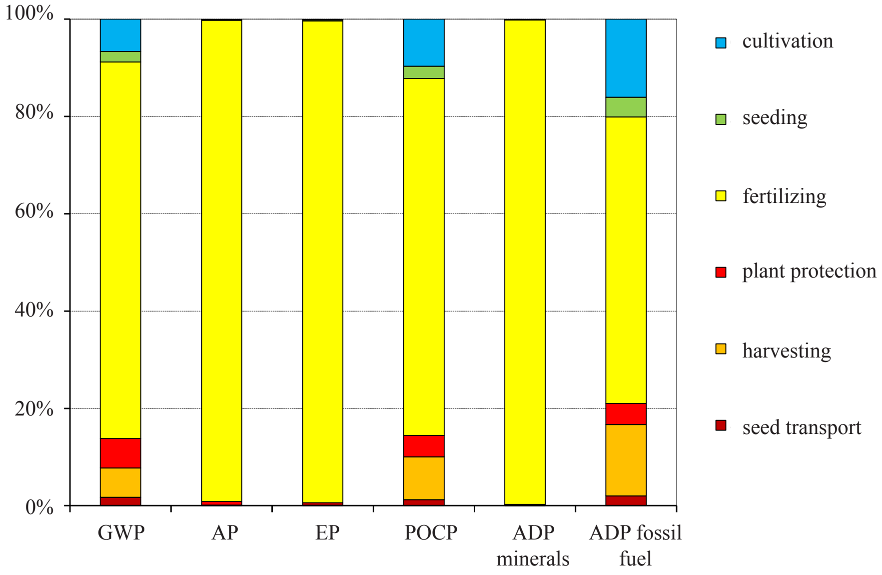

Figure 2. Percentage share of different technological operations in the analyzed impact categories for the winter rape production (average from the farms for the years 2011–2013).

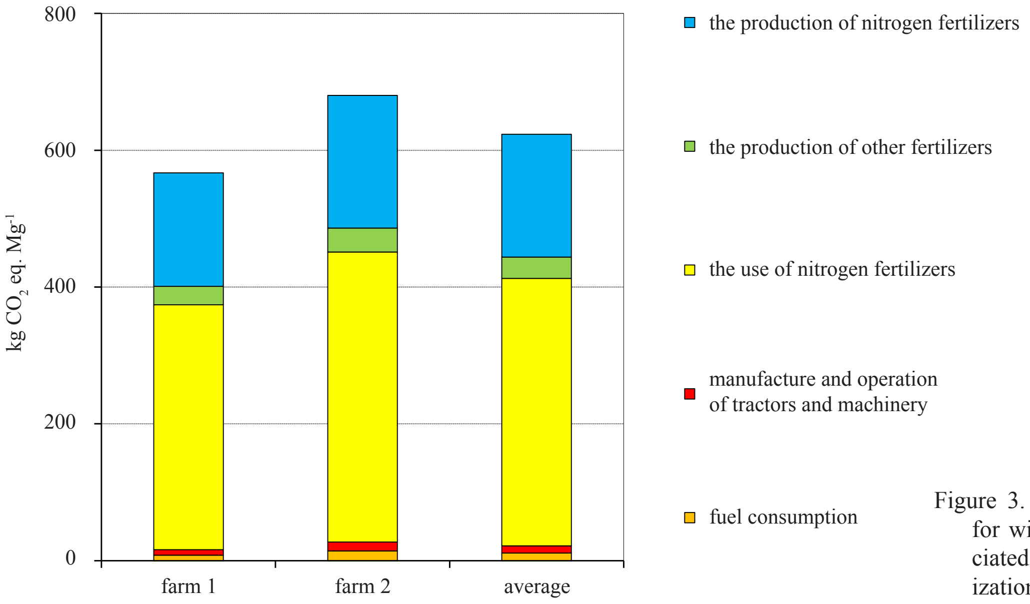

Figure 3. Components of the GWP for winter rape production associated with the process of fertilization in the analyzed farms.

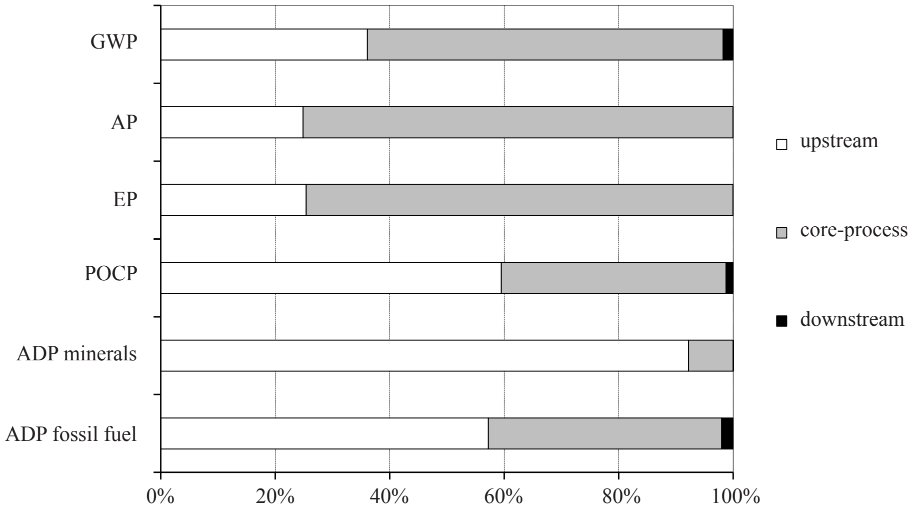

Figure 4. Share of life cycle stages in winter rape production for the analyzed impact categories (averages for farms and the years 2011–2013).

tribution to the three impact categories of ADP fossil fuel, ADP mineral and photochemical ozone creation potential (POCP). This stage is identified with mined raw materials and production of process materials used in farms, i.a. fossil fuel, fertilizers, plant protection products and packaging. Whereas the core stage of winter rape life cycle, identified with crop cultivation, accounted for a large part of the EP, AP and GWP category indicators. In a wider description, the core stage encompasses transport of inputs to farms and all crop operations carried out until the harvest of the crop. The final stage, known as the downstream process, involved in our study was the rapeseed transport to the client, as according to the system boundary. It turned out that the contribution of the downstream stage to the impact categories was not meaningful.

Calculating absolute values for the impact categories does not allow for the assessment of their relative importance in the rapeseed production system. In order to be able to compare impacts it is necessary that their indicators are normalized first. This procedure was carried out by relating individual indicators of the impact categories to their reference state of general impact on the environment. This way,

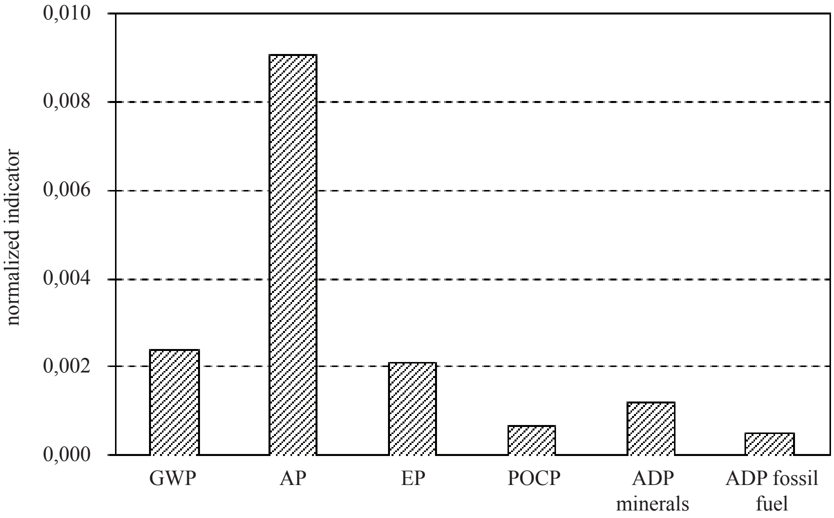

Figure 5. Normalized values of impact category indicators in winter rape production (averages for farms and the years 2011–2013).

each indicator was compared with its corresponding one which was calculated for a continental scale with all anthropogenic sources, thus bringing them into non-nominal units. The normalized indicator values for the environmental profile showed that the largest environmental threat induced by the rape production was associated with AP (Fig. 5). A high value of the normalized indicator for this impact category was most probably related to the process of fertilization, including production of fertilizers and subsequent application of mineral fertilizers to the fields. GWP potential was second in order of importance of adverse effects on the environment, though its value was almost four times smaller than the AP. Within all impact categories, ADP fossil fuel had relatively the smallest size of impact.

CONCLUSIONS

The inputs incurred on the rape production, which are dependent on both the intensity of operations and local soil conditions, could explain much of the differences in crop productivity and in the levels of impact on the environment. In Farm 1, the values were higher for all of the analyzed impact categories than in Farm 2 when they were related to the functional unit of 1 ha, while had lower indicators in terms of 1 Mg of rapeseed.

Mineral fertilizing had a major contribution to the profile of environmental effects, from among all technological processes considered, especially noticeable in the stage of fertilizer application on the field. It seems that by concentrating on the range of efforts toward improving technology of fertilizer production, simplifying tillage operations and adjustment made for timely application of optimized fertilizer rates, it is possible to reduce further the studied impact indicators.

The analyzed winter rape production, within the defined boundary system, turned out to have a generally less adverse effect on the environment as compared to many literature data what was demonstrated by particularly low indicators of the impact categories for GWP, EP and ADP. The life cycle assessment of rape production concludes that the relatively lower level of environmental impacts accompanying this production system in both farms was not linked with limitation of winter rape productivity, which in a broader meaning indicates rational field crop management. Undoubtedly, these results justify the existing role by the farms of being benchmarks objects for the conventional type of winter rape production in the Wielkopolska region.

The normalized environmental effects indicted that an acidification is a major threatening factor to the environment in rapeseed production. The collected data could be used as a primary information source for other LCA analysis (for database) in the process industry which uses rapeseed from large-area farms with intensive crop cultivation as a raw material in industrial processes.

REFERENCES

Audsley E., Stacey K., Parsons D.J., Williams A.G., 2009. Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. Cranfield University, Cranfield, Bedford UK.

Colomb V., Aït-Amar S., Basset-Mens C., Dollé J.B., Gac A., Gaillard G., Koch P., Lellahi A., Mousset J., Salou T., Tailleur A., van der Werf H., 2013. AGRIBALYSE: Assessment and lessons for the future, Version 1.0. Ed. ADEME, Angers, France.

CSO, 2013. Statistical Yearbook of the Republic of Poland. Statistical Publishing Establishment, Warszawa.

EU, 2009. Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009 on the promotion oft he use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union, L(140): 16-62.

Gasol C.M., Salvia J., Serra J., Antón A., Sevigne E., Rieradevall J., Gabarrell X., 2012. A life cycle assessment of biodiesel production from winter rape grown in Southern Europe. Biomass and Bioenergy, 40: 71-81.

Goedkoop M.J., Heijungs R., Huijbregts M., De Schryver A., Struijs J., Van Zelm R, 2013. ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition Report I: Characterisation. Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Hague.

Guinée J.B., Gorrée M., Heijungs R., Huppes G., Kleijn R., De Koning A. Van Oers L., Wegener Sleeswijk A., Suh S., Udo De Haes H.A., De Bruijn H., Van Duin R., Huijbregts M.A.J., Lindeijer E., Roorda A.A.H., Van Der Ven B.L., Weidema B.P., 2002. Handbook on life cycle assessment. Operational guide to the ISO standards. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Harasim A., 2002. A comprhensive assessment of crop rotations with different share of cereals and root crops. IUNG-PIB Puławy, Monografie i Rozprawy Naukowe, 1. (in Polish)

IPCC, 2006a. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Agriculture, Forestry and Other Land Use. Task Force on National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm. (accessed 10.12.2014)

IPCC, 2006b. 2006 IPCC Guidelines for national greenhouse gas inventories. Volume 2 Energy. Task Force on National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html. (accessed 10.12.2014)

Iriarte A., Rieradevall J., Gabarrell X., 2010. Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions. Journal of Cleaner Production, 18: 336-345.

Krzyżaniak M., Stolarski M., Śnieg M., Christou M., Alexopoulou E., 2013. Life cycle assessment of Crambe abyssinica production for an integrated multi-product biorefinery. Environmental Biotechnology, 9: 72-80.

Nemecek T., Heil A., Huguenin O., Meier S., Blaster S., Dux D., Zimmermann A., 2004. Life cycle inventories of agricultural production systems. Final report ecoinvent 2000. Agroscope FAL Reckenholz and FAT Taenikon, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

PN-EN ISO 14040, 2006. Environmental management. Life cycle assessment. Principles and framework. PKN, Warszawa.

Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Schmidt W.-P., Suh S., Weidema B.P., Pennington D.W., 2004. Life cycle assessment. Part 1: Framework, goal and scope definition, inventory analysis and applications. Environmental International, 30: 701-720.

Rudko T., 2011. Cultivation of winter rape: principles of cultivation – healthy food. The guidebook for producers. Institute of Agrophysics PAS, Lublin (in Polish).

Sleeswijka A.W., Van Oersc L.F.C.M., Guinéec J.B., Struijs J., Huijbregts M.A.J., 2008. Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. Science of the Total Environment, 390: 227-240.

Williams A.G., Audsley E., Sandars D.L., 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Cranfield University and Defra, Bedford, http://www.defra.go.uk. (accessed 20.11.2011)

received 20 April 2016
revised 30 October 2016