Review

Carbon Footprint: an Ecological Indicator in Food Production

Adam Więk*, Katarzyna Tkacz

Department of Industrial Commodity Science, Bases of Technique and Energy Management, University of Warmia and Mazury, 10-726 Olsztyn, Poland

Received: 26 January 2012
Accepted: 2 October 2012

Abstract

Decreasing energy resources, world population growth, and the development of societies based on the principle of sustainable development are the main factors increasing the importance of ecological aspects of production and consumption. One of the proposals taking into account the ecological aspect is the introduction of an ecological indicator – carbon footprint – characterized by all kinds of products and services. The proposed methodology for determining the value of carbon footprint does not include some important elements. Identified problems in this work are an unreliable estimation of greenhouse gas emissions and differences in the value of the carbon footprint (depending on the farming techniques used and the manner of its expression).

The aim of our study was to analyze the available literature data on the size of its carbon footprint during the production of animal materials. The tool used to determine the CFP value was life cycle analysis (LCA). A study of the literature showed that the CFP value in the production of pork in various agricultural systems ranges from the 2.06 kg CO_2eq/kg (good agricultural practice) to 3.97 kg CO_2eq/kg (organic agricultural production).

Keywords: carbon footprint, greenhouse gases, life cycle assessment, food production, indicator

Introduction

The systematically increasing demand for energy, the dynamically growing demand for goods, and the increasing human population are the most frequently indicated factors claimed to affect climatic changes on our planet [1]. Intensifying weather anomalies are suggestive enough to urge us to search for ways of rationalizing our functioning, i.e. the functioning of people as a basic social unit and of an organization as a structure having a significant impact on the functioning of this society. These attempts have resulted in efforts by scientists to identify the key ecological factors involved. The major factor implicated in affecting climatic changes is the emission of greenhouse gases (GHG).

*e-mail: adam.wiek@uwm.edu.pl

Organizations have been accomplishing their goals based on the so-called principle of sustainable development that merges economic, social, and ecological aspects. So far, attention has chiefly been paid to economic indicators of development. However, currently ecological issues are becoming increasingly important as well. The contemporary system used to determine the impact of an organization on the natural environment is referred to as integrated permissions (integrated pollution prevention and control – IPPC). However, they also concern "installations likely to cause considerable damage to particular natural elements or to the natural environment as a whole" [2]. Recently, the ecological aspect of an organization's activity also has begun to be perceived using another ecological indicator, namely its carbon footprint (CFP) [3]. Discussions over climatic changes, including the anthropogenic effects on this process, have begun with the analysis of CO_2 emissions. This issue has been a focus of interest for a number of years [4]. Reports on the increasing emission of other GHGs [5], mainly of methane and nitrogen suboxide [6], have prompted us to investigate the effect of human activity on climate change from a wider perspective. The concept of the carbon footprint is used to this end, though it (currently) does not refer only to carbon dioxide [3].

Greenhouse Gases (GHG)

The group of more than 30 compounds known as GHGs also include: carbon dioxide, methane, nitrous oxide, and substances controlled by the Montreal Protocol: hydrofluorocarbons, perfluorinated compounds, fluorinated ethers, perfluoropolyethers, hydrocarbons and other compounds [7]. These compounds differ in their global warming potential (GWP), an indicator comparing the impact on the warming potential of each greenhouse gas to that of carbon dioxide. GWP is calculated based on the effects on global warming, of one kilogram of GHGs at a given time horizon, relative to one kilogram of CO_2. The GWP value depends on many factors, mainly the ability to absorb infrared radiation, the wavelength range where absorption occurs, and lifetime in the atmosphere [7]. Agricultural production is associated primarily with the issue of three GHGs: carbon dioxide, methane, and nitrous oxide [8]. The 4th IPPC Assessment Report presents the following values of GWP over a 100-year time horizon, respectively for carbon dioxide, methane, nitrous oxide: 1, 25, 298 [7, 9].

The main sources of GHG emissions in Europe include: electrical power stations 31.1%, manufacturing and construction 12.4%, transport (excluding international air and sea) 19.6% (including international air and sea transport, about 24%), households and services 14.5%, industrial processes 8.3%, agriculture 9.6%, wastes 2.8%, and other emissions 1.7% [1]. In the opinion of the European Economic and Social Committee, the contribution of agriculture to the total emission of GHG accounts for 17-32% [8]. A lack of clear indication in this respect results from a lack of unequivocal methods for the evaluation of these emissions. Noteworthy is the 18% contribution of animal production to the anthropogenic GHG emission [6].

Carbon Dioxide

The concentration of CO_2 has been estimated to have increased from 280 ppm (parts per million) in pre-industrial times to 385 ppm in 2008 [1]. One of the ranges of radiation absorption by CO_2 approximates the maximum of the thermal radiation of the Earth [9]. Contemporarily, the global emission of CO_2 is estimated to reach 24.7 Gt annually [10]. The natural sources of CO_2 include volcanic emissions, as well as emissions resulting from respiratory processes, from fires, and the decomposition of organic matter. The quantity of CO_2 in the atmosphere is subject to continuous changes as affected by: the exchange of carbon between the atmosphere, biosphere, and surface layers of oceans, deposition of carbonates on the ocean bed, and the formation of carbonate rocks followed by their weathering [11].

Methane

Methane is a greenhouse gas with a GWP 25 times higher than CO_2 [7]. The average content of methane in the atmosphere accounts for 1.7 ppm [9]. Its presence in the atmosphere results chiefly from anaerobic metabolism of microorganisms. The natural sources of methane include emissions from swamps and oceans, whereas the secondary sources include emissions resulting from the output of mineral fuels and animal breeding – 37% of the anthropogenic emission of methane is due to the breeding of animals, particularly ruminants [6].

Nitrogen Suboxide

The major sources of nitrogen suboxide emissions are similar to those of methane and include emissions resulting from the output of fossil fuels and from the chemical industry. The use of nitrogen-based fertilizers, both synthetic and organic, is claimed to be the main source of the emitted nitrogen suboxide [9]. The excess nitrogen not utilized by plants penetrates to the atmosphere as a result of oxidation [8]. The quantity of released N_2O is determined, to the greatest extent, by microorganisms colonizing soil and plants cultivated on that soil. The balancing of the quantities of introduced nitrates with real possibilities of their assimilation by selected environment poses a severe problem [12, 13]. Animal production is claimed to be responsible for 65% of anthropogenic emissions of N_2O [6].

Carbon Footprint CFP

CFP, literally meaning the carbon imprint of a foot, has been differently defined in literature sources. Very generally, it may be explained as an estimated measure of the human effect on the climate, based on the volume of GHGs being produced and penetrating to the atmosphere, as induced by our vital tasks in which we directly and indirectly participate. The mode of expressing the carbon footprint varies and results from its definition. While determining the CFP of a product or a process, its life cycle assessment (LCA) should be taken into account, i.e. an assessment of each and every effect of raw materials and means indispensable for this process or for manufacturing a product, and then each means and conditions of using such a product, and finally means indispensable for its potential disposal [14]. The value of the CFP is expressed differently, usually as an equivalent of CO_2, referred to as a service or product. The different contribution of the GHGs to the greenhouse effect, expressed as the GWP, is converted in reference to CO_2 and understood as its equivalent.

The most established methodologies to determine CFP are: PAS 2050 [3] for products and services life cycle GHG emissions assessment, the ISO methodology for

CFP quantification (ISO 14067-1) [17] and communication (ISO 14067-2) [18], the GHG Protocol for companies [19], and the PAS 2060 – the first specification for carbon neutrality [20]. Before publishing the PAS 2050 (publicly available specification) by the British Standards Institution in 2008, the CFP was determined based on ISO standards only. The scientific foundation of CFP calculation is an LCA based on ISO 14040 [15] and 14044 standards [16]. The LCA framework in these standards specifies guidelines, requirements, and procedures for: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, results interpretation, critical review and limitations of LCA, conditions for use of value choices, etc.

LCA as a Tool for Quantitative Expression of Carbon Footprint

LCA is one of several techniques of natural environmental management that serve to investigate environmental aspects and potential impact on the environment; it is also applied to determine the CFP. This technique is based on the analysis of a product and its "life span" (i.e. "from cradle to grave"), spanning from raw material production through manufacture of a product, its use, and finally disposal. The methodological basis for determining GHG emissions and CFP values are ISO standards 14040 and 14044 [15, 16]. According to the above standards, the LCA should proceed in the following stages (Fig. 1).

The first stage involves determination of the goal and scope of analysis. It serves to specify the extent of analysis and to establish whether the analysis is conducted for the effect of a product on global warming or, perhaps, on destruction of the ozone layer or its effect on eutrophication. All of these aspects may be defined as the goal of the analysis. At the next stage, within the goal and scope of analysis, a set of data necessary to conduct analyses is defined, including: raw materials, components, and energy inputs for the pre-production, production, use, and disposal phases (with the energy inputs meaning consumption of both energy and fuels). A significant element of the analysis is to determine the contribution of renewable energy. The subsequent stage of LCA includes assessment of the impact of manufacturing a product on the environment (in the earlier-specified scope). At each stage, the actions undertaken should be subject to evaluation and interpretation [15, 16]. Computer-aided tools provided by various companies are useful for conducting LCA. They differ in terms of the feasible scope and goal of analysis and are based on different data.

Having determined the scope and aim of analysis, LCA practitioners face a serious problem, namely the collection of essential data. The variety of production processes and technologies, as well as the variety of raw materials and production components and the lack of complete production records, may contribute to: omission of significant elements and the necessity of using estimated data. The methodology of the LCA assumes the use of data collected in a given production plant, but it permits the use of databases if data collection is impossible at the production site [15, 16]. The databases used should, however, be representative of a given geographic area.

Methodology

The aim of this study was to analyze the available literature data on the size of the CFP during the production of animal materials (pig production). The study analyzed the production of livestock, which is increasing in both Poland and other European countries despite the increasingly lower profitability of this production. The tool used to determine the CFP value was an LCA. Additionally, the factors differentiating the value of CFP (obtained in a variety of systems of agricultural production) also were determined. The data of literature concerning the factors that hinder meaningful, reliable determination of the value of CFP in agricultural production were also analyzed.

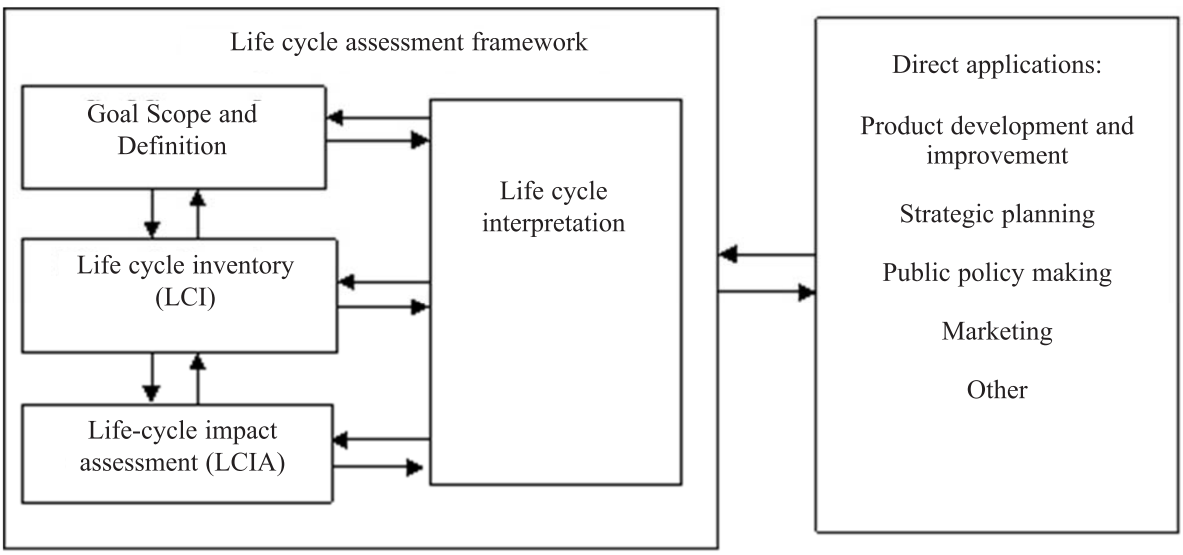

Fig. 1. The principles and framework for LCA in environmental management [15, 16].

Table 1. Differences in energy consumption in agricultural production, industrial agriculture, and ecology [21].

Winter wheat						
	Use of energy (GJ/ha)			Use of energy (GJ/t)		
Industrial agriculture	18.3	17.2	16.5	4.21	2.7	2.38
Organic agriculture	10.8	6.1	8.2	2.84	1.52	1.89
Difference [%]	**-41**	**-65**	**-51**	**-33**	**-43**	**-21**
Source	Data 1	Data 2	Data 3	Data 1	Data 2	Data 3
Potatoes						
	Use of energy (GJ/ha)			Use of energy (GJ/t)		
Industrial agriculture	38.2	24	19.7	0.07	0.08	0.05
Organic agriculture	27.5	13.1	14.3	0.08	0.07	0.07
Difference [%]	**-28**	**-46**	**-27**	**7**	**-18**	**29**
Source	Data 1	Data 2	Data 3	Data 1	Data 2	Data 3
Milk						
	Use of energy (GJ/ha)			Use of energy (GJ/t)		
Industrial agriculture	22.2		19.1	2.85		2.65
Organic agriculture	17.2		5.9	2.41		1.21
Difference [%]	**-23**		**-69**	**-15**		**-54**
Source	Data 4		Data 5	Data 4		Data 5

Data 1 – Alföldi et al., 1995; Data 2 – Haas and Köpke, 1994; Data 3 – Reitmayr, 1995; Data 4 – Cederberg and Mattsson, 1998; Data 5 – Wetterich and Haas, 1999

Data Analysis

Carbon Footprint in Animal Production

Agricultural production proceeds in a variety of systems, including: ecological farming, high-crop farming, and immediate farming forms, with the differentiating factors being: production scope, energy inputs, agricultural treatments, and production scale. All of these factors affect the value of the CFP. Energy inputs are identified as an important factor differentiating the value of CFP in organic and conventional agricultural production systems [21]. A number of studies have found lower energy consumption in ecological agriculture than in conventional agriculture (Table 1).

This lower energy consumption is due mainly to a diminished contribution of fertilizers, pesticides, and commercial feedstuffs, and the resulting lower energy consumption from their production process. It is estimated that the achieved reduction in energy consumption may reach 60%. In contrast, analyses show a 15% higher contribution of energy derived from fuels in ecological farms, as compared to conventional farms [21, 22]. The production of the commercial feedstuffs used on the farms show significant GHG emissions [23]. Alvarenga et al. [23] showed that the CFP due to the production of tons of feed for broiler diets ranges from 513 to 751 kg CO_2 eq. A significant share of this value are GHGs emitted as a result of fuel use [23].

An agricultural farm should be perceived as a complex manufacturing specified goods. Therefore, when evaluating the CFP of a given farm, the agricultural production should be treated as a set of closely correlated elements. Table 2 presents the values of the CFP and other parameters of the evaluation of pork production impact on the environment as determined by various authors [24].

Table 2. The environmental impact of pork production based on good agricultural practice (GAP) – values related to kg pork [24].

	Data 1	Data 2	Data 3	Data 4
CFP [kg CO_2 eq]	**2.30**	**2.06**	**3.73**	**3.66**
Eutrophication [kg PO_4 eq]	0.0208	0.0183	0.0182	LD
Acidification [kg SO_2 eq]	0.0435	0.0304	0.0305	LD
Use of non-renewable energy [MJ]	15.9	9.3	15.6	18.6
Use of land [m^2/year]	5.43	6.38	LD	LD

Data 1 – Basset-Mens and van der Werf, 2005; Data 2 – Cederberg, 2002; Data 3 - Blonk et al., 1997; Data 4 - Carlsson-Kanyama, 1998
LD – lack of data

Table 3. The environmental impact of pig production expressed per kg of pig and per hectare for good agricultural practice (GAP), organic agriculture (OA), intermediate forms (RL) [24].

Impact category	CFP [kg CO_2 eq]		Use of non-renewable energy [MJ]		Use of land [m^2/year]		Pig produced [kg]	
	Per kg of pig	Per hectare	Per kg of pig	Per hectare	Per kg of pig	Per hectare	Per kg of pig	Per hectare
GAP	**2.30**	**4,236**	**15.9**	**29,282**	**5.43**	10,000	1	**1,842**
OA	**3.97**	**4,022**	**22.2**	**22,492**	**9.87**	10,000	1	**1,013**
RL	**3.46**	**5,510**	**17.9**	**28,503**	**6.28**	10,000	1	**1,592**

CFP – carbon footprint

The highest value of CFP determined for one kilogram of pork – 3.66 kg CO_2 eq – corresponds to the highest consumption of energy from renewable sources. This result originates from 1998, when great emphasis was put on the need to reduce energy consumption [24]. The CFP values obtained in 2005 and 2002 should be considered similar, despite differences in the consumption of renewable energy. Basset-Mens and Van der Werf [24] have indicated the cause of discrepancies in the achieved CFP values and other parameters characterizing the negative impact of breeding on the environment. The range of nitrogen compound emissions and absorption reported by the experts is, however, far from real. The above-mentioned authors have demonstrated that these discrepancies may reach even 25% [24]. This is consistent with the findings reported by Pietrzak [12], who pointed to a dependency of nitrogen balance on the quantity of fertilizer used in a given ecosystem.

Basset-Mens and Van der Werf [24] also analyzed the effect of a breeding system on the CFP value of pork production. They determined the CFP value for agricultural production based on: good agricultural practice (GAP), organic agriculture (OA), and intermediate forms (RL). The CFP values determined for particular systems of agricultural production were then applied to the following units: kg of pork and hectare (Table 3).

The data collated in the table indicate that the highest value of CFP per kilogram of pork was achieved for pork produced in the system of organic agriculture. The farm operating in this system also was characterized by the lowest yield: 1013 kg pork/ha, and by the highest consumption of non-renewable energy [21]. Interestingly, the same CFP value applied to a hectare of land used in agricultural production yields a completely different picture, and organic production contributes the least to the emission of GHGs [24]. Numerous scientists are engaged in ongoing discussions regarding the optimal indications of functional units in LCA analysis of agricultural production [24, 25, 26]. Given the multi-functionality of agriculture, some investigators recommend conducting LCA in relation to both the functional unit (which is the unit of agricultural area) and in relation to agricultural production units [13, 26, 27]. CFP specified in relation to the unit determines the impact on the environment, the main factor affecting its value is production capacity. The reference value of the CFP to the unit area for use of agricultural land is more appropriate in determining the environmental impact locally [28, 29]. The choice of functional unit is essential when comparing organic farms and conventional, in which one element is the differentiating factor: productivity [13, 24].

The situation is complicated when the GHG emissions associated with agricultural activity must be attributed to several products which occurs, for example, in dairy farming. Standard ISO 14044 [16] recommends avoiding the use of allocation for two or more products in the analysis of LCA. If avoiding allocation is not possible, it is necessary to analyze the inputs and outputs of the system and break down products analyzed on the basis of physical causality. If the physical causality cannot be used, it is recommended to use economic causality [16, 30]. In order to determine the value of CFP for combined meat and milk production, researchers suggest different methods of allocation based on: physical causality [31, 32], economic value [33-35], or protein content [36]. Researchers also point to the need to precisely define the waste of LCA analysis (including livestock), and account for market surpluses and the quality of meat obtained in order to determine a fair and realistic allocation of CFP values for milk and meat [30, 37, 38]. This is the concept of system expansion [37]. Cederberg and Stadig [37] showed that the use of system expansion gives a lower value of CFP for milk. The application of the economic and physical allocation shows that milk in combined production accounted for 91% and 85% of GHG emissions, while the system expansion analysis shows only a value of 63% [37]. Similar arrangements were determined by Flysjö [30], indicating that the milk produced in combined production is responsible for 63-76% of the CFP value.

Difficulties of the Agri-Food Sector in Determining Carbon Footprint

Difficulties in determining the CFP are posed mainly by the stage of collecting data necessary to conduct analysis in the scope defined. In the case of the CFP, the specified scope of analysis covers data referring to: CO_2, N_2O, and CH_4. Some existing studies determine CFP based only on the energy demand of a process or a product [21]. However, the obtained value depicts mainly CO_2 emissions. This cannot be applied to agricultural production because, according to the opinion of the European Economic and Social Committee, agriculture contributes high amounts (40%) of methane and nitrogen suboxide emissions to the environment [8]. Studies conducted into the method of CFP determination in the case of agricultural products have attempted to define a universal CFP value for a given product. Nonetheless, agriculture is highly differentiated through the production scope, agricultural treatments and production scale. The effect of this variation is a different balance of nitrogen and methane on the farm.

The inputs considered in the balance of nitrogen include: purchase of mineral fertilizers, feed concentrates and bulky feeds, cereals, and animals for breeding; as well as biological assimilation of atmospheric nitrogen and precipitation. The outputs include the sale of plant and animal products. The effectiveness of nitrogen utilization is defined as the input-output ratio (%). Investigations conducted by Pietrzak [12], covering five agricultural farms located in northeastern Poland have demonstrated differences in the effectiveness of nitrogen utilization, which ranged from 12 to 40% [12]. The highest effectiveness was reached on the farms with smaller cattle stock. In turn, the farms with the lowest effectiveness of nitrogen utilization were demonstrated to use the highest quantities of nitrogen-based mineral fertilizers and feed concentrates as well as to have the greatest animal stock [12].

Why is the nitrogen balance of a given farm significant? Nitrogen derived from fertilizers is incorporated into the metabolic cycle of soil nitrogen. Plants exploit about half the nitrogen dose provided with the fertilizers, and another 20% is immobilized in the soil in the form of nitrates, whereas 25% involve gaseous losses (nitrogen escaping in the ammonium form (NH_3) and oxide form (NO_x) to the atmosphere), and finally 5% of nitrogen is leached into the soil profile. Gaseous losses also occur in the denitrification process under conditions of high moisture content of soil and low molecular pressure of oxygen, and consist in the reduction of nitrates to nitrogen (N_2) and nitrogen suboxide (N_2O) [39]. These proportions are, however, subject to changes along with the increasing quantities of applied fertilizers. The percentage of nitrogen assimilated by plants decreases, thus increasing emissions to the atmosphere. It is also worth noting that an excess of nitrogen exerts a negative effect on the vegetative processes of plants. This, in turn, affects carbon assimilation by plants. Backer et al. [13] suggests the use of inorganic fertilizers and the management of manure to control excess nitrogen compounds on the farm. They suggest agronomic solutions consistent with the philosophy of organic farming as a way of balancing the farm nitrogen balance (changes in cropping patterns, more use of catch crops in autumn and winter, etc.) [13]. These differences seem to be a significant factor differentiating the contribution of individual farms to GHG emissions. Therefore, it is impossible to adopt one value of the carbon footprint for a ton of wheat. This value may differ, to a great extent, as affected by the various energy consumption and nitrogen balances of particular farms. Therefore, indication of methods enabling the current analysis of emissions poses great difficulties.

Another problem faced by agriculture is the disposal of animal excreta originating from agricultural production. This problem is particularly important because of increasing meat production and its consumption [40]. In 2006 in Poland, the annual consumption of meat accounted for ca. 75 kg per capita, while in 2013 it is estimated to reach 80 kg [41]. Emissions of methane (CH_4) are generated by intestinal fermentation of ruminants and by animal feces. According to a report issued by the EC, 31% of methane emissions result from intestinal fermentation and another 11% from management of excreta originating from breeding [5]. This is highly generalized, however. Animals are bred in a variety of systems, with the animal stock and breeding method being the key determinants in this respect. In this context, rational management of animal excreta seems to be of the at most significance. Part of the excreta are used as fertilizing manure, especially in farms combining animal breeding and crop cultivation as well as on ecological farms. However, in large-stock breeding based mainly on commercial feedstuffs, the management of excreta poses a severe problem. Attempts have been made to effectively utilize wastes from agricultural production for biogas production [42]. Some reports may be found, however, which indicate that the production of biogas from farm wastes requires excessively high energy inputs for GHG reduction. Nonetheless, the use of agricultural wastes as a substrate for biogas production seems to be the most rational solution to their management [42].

A different problem is posed by agri-food processing. Farm products are intended to provide the human body with nutrients indispensable for its proper functioning. A significant nutritional factor is the biological value of these products. Technological and thermal processes used in food processing should serve to increase the absorption of dietary nutrients, neutralize detrimental compounds, and assure microbiological safety. Contemporary agri-food processing is aimed at manufacturing highly-processed food products involving high energy consumption. Thus, if the carbon footprint is treated as an approximate "measure" of energy consumption, its value should refer to the biological value of food produced. CFP relative to the nutritional value of food would be particularly important in the function of information to consumers [43]. Researchers suggest the possibility of adopting a functional unit such as nutritional value expressed as calorific value [44, 45] or protein content [36, 46, 47].

Results

The above-mentioned problems in the differentiation of agricultural production should constitute a significant element in an LCA determining the value of the CFP of particular agricultural products. Difficulties emerge, however, in selecting a methodology that would be effective for all types of farms. In the case of agriculture, identification of a methodology that considers the diversity of energy consumption, nitrogen balance, and waste management seems necessary [47].

Each agricultural farm constitutes a specific ecosystem. It is a part of our planet, used by people for specified purposes.

We should use this land reasonably, by balancing the emissions of GHGs originating from breeding with crop cultivation. Although reaching the null balance seems impossible, it should at least be as close to an equilibrium as possible. The CFP for a hectare of utilized land may thus become an indicator depicting the extent of agricultural production balance in a given farm. Such a determination of the CFP in respect to agricultural production seems to be the most reliable. It does not, however, exclude the application of the CFP indicator per kg of animal product or to a ton of crop. The CFP expressed in this way cannot, however, be perceived as a reliable indicator of the impact of a given farm on the environment. Determination of the CFP value per area unit of a given farm, and then referring this value to the size of agricultural production, seems to be an appropriate procedure in developing a credible and reliable indicator.

The introduction of an ecological indicator into our everyday life seems to be inevitable. As a result of the atmospheric phenomena observed outside the window, the warming of the climate is no longer an abstraction, but a real threat. The development of an indicator characterizing each and every product and service is not easy. Determination of the CFP will be of use only when consideration is given to geographical, technical, and technological differences, as well as in natural resources. Noting these differences and taking them into account while determining the value of an ecological indicator are necessary for the CFP to become:

- a guide for consumers – showing their contribution to the process of climatic change
- as a tool for conscious consumer choice and a teaching tool used to increase ecological awareness
- a marketing tool for producers and providers of services in pursuit of a customer, by determining the image of an organization
- a motivating factor for all people for rational energy consumption and responsible exploitation of the natural environment and its resources

Conclusions

The agri-food sector is characterized by a great diversity of forms of crops, livestock, and processing. The result of this diversity is the difficulties in determining the value of the CFP. These difficulties are an inspiration for further analysis of the issue, as evidenced by the research works.

The main directions of further research related to the methodology for determining the CFP of food products, including agricultural products, should be confrontation of methodology for determining the CFP currently indicated. It also seems necessary to have clear definition of terms used in environmental analysis (e.g. waste), LCA boundaries, and acceptable methods of allocation.

An important aspect of research in the further analysis of the environmental impact of agricultural production and food processing, it should be an analysis of the environmental cycle of GHG in geographic details. It also seems to be necessary to develop the new methods for measuring GHG emissions in a continuous system, which will enable credible collections and specific data for geographic areas.

The level of GHG emissions is the result of the used agricultural production system. Differences in emission of GHGs depend on many factors. The importance and participation in the differentiation of the level of GHG emissions requires research.

The researchers suggest the possibility of defining the CFP for different functional units (agricultural area, biological value, etc.). A particularly interesting concept appears to determine the value of the CFP to nutritional value. Such expressions of the CFP can help increase consumer awareness of nutrition.

Probably the research interests of the methods of agricultural waste management, mainly farming, will grow both in terms of ecological aspects concerning the reduction of GHG emissions, as well as due to the constant search for energy sources.

References

1. EEA 2010. The European environment – state and outlook 2010: Synthesis. European Environment Agency, Copenhagen, **2010** [In Polish].
2. Directive 2008/1/EC. Directive 2008/1/EC of the European Parliament and of the council of 15 January 2008 concerning integrated pollution prevention and control. Official Journal of the European Union **L24**, pp. 8-29, **2008**.
3. PAS 2050: 2008. Specification for the assessment of life cycle greenhouse gas emissions of goods and services, Carbon Trust, DEFRA and British Standards Institution, London, **2008**.
4. WIEDMANN T., MINX J. A Definition of 'Carbon Footprint'. In: C. C. Pertsova, Ecological Economics Research Trends: Chapter 1. Nova Science Publishers, Hauppauge NY, USA, **4**, **2008**.
5. Document Information AEE. The annual inventory of greenhouse gas emissions of the European Community from 1990 to 2007. The inventory report, May **2009**.
6. STEINFELD H., GERBER P., WASSENAAR T., CASTEL V., ROSALES M., DE HAAN C. Livestock's Long Shadow. Environmental issues and options. FAO, Food and Agriculture Organization of the United Nations, Rome, **2006**.
7. IPCC. Fourth Assessment Report, **2007**.
8. EESC 3.2.2009. Opinion of the European Economic and Social Committee on 'The link between climate change and agriculture at European level'. Official Journal of the European Union **C27**, pp. 59-65, **2009**.
9. SOLOMON S.D., QIN M., MANNING Z., CHEN M., MARQUIS K.B., AVERYT M.T., MILLER H.L. (Eds.) Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, **2007**.
10. HERTWICH E.G., PETERS G.P. Carbon footprint of nations: A global, trade-linked analysis. Environ. Sci. Technol. **43**, 6414, **2009**.
11. GERLACH T.M. Present-day CO_2 emissions from volcanoes. Eos Trans. AGU, **72**, (23), 249, **1991**.

12. PIETRZAK S. N and P budget in selected dairy farms in view of changes in Polish agriculture. WATER – ENVIRONMENT - RURAL AREAS 4, **1**, (10), 159, **2004** [In Polish].
13. DE BACKER E., AERTSENS J., VERGUCHT S., STEURBAUT W. Assessing the ecological soundness of organic and conventional agriculture by means of life cycle assessment (LCA): A case study of leek production. British Food Journal, **111**, (10), 1046, **2009**.
14. WEIDEMA B.P., THRANE M., CHRISTENSEN P., SCHMIDT J., LOKKE S. Carbon footprint a catalyst for Life Cycle Assessment? Journal of Industrial Ecology **12**, (1), 3, **2008**.
15. ISO 14040:2006. Environmental management – Life cycle assessment – Principles and framework, International Organization for Standardization, Geneva, **2006**.
16. ISO 14044:2006. Environmental management – Life cycle assessment – Requirements and guidelines, International Organization for Standardization, Geneva, **2006**.
17. ISO/CD 14067-1. Carbon footprint of products — Part 1: Quantification, International Organization for Standardization, **2010**.
18. ISO/CD 14067-2. Carbon footprint of products — Part 2: Communication, International Organization for Standardization, **2010**.
19. WRI/WBCSD. The greenhouse gas protocol, Product Life Cycle Accounting and Reporting Standard: e-reader version. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), USA, September **2011**.
20. PAS 2060. WHITE PAPER, PAS 2060, THE FIRST STANDARD FOR CARBON NEUTRALITY, CARBON CLEAR, January **2011**.
21. EL-HAGE SCIALABBA N., HATTAM C. (Eds) Organic Agriculture, Environment and Food Security, Environment and Natural Resources Service, Sustainable Development Department, Food and Agriculture Organization of the United Nations (FAO), Online document, http://www.fao.org/docrep/005/y4137e/y4137e00.htm. Accessed February 12, Chapter 2, **2009**.
22. STOLZE M., PIORR A., HÄRING A., DABBERT S. The environmental impacts of organic farming in Europe. Organic Farming in Europe: Economics and Policy, **6**, 1, **2000**.
23. DE ALVARENGA R.A.F., DA SILVA JÚNIOR V.P., SOARES S.R. Comparison of the ecological footprint and a life cycle impact assessment method for a case study on Brazilian broiler feed production. Journal of Cleaner Production **28**, 28, **2012**.
24. BASSET-MENS C., VAN DER WERF H.M.G. Scenario-based environmental assessment of farming systems: the case of pig production in France. Agric. Ecosyst. Environ. **105**, 127, **2005**.
25. MOURON P., NEMECEK T., SCHOLZ R.W., WEBER O. Management influence on environmental impacts in an apple production system on Swiss fruit farms: combining life cycle assessment with statistical risk assessment. Agr. Ecosyst. Environ. **114**, 311, **2006**.
26. CHARLES R., JOLLIET O., GAILLARD G., PELLET D. Environmental analysis of intensity level in wheat crop production using life cycle assessment. Agr. Ecosyst. Environ. **113**, 216, **2006**.
27. VAN DER WERF H.M.G., TZILIVAKIS J., LEWIS K., BASSET-MENS C. Environmental impact of farm scenarios according to five assessment methods. Agr. Ecosyst. Environ., **118**, 327, **2007**.
28. BERLIN D., UHLIN H.E. Opportunity cost principles for life cycle assessment: toward strategic decision making in agriculture. Progress in Industrial Ecology, An International Journal, **1**, 187, **2004**.
29. SCHAU E.M., FET A.M. LCA studies of food products as background for environmental product declarations. International Journal of LCA, **13,** (3), 255, **2008**.
30. FLYSJÖ A., CEDERBERG C., HERIKSSON M., LEDGARD S. How does co-product handling affect the carbon footprint of milk? Case study of milk production in New Zealand and Sweden. Int. J. Life Cycle Assess. **16**, 421, **2011**.
31. BASSET-MENS C., KELLIHER F.M., LEDGARD S., COX N. Uncertainties of global warming potential for milk production on a New Zealand farm and implications for decision making. Int. J. Life Cycle Assess. **14**, 630, **2009**.
32. CEDERBERG C., MATTSSON B. Life cycle assessment of milk production – a comparison of conventional and organic farming. J. Clean Prod. **8**, 49, **2000**.
33. ARSENAULT N., TYEDMERS P., FREDEEN A. Comparing the environmental impacts of pasture-based and confinement-based dairy systems in Nova Scotia (Canada) using life cycle assessment. Int. J. Agric. Sustain. **7**, (1), 19, **2009**.
34. THOMASSEN M.A., VAN CALKER K.J., SMITH M.C.J., IEPEMA G.L., DE BOER I.J.M. Life cycle assessment of conventional and organic milk production in the Netherlands. Agricultural Systems **96**, 96, **2008**.
35. CEDERBERG C., FLYSJÖ A. Life cycle Inventory of 23 Dairy Farms in South-Western Sweden. Report No. 728. SIK, the Swedish Institute for Food and Biotechnology, Gothenburg, Sweden, **2004**.
36. GERBER P., VELLINGA T., OPIO C., HENDERSON B., STEINFELD H. Greenhouse Gas Emissions from the Dairy Sector, A Life Cycle Assessment. FAO Food and Agriculture Organisation of the United Nations, Animal Production and Health Division, Rome, **2010**.
37. CEDERBERG C., STADIG M. System expansion and allocation in life cycle assessment of milk and beef production. Int. J. Life Cycle Assess. **8**, (6), 350, **2003**.
38. FLYSJÖ A., CEDERBERG C., HERIKSSON M., LEDGARD S. The interaction between milk and beef production and emissions from land use change – critical considerations in life cycle assessment and carbon footprint studies of milk. Journal of Cleaner Production **28**, 136, **2012**.
39. HATFIELD J.L., FOLLETT R.F. (Eds.) Nitrogen in the Environment: Sources, Problems, and Management, Second edition. Transformation and transport processes of nitrogen in agricultural systems. Amsterdam, Boston, Academic Press, Chapter **2**, **2008**.
40. MARQUER P. Pig farming in the EU, a changing sector. Agriculture and fisheries. Statistics in focus – Eurostat, **8**, **2010**.
41. IWAN B. Tendencies in changes in the consumption of dairy and meat products in Poland. Roczniki Naukowe SERiA **4**, 25, **2007** [In Polish].
42. EL-HADIDI Y.M., AL-TURKI A.I. Organic fertilizer and biogas production from poultry wastes. Journal of Food, Agriculture & Environment **5**, (1), 228, **2007**.
43. JUNGBLUTH N., TIETJE O., SCHOLZ R.W. Food purchases: impacts from the consumers' point of view investigated with a modular LCA. Int. J. Life Cycle Assess. **5**, 134, **2000**.

44. FRANKS J.R., HADINGHAM B. Reducing greenhouse gas emissions from agriculture: Avoiding trivial solutions to a global problem. Land Use Policy **29**, 729, **2012**.
45. TUROWSKI J., TKACZ K. The carbon footprint – an innovative index of the environmental impact of the food chain. Journal of Management and Finance, Quality and product safety and environmental protection in the agri-food sector. **2**, (1), 399, **2010** [In Polish].
46. MAILLOT M., DARMON N., DARMON M., LAFAY L., DREWNOWSKI A. Nutrient-Dense food groups have high energy costs: an econometric approach to nutrient profiling. The Journal of Nutrition **137**, (7), 1815, **2007**.
47. SMEDMAN A. Nutrient density of beverages in relation to climate impact. Food and Nutritional Research **54**, doi:10.3402/fnr.v54i0.5170, **2010**.
48. PAYRAUDEAU S., VAN DER WERF H.M.G. Environmental impact assessment for a farming region: a review of methods. Agr. Ecosyst. Environ. **107**, 1, **2005**.