Pol. J. Environ. Stud. Vol. 27, No. 3 (2018), 1261-1268
DOI: *10.15244/pjoes/76675* ONLINE PUBLICATION DATE: 2018-02-06

Original Research

Assessing Greenhouse Gas Emissions from Conventional Farms Based on the Farm Accountancy Data Network

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Received: 6 July 2017
Accepted: 26 August 2017

Abstract

Our paper uses the Intergovernmental Panel on Climate Change (IPCC) guidelines in combination with the Farm Accountancy Data Network (FADN) to estimate agricultural greenhouse gas emissions at the farm level. The study adopts a cross-cutting approach that combines emissions related to different categories (agriculture and energy/fuel). Overall, the aim was to assess the intensities of emissions from conventional farms classified according to production type, economic size, and utilized agricultural area (UAA). The results show that large variations in farms justify the micro approach to farm evaluation. Applying the methodology revealed that conventional dairy farm types, medium-small (25≤€<50) and medium-large (20<=UAA<30), were characterized by the highest GHG emissions intensity indexes compared to other farm types and sizes. The FADN originally was developed for evaluating the income of agricultural holdings and the impact of the Common Agricultural Policy (CAP). However, our study demonstrates that the current FADN database could also be used to provide indirect information on environmental farm performance, identify differences between farm types, and give insight into the environmental impact caused by the agricultural sectors in European countries. These results may also be useful for farm advisors to benchmark some aspects of farm environmental performance using farm financial data.

Keywords: emission intensity, FADN data, farm indicators, GHG emissions

Introduction

The agricultural sector in Poland accounted for 8% of the country's total greenhouse gas (GHG) emissions in 2014 [1]. It was the second largest source after the energy sector (81.3%) [1]. From 1988 to 2014 in Poland, GHG emissions from agriculture have decreased by 36%, whereas in the European Union (EU) the decrease has been 24% since 1990 [1-2]. The reduction of GHG emissions from agriculture was a consequence of implementing the following EU policies: Nitrate, Landfill Waste, and Renewable Energy Directives (RED), and the

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Common Agricultural Policy (CAP) [3]. The mitigation of GHG emissions was one of the main factors shaping the assumptions of CAP for the period 2014-20. The EU sets the GHG emissions reduction targets for short-, medium-, and long-term framework. The goal of the first period to the year 2020 is to cut GHG emissions by 20% in 2020 in comparison to the 1990 level [4]. The midterm perspective for the year 2030 defined binding targets by at least 40% GHG reduction by 2030 – to below the 1990 level [5]. To achieve this objective, GHG emissions should be cut by 43 and 30% (compared to 2005), respectively, in Emission Trading Sectors (ETS) and in non-ETS sectors (where agriculture is included). The long-term plan for 2050 suggests a reduction of GHG emissions to 80-95% by 2050 below the 1990 level, and the agricultural sector will have to cut its emissions by 42-49% [6].

Monitoring and reporting GHG emissions is a crucial step in each regulation related to the reduction of GHG emissions. In order to fulfill the commitments made under the United Nations Framework Convention on Climate Change (UNFCCC) and the European GHG emissions monitoring and reporting mechanism, each EU member state is obliged to prepare an annual National Inventory Report, which is the official tool for monitoring GHG emissions [1].

Within the framework of UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) has been responsible for developing common methodology for estimating emissions and removals of GHG from all sectors [7]. The IPCC Guidelines determinate three calculation methods (Tiers) based on available data [7]. Tier 1 methodology uses the default emissions factor provided by IPCC, assuming a linear relationship between emissions and activities data. The Tier 2 approach determines GHG emissions by adopting country- or region-specific emission factors indicating local pedoclimatic conditions. The Tier 3 method applies biogeochemical models. The Tier 1 and 2 methodologies require simple and accessible data, assuming that the sample data represent the full population, and, therefore, are appropriate for large-scale applications and for reporting.

Because agriculture is one of the most important sectors, in this context an appropriate assessment of emissions is one of the most difficult challenges [8]. Agricultural GHG emissions are a typical example of pollution originating from various sources, and then these emissions must be calculated indirectly. As stated before, the common indirect estimation methodology has been developed by the IPCC and is recognized globally as a standard related to aggregated data and does not appear to be particularly appropriate for micro data [7]. Coderoni et al. [9] adapted and applied the IPCC methodology in combination with data from the Farm Accountancy Data Network (FADN) to estimate GHG emissions at the farm level in Italy. The objective of FADN is to provide microeconomic data for evaluating the income of agricultural holdings and the impact of CAP for all EU member states. However, more and more often, FADN is used to assess environmental farm performance. Nevens et al. [10] used FADN data to examine N balances in dairy farms in Belgium. Westbury et al. [11] applied FADN data to the agri-environmental footprint index (AFP) to measure the environmental impact of three different types of agriculture in England. Gerrard et al. [12] used FADN data to compare environmental performance of organic and conventional farms. They stated that FADN could provide data to evaluate some aspects of farm environmental performance across many countries and access changes over time. Buckley et al. [13], based on FADN, applied a micro-level methodological approach to develop N and P sustainability indicators across a range of farm systems in the Republic of Ireland. Corson et al. [14] used FADN data to estimate emission inventories of French farms.

Coderoni et al. [9] stated that the use of FADN data has the advantage of making data collection on farm activities easier and standardized through all the different agricultural practices and farm types. In addition, using FADN data enables us to connect GHG emissions with other farm economic indicators, allowing for a defining hypotheses about possible causes of various emission intensities. By using FADN farm data connected to main agricultural activities, Coderoni et al. [9] estimated methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions in the following categories: animal and crop production, fertilizers, fuel, and land use. This approach makes it possible to compare emissions at different levels at a farm. In addition, it allows us to assess emission variations between farms due to economic size, type, utilized agricultural area (UAA), and location. Because they are strictly connected to farm production, the obtained values relate only to emissions that arise within the boundaries of the farm. In this method, the emissions resulted from the production of agricultural inputs, and transport of inputs and products are not taken into account. This "farm gate" approach in emissions estimation at the farm level has some benefits. The first advantage is to enable the farmer to control GHG emissions at each production stage and adjust the management practices to make them more environmentally friendly [15]. Secondly, this method provides the possibility of evaluating farm-level policies – mainly those that affect farmers' behavior in terms of choice of production technology and agricultural inputs applied.

The aim of our research was to assess environmental performance of conventional farms in Poland by estimating GHG emissions at the farm level and emissions intensity using FADN data.

Material and Methods

The methodology for estimating GHG emissions at farm level, as proposed in this study, is based on the adaptation of the IPCC methods [7] combined with the farm agricultural production data from the Polish

Table. 1 Emissions sources of the agricultural sector.

IPCC Category	Source	GHG
3A	Enteric fermentation	CH_4
3B	Manure management	N_2O, CH_4
3D	Agricultural soils	N_2O
3G	Urea	CO_2
1A	Energy	CO_2

Source: IPCC 2006

FADN database. According to IPCC methodology, the "Agriculture" sector (referring to agricultural holdings) emits principally two greenhouse gasses – CH_4 and N_2O – in nine different categories, six of which are estimated in the National Centre for Emission Management (KOBiZE) GHG inventory reports because they occur in Polish conditions. These include: enteric fermentation, manure management, agricultural soils, filed burning of agricultural residues, and liming and urea fertilization. Emissions of CO_2 from the use of machinery, farm buildings, and transport of agricultural products are classified in the "energy" sector. Furthermore, emissions and removal of CO_2 from agricultural soils and biomass are accounted for in the land use, land use change, and forestry (LULUCEF) sector. However, for appropriate assessment of GHG emissions at farm level the adopted methodology has been used, including emissions classified in two different sectors, i.e., agriculture and energy. All the sources of GHG emissions included in the applied methodology are presented in Table 1. In order to express emissions in CO_2 equivalents, the individual emissions (N_2O, CH_4, and CO_2) were multiplied by the Global Warming Potential (GWP) index. The values of GWP in a 100-year time frame are: 1 for CO_2, 298 for N_2O, and 25 for CH_4 [16]. In this study the IPCC emission factors were used to estimate GHG emissions. However, to reflect the specifics of national conditions some emission factors developed for Poland were applied, too. Those indicators are presented in official reports prepared by KOBiZE, which in Poland is responsible for compiling the GHG inventory for the purposes of the European Union and UNFCCC [1, 7]. GHG emissions from various sources were aggregated into four categories: animal production, crop production, fertilizers, and fuel. Table 2 presents the data from the FADN database that was used to estimate the individual emission categories.

Since the FADN database was not designed to collect the data needed to estimate GHG emissions at the farm level, some assumptions were necessary in order to complete the relevant data for calculating emissions by the four categories mentioned above. GHG emissions from livestock production include emissions from enteric fermentation and manure management. Enteric fermentation is a process including anaerobic decomposition of fibers derived from roughage. The amount of CH_4 emitted depends on the following factors: type, age, and weight of the animal, quantity and quality of the feed, and energy requirements. Two methods

Table 2. Summary of GHG emission sources considered and the respective FADN data applied.

Emission source	Emission category	FADN data
N_2O manure management	Animal production	Animal numbers
CH_4 manure management	Animal production	Animal numbers
CH_4 Enteric fermentation	Animal production	Animal numbers
N_2O agricultural soil		
N_2O direct emissions		
Use of N mineral fertilizers	Fertilizers	N quantities
Use of N organic fertilizers	Fertilizers	Animal numbers
Crop residues	Crop production	Crop area (UAA) and crop yield
Urine and dung depositing by grazing animals	Crop production	Animal numbers
N_2O indirect emissions		
Atmospheric deposition	Fertilizers	N quantities / Animal numbers
Leaching and run-off	Fertilizers	N quantities / Animal numbers / area and crop yield
CO_2 Urea	Fertilizers	Urea quantities
CO_2 Energy	Fuel	Fuel quantities

Source: Our own elaboration based on Coderoni et al. 2013 were used for estimating CH_4 emissions from enteric fermentation. The first, simplified, was based on the default values recommended by the IPCC, and the second used country emission factors. The Tier 1 method was applied in emissions estimation for pigs, goats, and horses, and Tier 2 for cattle. The country CH_4 emission factors for ruminants have been developed on the basis of daily animal energy requirements. CH_4 emissions from poultry were not estimated due to the lack of IPCC guidelines. The total amount of CH_4 emissions from enteric fermentation were calculated as a ratio of the annual average number of animals in each category and the emission factor (EF).

The next important source of CH_4 emissions was animal excrement decomposing under anaerobic conditions. The resulting amount of CH_4 fluxes depended on the weight of the excrement and storage technology. The CH_4 emissions from ruminant and non-ruminant manure were estimated using country emission factors developed in agreement with IPCC methodology. The emission factors, as in enteric fermentation, depend on the animals' daily demand for energy and their maintenance system. The amount of CH_4 emitted from manure management was obtained by multiplying the average annual animal number and specific EF. Within this category emissions from the burning of manure and those occurring during biogas production were not included. During the storage of animal excrement beyond CH_4 emissions into the atmosphere there is also N_2O emission. Estimations of N_2O emissions at Tier 2 were based on national data on livestock maintenance systems [1]. The basis for calculating the amount of nitrogen (N) in animal excrement were the country standard coefficients based on the quantity and digestibility of feed. As the FADN database contains very detailed data on livestock, in GHG emissions estimation weight and age categories of animals were taken into account. In our study, GHG emissions from plant production included N_2O emissions from crop residues and urine and dung deposited by grazing animals.

The analysis omitted emissions from organic soils, because none of the households had this type of soil. The N_2O emissions from crop residues were estimated on the basis of the area of each crop and their yields. Calculations of N_2O emissions resulting from animal urine and dung deposited on pastures were based on animal population and amount of nitrogen content in animal excreta. In the calculation of N_2O emissions from crop production, country-specific parameters applied in the national GHG inventory reports and the default emission values were used. GHG emissions from fertilizers constitute another category occurring at the farm. This includes emissions from the use of: mineral and organic fertilizers, urea, atmospheric deposition, and nitrogen leaching and run-off. Calculations of these emissions were based on the FADN data on: the amount of nitrogen and urea used, animal population, crop area, and the yield of each plant on the farm. For each of these emission sources the default values were taken from the IPCC [7]. In order to estimate the GHG emissions associated with fuel consumption on the farm, the CO_2 emission factor for Europe from the

Table 3. Economic and environmental farm level data for different farm types; standard deviations are shown in brackets.

Variable	Unit	Total	Field crops	Perm. crops	Fruits	Dairy	Grazing livestock	Pigs	Poultry	Mixed crops and livestock
Economic data										
Farm represented		688,967	136,104	28,353	30,644	93,350	30,013	25,814	4,769	339,922
Sample farms		11,701	3,185	348	402	2,703	428	768	73	3,794
Economic size	Euro	47,557	43,330	72,318	25,369	49,881	32,827	100,578	216,776	37,204
Total utilized agricultural area	ha	36	55	7	14	32	31	33	23	29
Total livestock unit (LU)	LU	28	3	1	0	41	31	108	200	25
Total output	PLN	235,075	241,512	379,157	181,707	234,824	119,276	440,615	1,689,403	165,764
Emissions data										
GHG farm	Mg CO_2 eq.	96.47 (113.8)	65.4 (80.4)	14.0 (19.2)	12.6 (14.2)	184.9 (144.2)	108.2 (119.6)	111.4 (121.9)	93.9 (87.9)	71.3 (80.0)
Emission intensity	g CO_2 eq. PLN^{-1}	410 (300)	270 (270)	40 (20)	70 (70)	790 (590)	910 (830)	250 (170)	60 (60)	430 (420)
Emission intensity per ha	Mg CO_2 eq. ha^{-1}	2.7 (2.7)	1.2 (1.3)	2.1 (1.9)	0.9 (1.3)	5.7 (6.4)	3.5 (3.3)	3.3 (3.3)	4.1 (2.8)	2.5 (2.9)
Emission intensity per LU	Mg CO_2 eq. LU^{-1}	3.5 (2.11)	2.2 (9.5)	24.3 (7.9)	-	4.5 (4.6)	3.5 (3.9)	1.0 (9.1)	0.5 (0.4)	2.8 (2.9)

Source: own calculation based on FADN data

Table 4. Economic and environmental farm level data for different economic farm sizes. Standard deviations are shown in brackets.

Variable	Unit	Total	Very small (2,000≤€ <8,000)	Small (8,000≤€ <25,000)	Medium-small (25,000≤€ <50,000)	Medium-large (50,000≤€ <100,000)	Large (100,000≤€ <500,000)	Very large (€≤500,000)
Economic data								
Farm represented		688,967	254,311	291,725	92,997	34,684	14,726	524
Sample farms		11,701	558	3,848	3,726	2,530	1,019	20
Economic size	Euro	47,557	6,523	16,253	36,093	68,716	162,590	813,586
Total utilized agricultural area	ha	36	9	16	30	52	104	152
Total livestock unit (LU)	LU	28	2	8	20	42	98	772
Total output	PLN	235,075	29,639	74,979	168,161	333,175	871,356	4,407,207
Emissions data								
GHG farm	Mg CO_2 eq.	96.47 (113.8)	10.2 (6.3)	30.6 (22.1)	83.7 (49.3)	159 (92.3)	274.3 (216.4)	568.3 (406.5)
Emission intensity	g CO_2 eq. PLN^{-1}	410 (300)	350 (370)	410 (400)	500 (580)	480 (650)	310 (320)	130 (140)
Emission intensity per ha	Mg CO_2 eq. ha^{-1}	2.7 (2.7)	1.2 (1.1)	1.9 (2.7)	2.7 (5.9)	3.1 (3.1)	2.6 (2.4)	3.7 (2.1)
Emission intensity per LU	Mg CO_2 eq. LU^{-1}	3.5 (2.11)	4.1 (2.7)	4.1 (3.1)	4.2 (3.4)	3.8 (3.2)	2.8 (2.4)	0.7 (1.1)

Source: Our own calculation based on FADN data

Table 5. Economic and environmental farm-level data for farms divided according to utilized agricultural area; standard deviations are shown in brackets.

Variable	Unit	Total	Very small (≤5 ha)	Small (5≤10 ha)	Medium-small (10≤20 ha)	Medium-large (20≤30 ha)	Large (30≤50 ha)	Very large (>50 ha)
Economic data								
Farm represented		688,967	62,079	219,529	247,307	83,446	50,445	26,161
Sample farms		11,701	337	1,114	3,237	2,314	2,454	2,245
Economic size	Euro	57,603	59,137	17,650	23,810	36,705	52,986	100,152
Total utilized agricultural area	ha	36	2	8	15	25	39	94
Total livestock unit (LU)	LU	28	22	7	16	27	37	49
Total output	PLN	235,075	416,998	80,893	106,550	168,120	249,221	523,141
Emission data								
GHG farm	Mg CO_2 eq.	96.47 (113.8)	16.2 (40.6)	18.3 (19.2)	46.6 (43.7)	85.1 (64.0)	123.2 (93.3)	201.7 (176.0)
Emission intensity	g CO_2 eq. PLN^{-1}	410 (300)	40 (40)	230 (120)	440 (270)	510 (330)	490 (450)	390 (320)
Emission intensity per ha	Mg CO_2 eq. ha^{-1}	2.7 (2.7)	6.8 (24.8)	2.3 (13.6)	3.1 (15.0)	3.5 (21.8)	3.2 (16.4)	2.1 (2.7)
Emission intensity per LU	Mg CO_2 eq. LU^{-1}	3.5 (2.11)	0.7 (0.3)	2.8 (1.4)	2.9 (1.5)	3.2 (1.9)	3.3 (2.0)	4.1 (1.9)

Source: Our own calculation based on FADN data transport sector was applied. The GHG emissions were calculated as a ratio of the quantity of fuel used and the emission factor. In our research, GHG emissions from the LULUCF sector were not included because the study concerns only one year. The main source of information used in the paper was data from the Polish FADN database on 2015 production. The farm samples were divided according to type of farming, economic size, and utilized agricultural area. Tables 3-5 present detailed farm characteristics in each grouping. The GHG emissions for all farms are expressed in CO_2 equivalents. To assess the impact of farm activities on the environment, we applied the three GHG emission intensity indicators. The first presents the level of GHG emitted to produce each one PLN (polish currency). The second is GHG emissions per hectare of utilized area, and the third is GHG emissions per livestock unit. Data are presented as average values with standard deviation.

Results and Discussion

The average size of agricultural holdings in our sample amounted to 36 ha (Table 3). The UAA of farms with animal production was lower than average, but on a similar level (with the exception of poultry farms). The average size of poultry farms was 36% lower than average. The total outputs of animal farms were different. The values of farm production from the largest to the smallest were as follows: poultry > pigs > dairy > mixed crop and livestock > grazing livestock. The results show that farms specializing in pig production made better use of available land resources than dairy and grazing livestock farms. The GHG emissions related with animal production were the most important emission sources at the farm level. This is in agreement with calculations performed by Baldoni et al. [17]. Estimated GHG emissions in the studied farm types show that the highest emissions occurred in dairy farms, e.g., 180% higher than in field crop farms. The farm types decided the share of each emission in total GHG emissions at a farm. In specialized animal farms, the emissions from livestock production ranged from 54 (pigs) to 67% (dairy) (Fig. 1), whereas the contribution of fertilizers amounted to 15% in the dairy, grazing livestock, and poultry farms. In pig farms it was higher (33%) because these farms applied more fertilizers to produce cereal for feeds. In field crop farms fertilizer emissions were about 65%. Emission intensity differed across farm types whether financial output, UAA, or livestock unit (LU) was dominant. The highest emission intensity per 1 PLN was recorded in grazing livestock farms and was due to very low production values. In studies performed on Italian FADN the highest GHG emissions were also assessed for grazing livestock and dairy farms [17]. The mixed crops and livestock-type farms are more environmentally sustainable.

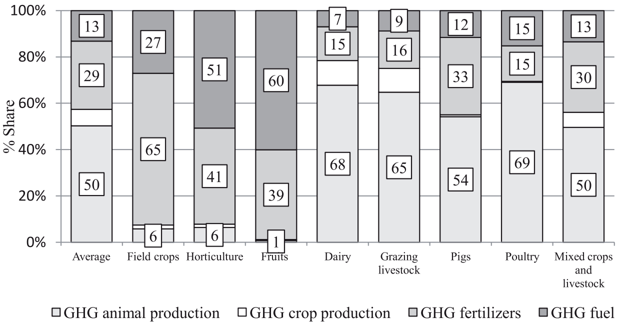

Fig. 1. Percentage share of animal, crop, fertilizer, and fuel GHG emissions at the farm level for different farm types.

The shares of GHG emissions from animal production and fertilizers applied were 49 and 30%, respectively (Fig. 1). Although emission intensities of these farms per UAA and LU were lower than those of specialized animal farms, the financial outputs of mixed farms were 30 and 32% lower, respectively, compared to dairy and field crop farms. The scale effect makes total financial output and GHG emissions grow with the size of agricultural holdings (Table 4). In our study, emission intensity per farm and LU increased from very small to medium-small farms. Then a decrease was recorded, which was a result of the higher increase of farm output and economic farm size. Our results are similar to those obtained by Baldoni et al. [17]. In their study, the medium farms were the highest emitters of GHG. Among very large farms poultry farms prevailed, which emitted less GHG per LU (0.7 Mg eq. CO_2 LU^{-1}) and more per ha (3.7 Mg eq. CO_2 LU^{-1}) than other farms. Fig. 2 reveals the percentage share of animal, crop, fertilizer, and fuel GHG emissions at farm level for different economic farm sizes. The share of individual GHG emissions in all farms from the largest to the smallest was as follows: animal production > fertilizers > fuel > crop production. GHG emissions from animal production varied from 40% in very small farms to 57% in very large. In all farms the share GHG emissions from crop production was below 8%.

The scale effect related to production values and GHG emissions was analysed in relation to UAA. The growth of farm area affected increases in financial output and GHG emissions (Table 5). The highest emissions per ha were recorded for very small farms because in this group are classified poultry farms, which are

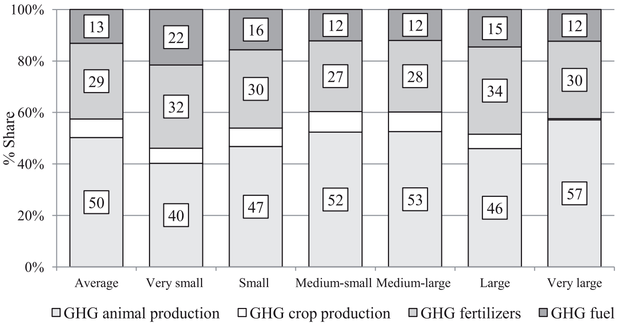

Fig. 2. Percentage share of animal, crop, fertilizer, and fuel GHG emissions at the farm level for different economic farm sizes.

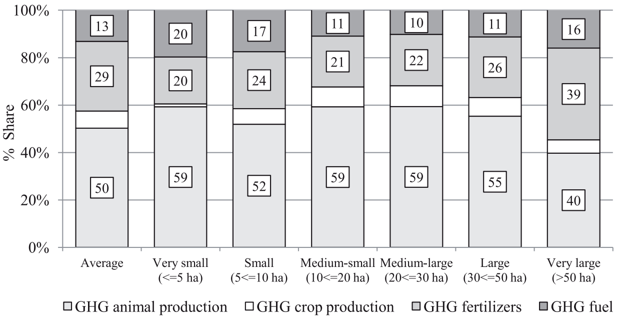

Fig. 3. Percentage share of animal, crop, fertilizer, and fuel GHG emissions at the farm level for farms divided according to utilized agricultural area.

characterized by high production value and small area of agricultural land. The emission intensity of small farms in Poland was on a similar level as small farms in Italy [17]. Emission intensity per ha of small farms was 2.3 Mg CO_2 eq. This value was similar to GHG emissions recorded for winter wheat production in field crop farms, where UAA was lower than 10 ha [18]. In our sample, the farms from 20 to 30 ha of UAA marked the highest emission intensity per PLN and LU. This was due to the fact that on these farms the number of animals was higher than the agricultural area. The share of GHG emissions from animal production in this group amounted to 60% (Fig. 3). Increases in UAA resulted in a decrease of GHG emissions from animal and crop production and growth of emissions from applied fertilizers and fuel. The presented results demonstrate that the FADN database has proved to be a valuable source of information in providing data required for assessing GHG emissions. This is an agreement with Dalgaared et al. [19], who concluded that FADN data could be applied to perform area-based environmental assessment, including farm emissions, which have an effect on the local environment. They also stated that there is a significant difference in resource use and emissions between farms of the same main enterprise, and for that reason it is insufficient to evaluation and compare agricultural products on case studies.

Most of the existing life cycle assessment (LCA) is based only on data from one or a few farms [18, 20]. An important strength of the applied methodology is that all the farm types are representative because they use valid farm data from farm accounts. Additionally, the farm types created were based on accurate and well-documented resources showing average production and efficiency levels within different farm types. The next strength of this method is a simple methodology, because only a few data are required, which allows us to measure the possibility of emissions reduction in a cost-effective manner. In effect, the farmer could control GHG emissions at the farm gate. Also, policy implemented at the farm level can be better evaluated without additional funds. The presented methodology is novel and contains some of issues that should be considered further in the work. Dick et al. [15] stated that national average emission factors can hide some farm level improvements and do not include new mitigation measures. The next issue, brought by Coderoni et al. [9], is how to count relatively immediate land-use change emissions over time. However, despite these weaknesses, the proposed methodology provides the opportunity to measure the possibility of reducing emission in a cost-effective manner.

Conclusions

The primary objective of our paper was to present the impact of conventional farms on the environment in Poland. Environmental performance was assessed by calculating GHG emissions and intensity indexes at the farm level based on the PL FADN database. The agricultural holdings were classified according to type of production, economic size, and utilized agricultural area. The comparable farms differed in their organization of production, productivity, and income. The results show that large variations in farms justify the micro-approach of farm evaluation. Medium-small (25≤€<50) and medium-large (20≤UAA<30) conventional dairy farm types were characterized by highest GHG emission intensity indexes compared to other farm types and sizes. The obtained indicators could be used by farm advisors to assess some aspects of environmental performance in an individual farm or group of farms. Additionally, they give a possibility to disseminate the best management practices that reduce GHG emissions. A methodology based on FADN could allow for an integrated assessment of GHG mitigation in a cost-effective manner because FADN data are collected for economic analysis.

Acknowledgements

Our studies were supported by National Centre for Research and Development within the project "Support for low carbon agriculture able to adopt to observed climate change in the perspective of 2030 and 2050".

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