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Calculation of the carbon footprint for family farms using the Farm Accountancy Data Network: A case from Lithuania

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ABSTRACT

This study appraises the greenhouse gas (GHG) emissions for Lithuanian family farms based on the Intergovernmental Panel on Climate Change (IPCC) guidelines using Lithuanian emission factors from Lithuania's National Inventory report (LNIR). Family farm activity data are derived from Lithuanian sample of the Farm Accountancy Data Network (FADN) for 2016. The GHG emission profile for Lithuanian family farms includes the estimates for methane (CH_4) from enteric fermentation of domestic livestock population, CH_4 from manure management, direct and indirect nitrous oxide (N_2O) emissions from manure management, direct and indirect N_2O emissions from managed soils, and carbon dioxide (CO_2) from combustion of fuel. In Lithuanian family farms, on average, the key source categories of on-farms emissions were CH_4 from enteric fermentation and N_2O direct emissions from agricultural soils, as they together constituted 69.3% of the total emissions. The environmental pressures related to family farming were measured in terms of the Carbon Footprint (CF), which refers to the total amount of GHG produced by farming activities, and Carbon Intensity (CI) using a range of metrics including CI per land area, total output and Livestock Unit (LU). In 2016, CF stood at the average value of 57.8 t CO_2eq farm^{-1}, CI per UAA – 1.5 t CO_2eq ha^{-1}, CI per total output – 2.7 kg CO_2eq EUR^{-1} and per LU – 6.0 t CO_2eq LU^{-1}.

1. Introduction

The climate change has raised concerns across different sectors of economy (Guo et al., 2018; Savitz and Gavriletea, 2019; Song et al., 2019). The measurement of the CF an important task for deriving effective policy measures. This is important for agricultural sector which is responsible for substantial share of the GHG emission and is impacted by different support schemes across the world. As regards the European Union (EU), the Common Agricultural Policy (CAP) is implemented there in order to improve competitiveness and sustainability of the agricultural sector. The CAP has been significantly modified in order to affect the choices and behavior of farmers that considerably influence their production, environmental performance and lower GHG emissions (Coderoni and Esposti, 2018).

Lithuania has been submitting the National Inventory Reports to United Nations Framework Convention on Climate Change on an annual basis since 2004. The methodological basis for the measuring GHG in the reports relies on the guidelines developed by the IPCC. These guidelines are widely adapted and applied to estimate GHG emissions in different countries (Browne et al., 2011; Riaño and García-González, 2015; Lynch et al., 2018; Schueler et al., 2018). This allows tracking the achievements in terms of pre-set targets outlined in strategic documents (IEEP, 2011; EC, 2017; EC, 2018; European Council, 2018). Lithuanian agriculture between 2005 and 2016 saw a 6.2% increase of GHG emissions and the latter sector remained responsible for 22.1% of the total national GHG emission in 2016. The main share of agricultural GHG emissions was related to the management of agricultural soils (53.4%) as of 2016 (LNIR, 2018). In Lithuania, during 2005–2016, the consumption of inorganic nitrogen fertilizers increased by 34.7% mainly due to a decline in cattle number by 8.8% and an increase in crop area by 19.8% (Eurostat, 2020; Statistics Lithuania, 2020). The higher level of inorganic nitrogen application led to increased direct and indirect N_2O emissions from agricultural soils. The implementation of 2014–2020 Rural Development Program for Lithuania enabled to save relatively small amount of GHG emissions and the effectiveness of support under this Program for climate change mitigation was not significant (FPP Consulting, 2019). Hence, increasing emissions of GHG from agriculture will present great challenges for

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Lithuania to meet a target of 9% reduction by 2030 compared to 2005 baseline which is set for sectors, like agriculture, not included in the EU Emissions Trading System under the EU Effort Sharing Regulation (Regulation (EU) 2018/842) (European Council, 2018). Therefore, it is important to quantify the GHG emission in Lithuanian agricultural sector related to multiple interlinked factors.

This study focuses on the analysis of the GHG emissions at the farm level. The rationale for that is twofold. First, there is no methodology for appraisal of the GHG emissions at the farm level for the case of Lithuania. Indeed, a number of GHG emissions calculators are available for different countries (Colomb et al., 2012), yet they cannot be generalized as emissions factors values and other country specific criteria differ across countries. Second, as the GHG emissions are unobserved at the farm level, farmers' decisions related to production processes have no relation with the desirable change in the CF. This precludes creation of the climate-smart agriculture, which integrates climate change into the planning and implementation of sustainable agriculture (Campbell et al., 2014). The impacts of climate change on agriculture and vice versa are not contested, therefore, this paper seeks to provide a methodology to assess the farm-level GHG emissions for Lithuanian family farms. The proposed methodology is then applied to assess CI across farm farming types and farm size groups (both economic and physical).

The major contribution of the present research with respect to previous studies (Dabkienė, 2017, 2018) lies in expanding the scope of the emission sources by including emissions resulting from fuel combustion and electricity use, emissions from crop residues and emissions from urine and dung deposited on soil from grazing animals. The GHG emission from fuel combustion is an important contributor of GHG emissions on farm: GHG emissions from fuel comprised 13% in Polish farms in 2015 (Syp and Osuch, 2018) and accounted 15% in Italian farms in 2013 (Baldoni et al., 2017) of the total on-farm GHG emissions. Ryan et al. (2016) reported that emissions from fuel combustion and electricity amounted to values in between 5% and 8% of the total GHG emissions per kg of output on farms depending on farm system. Henriksson et al. (2011) concluded that the use of diesel variates greatly due to different management systems in milk farms, in turn, resulting in large variations of the CF. Coderoni and Esposti (2014) emphasized the importance of fuel on GHG emissions in farms. In general, fuel is often disregarded in the empirical studies on the agricultural contribution to the GHG emission, as this source of emissions is attributed to the energy sector in the IPCC methodology.

What is more, this is the first study reporting the CF for Lithuanian family farms on the basis of the weighting used in the Lithuanian FADN sample (LAEI, 2017). According to the FADN (2018) methodology, weights as an extrapolation factors are applied at the farm level so that the sample farms results represent the national farm population. The on-farm GHG emissions could be appraised by considering the Life Cycle Analysis (emissions minus removals) and taking into account emissions under category Land Use, Land Use Change and Forestry (LULUCF). However, the emissions or removals from changes in forest land, cropland, wetlands and other are not considered in this study due to the lack of data regarding farming within certain types of terrain (e. g. wetlands) and on conversion of farm land area to other types of land use (land converted to forest land, land converted to cropland etc.).

The rest of the paper is structured as follows: Section 2 gives a detailed overview of the methodology for calculation of the GHG emission at the farm level that is applied for the empirical research. Section 3 presents the calculation of GHG emissions for Lithuanian family farms. GHG emissions across farming types and farm size groups are discussed. The comparative analysis is also presented. The concluding remarks are provided in Section 4.

2. Methods

One of objectives of this paper is to present GHG assessment tool for Lithuanian farms, therefore detail information is provided in terms of the source of the certain data (equations and emission factors). The methodology proposed for this paper is based on IPCC guidelines (IPCC, 2006) and LNIR, 2018, as the latter contains some developed emission factors reflecting to the country specific information. Considering the main GHG emission sources of agricultural sector and the availability of farms activity data in FADN, the emissions from enteric fermentation of domestic livestock, direct and indirect emissions from manure management, direct and indirect N_2O emissions from managed soils, and combustion of energy in the study were inventoried (Table 1). The GHG emissions inventoried in the study were distinguished into the three main sub-categories for presenting results across farm farming types, economic and physical sizes: 1) "GHG enteric fermentation and manure management", which include CH_4 emissions from enteric fermentation and CH_4 from manure management, and N_2O direct and indirect emissions related to manure management; 2) "GHG agricultural soils", N_2O direct and indirect emissions related to agricultural soils fell into this sub-category, and 3) "GHG energy" include emissions from fuel and electricity combustion.

Methane emissions from enteric fermentation and CH_4 and N_2O emissions from manure management are directly related to the number of domestic livestock on farm. FADN activity data related to the raised livestock on farms is detailed presenting livestock sub-categories by their species and age. This data was adjusted to the livestock sub-categories to correspond to the estimated emissions factors provided for livestock by LNIR (2018). GHG emissions from enteric fermentation were estimated using equation 10.19 from IPCC (2006) guidelines, i. e. the emission factor for the defined livestock population was multiplied by the number of head of livestock sub-category. The country specific emission factors were taken for dairy cattle from Tables 5–18, for non-dairy cattle sub-categories from Tables 5–19, for swine sub-categories from Tables 5–20 and for sheep from Tables 5–21 in LNIR (2018). The IPCC default values for goats (5 kg/CH_4/head/year) and for horses (18 kg/CH_4/head/year) provided in Table 10.10 or LNIR (2018) Tables 5–22 were used as country-specific values were not estimated by LNIR. CH_4 emissions from manure management depend on the amount of manure produced and the fraction of the manure that decomposes anaerobically. The amount of CH_4 emitted on farm is affected by the rate of manure production per domestic livestock and the number of domestic livestock. The manure management system, the climate conditions during the storage and the retention time of the storage unit affect the amount of methane produced. LNIR (2018) provides country-specific emissions factors from manure management for dairy (Tables 5–30 non-dairy (Tables 5–31), swine (Tables 5–32) and for sheep (Tables 5–33). The default values for goats and horses were taken from Table 10.15 (IPCC, 2006) given for developed countries with an average annual temperature bellow 15 °C.

N_2O emitted during the storage of manure (as manures contain substantial quantities of N) were taken into account. Equation 10.25 in IPCC (2006) is used to calculate the emissions. The main data required for calculation is the number of domestic livestock on farms. The data related to the manner in which manure is treated on farms are not included in the FADN. Therefore, the assumption provided in LNIR (2018) is taken into account. In Lithuania, 37.8% of manure from dairy cattle during the stable stage is handled in the solid and 22.1% – in the liquid management systems. Approximately 40% of dairy cattle manure is settled on pastures. Manure management systems for non-dairy cattle are distributed as follows: 37.8% in solid, 21.4% in liquid and 9.5% in deep bedding

Table 1
GHG emission sources accounted for.

Emission sources	FADN activity data	Source in IPCC, 2006 (Volume 4)
CH_4 enteric fermentation	Animal numbers	Equation 10.19, 10.20
CH_4 manure management	Animal numbers	Equation 10.22
Manure management:		
N_2O direct	Animal numbers	Equation 10.25
N_2O indirect	Animal numbers	Equation 10.26–10.29
Agricultural soils:		
N_2O direct		
Use of inorganic fertilizers	N fertilizers	Equation 11.1, Table 11.1
Urine and dung	Animal numbers	Equation 11.1; 11.15
Reutilization of crop residues	Crop area, production	Equation 11.1; 11.6
N_2O indirect		
Atmospheric deposition	N fertilizers	Equation 11.9, Table 11.3
Leaching and run-off	N fertilizers	Equation 11.10, Table 11.3
Use of energy	Fuel, electricity costs	Equation 3.3.1 (Volume 2)

manure management systems. About one third of non-dairy cattle manure was deposited on pastures. The liquid manure management system is dominant for swine manure treatment accounting 65.1%. The rest part of swine manure is handled as follows: the anaerobic digesters manure management systems amount to 22.8%, solid system − 10.1% and deep bedding system − 2% Country-specific information regarding N extraction factors per livestock head from LNIR (2018) tables 5−39 and 5−40 and default emission factor (EF_3) for direct N_2O emission from Tables 5−42 were taken for calculation. Indirect N losses during the storage of manure due to volatilization and leaching and run-off were inventoried. Country-specific default values for N loss due to volatilization and leaching from a certain manure management system from Tables 5−46 (LNIR, 2018) and the default emission factors (EF_4 and EF_5) from Table 11.3 (IPCC, 2006) were used.

Direct N_2O emissions (from N directly applied to soils) arising through the processes of nitrification and denitrification were included. In this research the nitrogen inputs from the application of inorganic fertilizers, cultivation of N-fixing crops, and incorporation of crop residues into soils, urine and dung from grazing animals were considered. As FADN statistics provides data on the quantities of inorganic fertilizers applied on farms, the emissions were calculated as the ratio of N fertilizers applied on farm and the default emission factors. Default emission factor used for inorganic N fertiliser was 0.01 kg N_2O−N/kg N (EF_1 tables 5−48).

Indirect N_2O emissions result from nitrogen which is lost from the field as NO_x, NH_3 or after leaching or run-off. Default emission factors were 0.01 kg N_2O−N/kg for indirect N_2O emission from the volatilization (EF_4 tables 5−58) and 0.0075 kg N_2O−N/kg N (EF_5 tables 5−58) for indirect leached/runoff emissions. Fraction of inorganic N fertiliser volatised was $Frac_{GASF}$ 0.069 (tables 5−60) and fraction of inorganic N fertiliser leached/runoff $Frac_{LEAC-(H)}$ was 0.3 (Tables 5−58 in LNIR, 2018).

The next important source of direct N emissions is the amount of nitrogen that is returned to soil by crop residues. The FADN activity data on non-N-fixing grain crops (namely, winter and spring wheat, triticale, rye, barley, oats, grain maize, winter and spring rape), N-fixing crops and potatoes, sugar beet and fodder beet area and yield was taken into estimation. In this research it is assumed that from non-N-fixing crops the straw after the harvest is processed for bedding or for the usage as biomass in renewable energy after harvesting cereals. Therefore, the N from the non-N-fixing grains plants stubbles and roots that are usually left on the field in order to increase soil fertility and reduce growth of tares was estimated. The emissions from crop residues were estimated using Equation 11.6 from IPCC (2006). The country specific data of each crop type in regard to the ratio of above-ground residues and ratio of below-ground residues dry matter to harvested yield, N content of above-ground and below residues were taken from LNIR (2018), Annex VII, tables 5−51 The emissions of N deposited on pasture range and paddock soils by grazing animals was estimated using the data on the number of livestock by sub-categories, annual N excretion rate per livestock head, the fraction of total annual N excretion for livestock sub-category deposited on pasture, range and paddock and EF_3 (tables 5−48 in LNIR (2018)).

The calculation of CO_2 emissions from energy uses on-farm is based on the methodology provided by IPCC (IPCC, 2006). The main farm activity data extracted from FADN was expenses for the main two energy consumption categories on farms, namely electricity and fuels. The primary data of electricity and fuel consumption was expressed in value. The quantities of electricity used were derived from the expenditure on electricity in euros and dividing this by electricity tariff (EUR/kWh) in 2016 taken from National energy regulatory council (2016), and then multiplying by electricity factor for Lithuania provided by Koffi et al. (2017). In order to convert diesel consumption data expressed in value to volume, the diesel price for agricultural sector in Lithuania in 2016 was used from AIRBC (2019). Equation 3.3.1 in IPCC (2006) and the emission factor for off-road vehicles and other machinery used in agricultural sector were gathered from LNIR (2018) "Energy" sector tables 3−63

GHG emissions (in CO_{2eq}) were calculated by summing up CO_2, CH_4 and N_2O emissions based on their equivalence factor in terms of CO_2 (100-year time horizon): 1 for CO_2, 25 for CH_4, and 298 for N_2O.

Another objective of this paper is to compare the on-farm CF constructed from aggregate (national) level datasets for agricultural sector with those obtained using the farm level data. The sectoral data on UAA (in ha), LU and number of farms were taken from Farm Structure Survey (Statistics Lithuania, 2018). Data on total output of Lithuanian agricultural sector for 2016 was obtained from Statistics Lithuania (2020). Sectoral data on the GHG emissions that arise from agriculture were obtained from LNIR (2018). Focusing on the year 2016 was based on the availability of the latest national statistics. The on-farm GHG emissions analysis considered 1301 individual farms covered by the Lithuanian FADN data in 2016. Three main indicators to estimate the GHG emissions were calculated: CF, which refers to the total amount of GHGs produced on farm, CI per ha UAA and CI per LU in terms of farm inputs and CI per farm total output. CF and the CI indicators are often presented in studies (e. g. Zehetmeier et al., 2014; Ryan et al., 2016; Silva et al., 2016; MacLeod et al., 2016; Syp and Osuch, 2018) assessing GHG emissions from agriculture as these indicators allow to compare the results among different groups within analysed sample and as well enables to compare results with other farms/farm groups located in similar geographical region.

The influence of type of farming, farm economic and physical size to CF and CI on farm was examined. The analysis was carried out for nine major types of farming defined in terms of the standard output, namely, for specialist cereals, oilseeds and protein crops (COP) (TF 15), general field cropping and mixed cropping (TF 16), horticulture (TF 20), various permanent crops combined (TF 36), specialist dairying (TF 45), grazing livestock (TF 49), specialist granivores (TF 50), field crops-grazing livestock combined (TF 80) and various crops and livestock combined. The results were obtained for the six economic size classes according to Standard Output (SO) value in EUR:

(I) 2000–8,000,
(II) 8000–25,000,
(III) 25,000–50,000,
(IV) 50,000–100,000,
(V) 100,000–500,000,
(VI) ≥ 500,000.

The Lithuanian FADN sample represents family farms with an SO value of over EUR 4,000, due to this the first class only covers farms with the economic size of EUR 4000–8000. In order to reveal the scale effect related to CF and CI in terms of utilized agricultural area (UAA), the data set was divided into six physical farm size classes in ha:

1) < 30,
2) 30–50,
3) 50–100,
4) 100–200,
5) 200–500,
6) ≥500.

The normality of data on emissions intensities was tested by the Shapiro-Wilk test. As the data did not follow the normal distribution, Kruskal–Wallis one-way analysis of variance was used to examine the significance of differences in GHG emission intensities across the farming types and farm size groups. Following Mazor et al. (2009), the coefficient of variation (CV), expressed as a percentage, was used to indicate low (CV < 20%), moderate (20 < CV < 30), high (30 < CV < 40), sever (40 < CV < 70) and extremely high (CV > 70%) variability level of CF and CI values across farm sizes and types of farming.

3. Results and discussion

Table 2 presents the results of the comparative analysis of the CF and CI using sectoral and farm level data in Lithuania in 2016. The CF an average value of 29.6 t CO_{2eq} farm^{-1} using sectoral data was two times lower than that estimated using farm level data. This difference might occur due to differences in the sampling. The Farm Structure Survey excludes farms having less than 1 ha UAA and farms with annual agricultural income of less than EUR 1,520, while the Lithuanian FADN sample includes only farms exceeding EUR 4000 of the SO. Farm Structure Survey is carried out by all EU Member States and provides comparable results among countries. Based on Farm Structure Survey, the Lithuanian agriculture CF value as compared with results obtained for neighbor countries, namely, Latvia and Poland was 25.3% lower than in Latvia and 37.6% higher than in Poland. In Lithuania, the CI per ha UAA amounted to 1.5 t CO_{2eq} ha^{-1} using both sectoral and farm level data. The obtained result for Lithuanian agricultural sector was lower than in Poland (2.1 t CO_{2eq} ha^{-1}) and slightly higher than in Latvia (1.4 t CO_{2eq} ha^{-1}). The CI per LU on Lithuanian family farms using farm level data was 15% higher than that obtained using sectoral data. The CI per LU of Lithuanian agricultural sector was slightly lower than in Latvia (6%) and by 63% higher than in Poland. The CI per total output on Lithuanian family farms using farm level data was 35% higher than relevant value gathered using sectoral data. Lenerts et al. (2019) stated that the CI quantity-based (CO_{2eq} kg product^{-1}) and value-based (CO_{2eq} EUR^{-1}) metrics more objectively indicate agricultural CI than those measured per country and territory. However, when using FADN data, it is challenging to develop CI per unit product indicators as it requires to allocate CF to a particular crop or product (Ryan et al., 2016).

In Lithuanian family farms, on average, the key source categories of on-farms emissions were CH_4 from enteric fermentation and N_2O direct emissions from agricultural soils, as they together constituted 69.3% of the total farms' emissions. The emissions from fuel combustion accounted for 16.7%, indicating the importance to report and account these emissions in farms (Fig. 1).

Table 3 reports economic performance of family farms across different types of farming. The economic size of family farms averaged to EUR 27.6 thou. The biggest economic size was registered for COP farms, which was 59% higher than average. COP farms were largest in terms of physical size of farm and averaged at 72.5 ha UAA. The highest output value was observed in specialist granivore farms and it was two-fold higher than the average for Lithuanian sample as whole. The specialist granivore farms were the largest in terms of the number of raised livestock.

The CF value varies considerably across farm types as CV value was extremely high (CV 75.1%) (Table 4). The field crops-grazing livestock combined farms have the highest CF as the emissions amounted 75.1 t CO_{2eq} farm^{-1}. On these farms, the largest share (63%) of GHG emissions was attributed to enteric fermentation and manure management (Fig. 2). The lowest value of CF was observed on horticulture farms (8.9 t CO_{2eq} farm^{-1}) followed by permanent crops farm type (12.0 t CO_{2eq} farm^{-1}). The GHG emissions generated from the use of fuel and electricity were the most significant contributors and amounted to 70% and 53%, on permanent crops and on horticulture farms, respectively.

Table 2
CF and GHG EI using sectoral and farm level data in Lithuania in 2016.

Indicator	Unit	Mean values for Lithuanian agriculture (sectoral level)	Mean values for Lithuanian FADN sample (farm level)
Physical size	ha UAA farm^{-1}	19,6	42,6
Herd size	LU farm^{-1}	5.7	8.7
Total output	EUR farm^{-1}	15,101	26,376
CF	t CO_{2eq} farm^{-1}	29.6	57.8
CI per ha UAA	t CO_{2eq} ha^{-1}	1.5	1.5
CI per LU	t CO_{2eq} LU^{-1}	5.2	6.0
CI per EUR of total output	kg CO_{2eq} EUR^{-1}	2.0	2.7

Note: LU (Livestock Unit) – average number of animals converted to livestock units by multiplying this number to a coefficient related to the sub-category of animal using the ratios in the EU FADN (2018), e.g. one dairy cow is 1 LU, one sheep or goat is 0.1 LU.
Sources: own calculations based on Statistics Lithuania (2018, 2020), LNIR (2018), LAEI (2017).

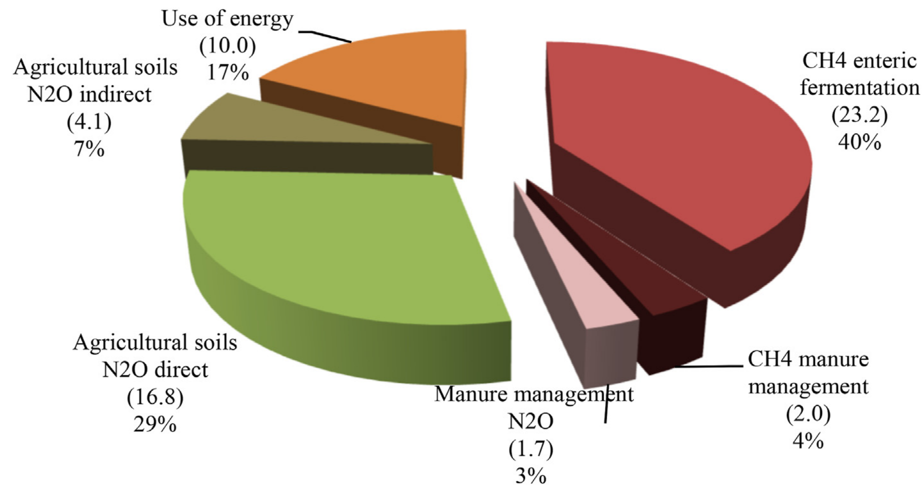

Fig. 1. The structure of CF by GHG emissions by sources.
Note: numbers in parentheses indicate the emissions in t CO_{2eq}.

Table 3
Economic performance of Lithuanian family farms by farming type.

Indicator	Unit/TF	COP (TF 15)	Field crops (TF 16)	Horticulture (TF 20)	Permanent crops (TF 36)	Dairy (TF 45)	Grazing livestock (TF 49)	Specialist granivores (TF 50)	Field crops-grazing livestock combined (TF 80)	Various mixed farms	Total
Sample farms	number	449	114	37	36	322	120	15	162	46	1301
Farms					represented	number	17,024	3825	924	316	18,030
3678	167	5993	6807	56,764							
Economic size	EUR SO	43,836	22,630	21,136	27,790	22,702	15,642	36,226	27,778	9330	27,553
Physical size	ha UAA	72.5	33.2	9.1	35.0	28.6	42.6	12.4	47.9	10.7	42.6
Herd size	LU	1.7	1.5	0.8	0.2	15.0	19.0	31.7	15.2	3.0	8.7
Total output	EUR	41,633	24,016	24,236	19,978	19,937	18,787	52,752	25,141	11,728	26,376

Table 4
CF and CI by farming type in Lithuanian family farms.

Indicator	Unit/TF	COP (TF 15)	Field crops (TF 16)	Horticulture (TF 20)	Permanent crops (TF 36)	Dairy (TF 45)	Grazing livestock (TF 49)	Specialist granivores (TF 50)	Field crops-grazing livestock combined (TF 80)	Various mixed farms	Total	Significance	CV%
CF	t CO_{2eq} $farm^{-1}$	71.7	27.1	8.9	12.0	64.2	69.1	28.6	75.1	11.9	57.8	*	75.1
CI per ha UAA	t CO_{2eq} ha^{-1}	0.9	0.9	2.5	0.3	2.4	2.0	2.2	1.5	1.0	1.5	*	50.2
CI per LU	t CO_{2eq} LU^{-1}	10.6	2.5	1.2	1.1	4.5	4.0	0.9	5.4	3.2	6.0	*	59.9
CI per EUR of total output	kg CO_{2eq} EUR^{-1}	1.9	1.2	0.5	1.0	3.7	3.6	0.4	3.6	1.4	2.7	*	75.5

Note: * Indicates significant differences in means at the 1% level.

The variation of CI per ha of UAA across farming types was apparent, evident by sever CV value (CV 50.2%): permanent crops farms showed the lowest intensity, whereas, horticulture farms recorded the highest intensity, 0.3 t CO_{2eq} ha^{-1} and 2.5 t CO_{2eq} ha^{-1}, respectively. These results are linked to the farm structure, as horticulture farms are the smallest in terms of physical size in Lithuania, and as compared with permanent crops farms, they were smaller 3.9 times.

The CI in terms of total farm output averaged 2.7 kg CO_{2eq} EUR^{-1}. The highest intensity was found on dairy farms (3.7 kg CO_{2eq} EUR^{-1}) followed by grazing livestock farms (3.76 kg CO_{2eq} EUR^{-1}). The generated output of these farms was by one-fourth lower than for whole family farm sample, on average, in 2016. On the contrary, the lowest CI per total output was observed on specialist granivore farms (0.4 kg CO_{2eq} EUR^{-1}) due to recorded the highest total output in the sample. The largest variability across farm types was estimated for CI per total output (CV value equalled to 75.5%) as compared to CF and CI per ha UAA and CI per LU. The differences of CF, CI per ha UAA, LU and total output were statistically significant ($p < 0.001$) across types of farming.

The economic performance of family farms, CF and CI in relation to the six economic size classes of farms are presented in Tables 5

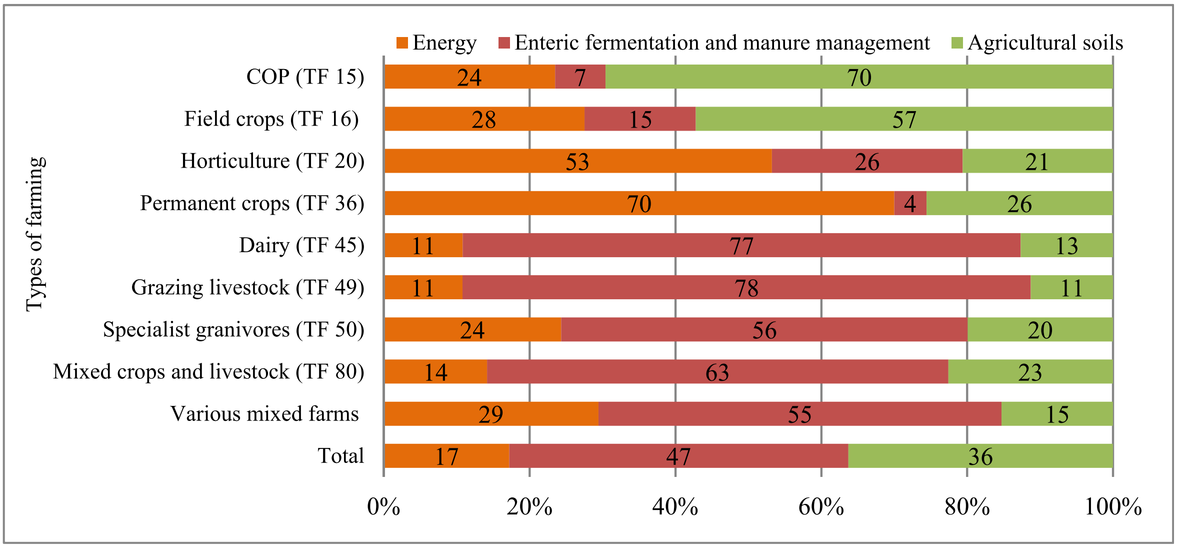

Fig. 2. The structure of CF by emissions sources for types of farming in Lithuanian family farms.

and 6. The economic size of farm is measured as the total SO of the farm expressed in euro. In Lithuania, physical size of farm, generated output value and LU increase with the economic size of family farm. The CF has the same tendency. The lowest value of CF was found on farms in the SO class I and the highest – in the SO class VI, 13.7 t CO_{2eq} $farm^{-1}$ and 1375.1 t CO_{2eq} $farm^{-1}$, respectively. The economic size of farm reflects the farm specialization in relation to physical farm size tendency in Lithuanian agriculture: the COP farms represent the largest share (67.4%) of farms in the SO class VI. The major component of emissions in the case of farms in SO classes I–IV was emissions from enteric fermentation and manure management, whereas in classes V–VI the GHGs from agricultural soils were leading (Fig. 3). The CI per ha UAA were fairly different (CV 10%) across economic sizes and ranged from 1.4 t CO_{2eq} ha^{-1} to 1.8 t CO_{2eq} ha^{-1}, in the SO class II and in SO classes V–VI, respectively. The highest CI per output was observed in the SO class III, the lowest – in the SO class VI, 2.9 kg CO_{2eq} EUR^{-1} and 1.7 t kg CO_{2eq} EUR^{-1}, respectively. The moderate variation of the CI per output across the farm economic size classes was determined and made 18.0%. The great variation was observed in terms of CI per LU across SO classes (CV 107%) and emissions spread a range of 2.8–82.4 t CO_{2eq} LU^{-1}, in SO class I and SO class VI, respectively. The differences of CF, CI per ha UAA, LU and total output and were statistically significant ($p < 0.001$) across economic size classes.

The economic performance of family farms, CF and CI across the six physical size classes of farms are presented in Tables 7 and 8. The lowest CF was found on the smallest farm size class up to 30 ha of UAA with emission value of 19.0 t CO_{2eq} $farm^{-1}$ and at the other end of spectrum, the highest – on the biggest farm size class above 500 ha UAA. It should be noticed, that the smallest farms (up to 30 ha UAA) made 62.2% and the largest (above 500 ha UAA) only 0.4% of total represented farms in the sample. The variation of CI per ha of UAA among physical farm size classes was low (CV 11.1%). The CI per ha UAA was the lowest on farms size class from 50 ha UAA to 100 ha UAA and the highest on farms size class up to 30 ha UAA, 1.2 t CO_{2eq} ha^{-1} and 1.7 t CO_{2eq} ha^{-1}, respectively. The CI per output increases to farm size class up to 50 ha UAA and then the decrease is observed. The CI per total output ranged from 1.9 kg CO_{2eq} EUR^{-1} to 3.0 kg CO_{2eq} EUR^{-1}, on farms size class above 500 ha UAA and on farms size class above 30 ha UAA up 50 ha UAA (Table 8). The highest CI per LU was found on the largest physical farm size class (above 500 ha of UAA) as the COP farms represent the largest share (82.9%) of farms on this farms size class. The main source of GHG emissions on farms up to 200 ha UAA was enteric fermentation and manure management, whereas, on farms above 200 ha UAA – agricultural soils dominate. GHG emissions from the use of fuel comprised 16–19% of the total emissions on farms across farm physical size classes (Fig. 4). The differences of CF, CI per ha UAA, LU and total output were statistically significant ($p < 0.001$) across physical size classes.

The studies that are directly comparable to our research are Syp and Osuch (2018) and Baldoni et al. (2017). Indeed, these studies apply the FADN data and IPCC guidelines. The key methodological difference is that, in the present study, the results are based on weighting, though this step of analysis is not clarified in Syp and Osuch (2018) and Baldoni et al. (2017). Indeed, assigning weights to the farms may lead to different CF values. This is evident by the average CF value for Lithuanian family farms obtained in this study which is 3.2 times higher if compared to the value reported by Dabkienė (2017) for 2014. In contrast to the present study, Syp and Osuch (2018) and Baldoni et al. (2017) did not follow the EU FADN (2018) grouping of farms according to their specialization and the

Table 5
Economic performance of Lithuanian family farms by economic size classes.

Indicator	Unit	I	II	III	IV	V	VI	Total
Sample farms	number	85	300	241	242	385	48	1301
Farms represented	number	22,468	21,471	5991	3893	2806	135	56,764
Economic size	EUR SO	6425	13,604	36,175	71,999	189,123	73,9720	27,553
Physical size	ha UAA	12.5	26.2	57.9	103.7	250.9	868.3	42.6
Herd size	LU	2.8	6.3	14.0	21.1	41.4	82.4	8.7
Total output	EUR	6274	12,715	30,153	61,843	193,040	889,955	26,376

Table 6
CF and CI by economic size classes in Lithuanian family farms.

Indicator	Unit	I	II	III	IV	V	VI	Total	Significance	CV%
CF	t CO_{2eq} farm^{-1}	13.7	30.8	78.2	150.0	383.0	1375.1	57.8	*	155.2
CI per ha UAA	t CO_{2eq} ha^{-1}	1.6	1.4	1.5	1.7	1.8	1.8	1.5	*	10.0
CI per LU	t CO_{2eq} LU^{-1}	2.8	6.3	14.0	21.1	41.4	82.4	8.7	*	107.0
CI per EUR of total output	kg CO_{2eq} EUR^{-1}	2.5	2.8	2.9	2.6	2.2	1.7	2.7	*	18.0

Note: * Indicates significance at 1% level.

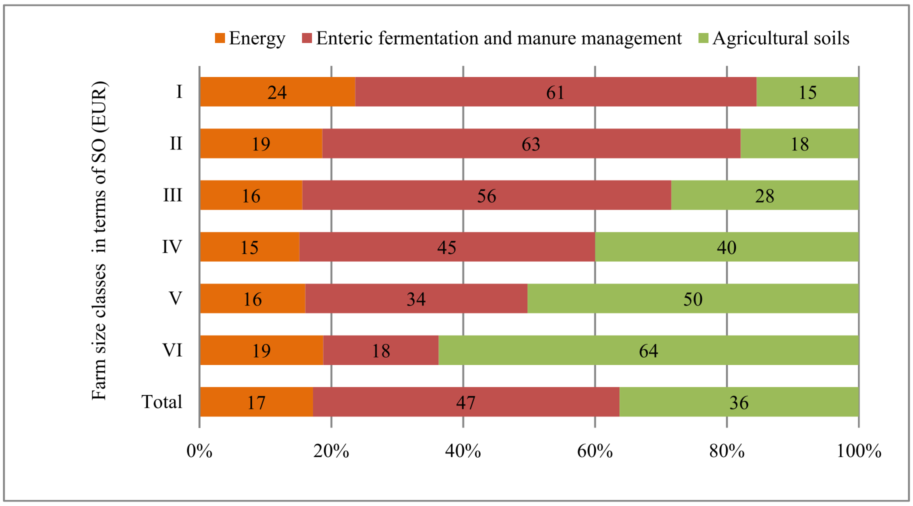

Fig. 3. The structure of CF by emissions sources for economic size classes in Lithuanian family farms.

Table 7
Economic performance of Lithuanian family farms by physical size classes (in ha).

Indicator	Unit	<30	30-<50	50-<100	100-<200	200-<500	≥500	Total
Sample farms	number	281	183	291	252	227	67	1301
Farms represented	number	35,324	7622	7986	3836	1745	251	56,764
Economic size	EUR SO	9391	20,907	33,953	81,671	202,430	538,861	27,553
Physical size	ha UAA	12.6	39.1	63.5	122.9	288.8	759.2	42.6
Herd size	LU	4.0	10.1	13.9	24.0	36.4	38.2	8.7
Total output	EUR	8734	18,455	29,473	75,529	211,931	609,983	26,376

Note: * Indicates significance at 1% level.

Table 8
CF and CI by physical size classes (in ha) in Lithuanian family farms.

Indicator	Unit	<30	30-<50	50-<100	100-<200	200-<500	≥500	Total	Significance	CV%
CF	t CO_{2eq} farm^{-1}	19.0	51.8	76.6	171.2	392.6	1055.0	57.8	*	143.0
CI per ha UAA	t CO_{2eq} ha^{-1}	1.7	1.4	1.2	1.3	1.4	1.4	1.5	*	11.1
CI per LU	t CO_{2eq} LU^{-1}	4.4	5.4	9.8	9.7	12.7	32.4	6.0	*	84.3
CI per EUR of total output	kg CO_{2eq} EUR^{-1}	2.6	3.0	2.8	2.3	2.1	1.9	2.7	*	16.0

results are, therefore, not easily comparable. In addition, the differences between studies arise regarding country-specific nature of agricultural sector. In light of above-mentioned methodological issues, caution is needed when comparing the results across studies.

Syp and Osuch (2018) reported CF and CI in Polish farms using FADN, 2018 data and IPCC (2006) guidelines. The average CF value estimated in Polish farms was by 67% higher than in Lithuanian family farms determined in the present study. The CF structure by emissions sources for whole Polish farm sample corresponds closely to that assessed in the present study for Lithuanian family farms'. The CF values across farm types were found 2.9 times for dairy, 2.4 times for field crops and 1.6 times for grazing livestock lower for Lithuanian family farms presented in the present study as compared to CF values established by Syp and Osuch (2018) for relevant Polish farms. The uniform classification of farms in terms of their economic size based on FADN (2018) guidelines enables to compare obtained results in the present study and in Syp and Osuch (2018). The estimated CF within economic size classes in the present study are roughly in line with Polish farms for I–V economic farm size classes, whereas the CF for largest-size SO class (VI) was found 2.4 times higher in Lithuanian farms than in Polish. The differences between Polish and Lithuanian farms regarding CI per UAA and LU across economic size classes might be explained by bigger in terms of UAA and smaller in raised livestock Lithuanian farms in all economic size classes (except for I SO class)

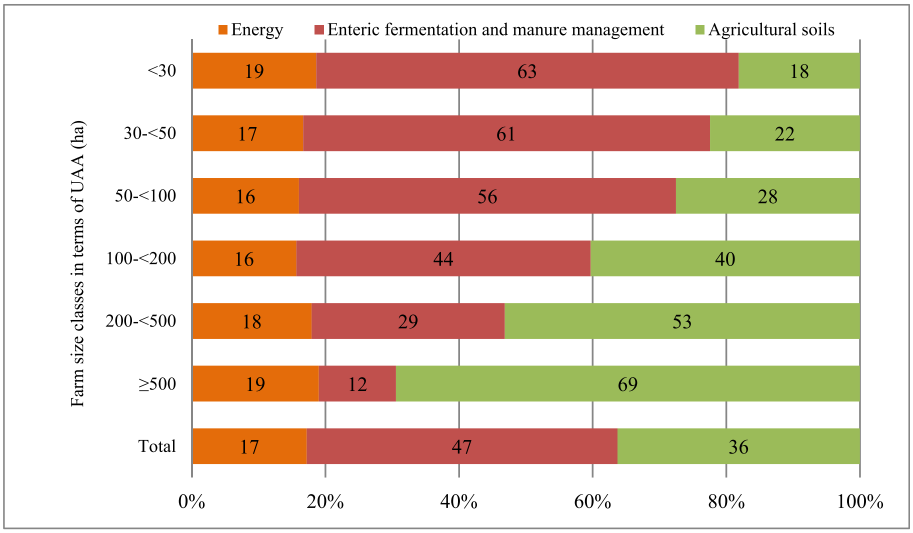

Fig. 4. The structure of CF by emissions sources for physical size classes (in ha) in Lithuanian family farms.

as compared with relevant Polish farms.

Baldoni et al. (2017) assessed the relationship between farm productivity and environmental performance, where the environmental performance focuses on CI expressed as total GHG emissions divided by SO. To measure CF, Baldoni et al. utilized farm activity data from Italian FADN sample for 2008–2013 (Lombardy region) and IPCC (2006) guidelines. The average CF value reported for Lombardy farms in 2013 was by 4.7 and 2.8 times higher than those estimated in the present study and Polish farms (reported by Syp and Osuch, 2018), respectively.

4. Conclusions

This study presents a methodology for appraisal of the carbon factor for Lithuanian family farms. The calculation of the CF and CI indicators was based on the farm-level data from the FADN. The scope of the emission sources has been extended and thus allowed for an improved analysis of the environmental pressures generated by the Lithuanian family farms. Research results allow identifying the relative contribution of different farms by type of farming and size to a total carbon budget of agricultural sector. The resulting data can be integrated into different decision making frameworks.

The CF and CI results based on sectoral data provide valuable information in terms of cross-country comparison. Taking into account the differences of sectoral and farm level surveyed samples, the CI related to farm inputs (per UAA and LU) differed marginally. Farm level (FADN) data has advantages in CF and CI assessment compared to national level data. The first advantage, is that FADN data is collected annually, thus the sectoral data, namely, Farm structure survey, is carried out as every 3 or 4 year as sample survey, and once in 10 years as a census. Secondly, the GHG measured on the basis of FADN data is connected to farm activity data, and that expands the scope of the analysis of GHG emissions on farms (e. g. CAP expenditure effects on-farm GHG; relationship between productivity and GHG, synergies between the different CAP instruments) identifying low CF development solutions. Thirdly, FADN sample enables the comparison results between different groups of farms. In addition, FADN data enables to measure the variability of CF and CI within farms in one group. However, FADN sample only covers farms considered as commercial and thus limits the analysis of smaller farms.

The results based on FADN showed that the key sources of GHG emissions on Lithuanian farms were related to enteric fermentation from livestock and direct N_2O emissions from agricultural soils. This suggests that the implementation of new management and nutrition technologies, livestock breeding, methane capture technologies should be considered as a priority in Lithuania. The application of inorganic fertilizers leads to high level of CF on COP and on field crop farms, indicating a need for more efficient use of inorganic fertilizers on these farms (e. g. precision agriculture).

The average CF of 57.8 t CO_{2eq} farm^{-1} was obtained for Lithuanian family farms. It ranged from 8.9 t CO_{2eq} farm^{-1} for horticultural farms to 75.1 t CO_{2eq} farm^{-1} for field crops-grazing livestock combined farms. The CF increases with the economic farm size: from 13.7 t CO_{2eq} farm^{-1} up to 1375.1 t CO_{2eq} farm^{-1}, for the smallest and largest farms in terms of the SO, respectively. The same pattern was observed for farms across the physical size classes, as the lowest CF of 19.0 t CO_{2eq} farm^{-1} was associated with the smallest farms (up to 30 ha UAA), whereas the highest value of 1055.0 t CO_{2eq} farm^{-1} was observed for the largest farm (above 500 ha UAA). CIs varied across farm size groups with different patterns in regards to physical and economic size. Regarding CIs across farm economic sizes, CIs per inputs were found highest in largest-size SO classes, whereas the highest CI per output was obtained for SO class III. The highest CIs across physical farm sizes were obtained on farms size class up to 30 ha UAA and on farm size class above 500 ha UAA, per ha UAA and per LU, respectively. In terms of CI per total output, the highest value was estimated in largest-size class farms (above 500 ha UAA).

This study features certain limitations in terms of data used and methods of aggregation. The analysis could embark on the footprint databases to derive more accurate LCA measures which could be further combined with economic measures. The present study presented the point estimates. The further studies could seek to account for uncertainty and deliver the interval estimates of the carbon footprint.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Vida Dabkienė: Conceptualization, Data curation, Formal analysis, Writing - original draft. **Tomas Baležentis:** Funding acquisition, Investigation, Methodology. **Dalia Štreimikienė:** Validation, Writing - review & editing.

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