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METHODOLOGICAL ASSUMPTIONS TO ASSESS THE ECONOMIC EFFECTS OF REDUCTION IN GREENHOUSE GAS EMISSION IN AGRICULTURE*

Abstract

The paper presents a method for assessing the economic impact of on--farm application of technology that causes reduction in greenhouse gasses emission. The proposed method takes into account the incomplete depreciation of technical means used under conditions of crop and animal production technologies applied to date. The scope of its application, in the form presented in the paper, is confined to the farm scale. The use in the scale of the whole agriculture would require, on the one hand, omission of technologies applied to date, and on the other hand – taking into account the emission transfer between national economy sectors and the ones resulting from foreign trade.

Keywords: greenhouse gas emission, reduction, farm, cost, assessment, method.

JEL codes: O33, Q16, Q52, Q55, Q58.

Introduction

Agriculture of the EU Member States is responsible for about 10% of total greenhouse gases (GHGs) on average emitted by this sector to the atmosphere (Eurostat, 2015). The smaller shares (7%) are reported by Franks and Hadingham (2012) for Great Britain and by Parton et al. (2011) for the USA. The differences probably result from the differentiated level of industrialisa-

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tion of particular countries as well as the share of agriculture in generation of the national income, which is positively correlated with the share in the greenhouse gas emission. Despite the insignificant share of agriculture in the total GHGs emission, calculated as the CO_2 equivalent, this sector emits as much as 53% of the total greenhouse gases other than CO_2 (Beach et al., 2015). Nitrogenous fertilizers are the source of the highest emission of greenhouse gases in plant production (Nalley et al., 2011). According to the structure of greenhouse gases' emission, the share of soils (including grassland) is the highest (45%). The shares of the other sources are as follows: the animal production, which is responsible for the most part of methane emission – 25%, the usage of means of mechanization in agriculture – 13%, manuring – 11%, others – 6%.

Agriculture is included in the non-ETS area (i.e. beyond the emission trading scheme) in the programmes to reduce greenhouse gases. The domestic list covers the following greenhouse gases and their groups: carbon dioxide (CO_2), methane (CH_4), nitrogen monoxide (N_2O), the groups of HFC gases (hydrofluorocarbons) and PFC (perfluorocarbons), sulphur hexafluoride (SF_6) as well as nitrogen trifluoride (NF_3). However, the first three gases predominate.

According to KOBiZE (2014), carbon dioxide had the highest share (59.8%) in the structure of greenhouse gases emitted in the Polish agriculture in 2014. The share of methane and nitrogen monoxide was 36.8% and 3.4%, respectively. Agriculture generated only 0.3% of emitted carbon dioxide[1], but the share of methane was 33.7% and the share of nitrogen monoxide – as much as 78.9%.

Carbon dioxide is emitted as a result of oxidation of organic matter during the respiration of plants and animals and as a result of the soil processes. On the other hand, land-use, land-use change and forestry (LULUCF) cause absorption of carbon dioxide from the atmosphere, particularly through photosynthesis. But as for methane and nitrogen monoxide, such activities cause only small growth of emission.

Methane emitted from agriculture is a gas generated in the digestive tract of ruminants (intestinal fermentation) and in the conditions of anaerobic decomposition of faeces. Penetrating into the stratosphere it indirectly participates in catalytic ozone depletion, thus contributing to the creation of the so-called ozone hole. Average lifespan of methane in the atmosphere is 12 years. The global warming potential[2] (GWP) for methane is almost 23 times and for nitrogen monoxide approx. 296 times higher than for carbon dioxide.

Nitrogen monoxide in agricultural production is emitted mainly from soil fed with mineral and organic fertilisers and in livestock buildings, where it is emitted together with ammonia. Nitrogen monoxide is a gas of very high GWP.

[1] Using the means of mechanization of agriculture is not taken into account, as it is not reported within the agricultural sector.

[2] The GWP is calculated based on the effects of impact of one kilogramme of the given gas on global warming over 100 years, as compared to the impact of one kilogramme of CO_2.

Growth in its concentration in the stratosphere may indirectly strengthen the process of ozone layer degradation (Jugowar et al., 2015).

Activities aiming at reduction of GHGs emission in agriculture should be conducted in three stages: (1) identification of farms emitting the largest quantities of greenhouse gasses; (2) finding variants of solutions ensuring reduction of emission of GHGs matching the farms; (3) selection of a variant guaranteeing the highest economic efficiency (Franks and Hadingham, 2012). Using accordingly modified agricultural production technologies can reduce the overall level of this emission by 1/3 (Parton et al., 2011). If, as a result of such activities, the level of yields is reduced or the efficiency of incurred inputs is decreased, there appears an economic barrier hindering their implementation. Foreign authors taking up this issue propound to use financial subsidies enabling to overcome this barrier (Beach et al., 2015; Horovitz and Gotlieb, 2010; Paustian et al., 2006; Parton et al., 2011). Estimation of the necessary amount of such subsidies and assessment of economic effects of implementing environment-friendly technologies requires the use of rather precise methods. This paper aims at presentation of the proposal of the method for economic assessment of the effects of using on farms technologies causing reduction in GHGs, considering incomplete depreciation of technical facilities, used in the conditions of applying the former technology in case of analysis conducted on the scale of a farm.

Possibilities of reducing GHGs emission in agriculture

The potential possibilities of reduction of GHGs emission and air polluting substances in agricultural production should be sought for in relevant modernisation of this production technology. This involves a need to apply more environment-friendly technical facilities, here understood as a set of means for mechanization of agriculture and broadly-conceived building objects, rationalisation of fertilisation, with special consideration of mineral nitrogen fertilisers as well as organic fertilisers – manure and slurry. The implementation of technologies conductive to reduction of GHGs emission and air polluting substances is linked, above all, to the need to incur capital expenditures for new technical facilities, including those ensuring rationalisation of fertilisation and plant protection in line with the rules of precise agriculture.

Agriculture may take part in mitigation of threats caused by climate change by:

- reduction of GHGs emission;
- increase in CO_2 absorption by plants due to longer time of keeping plant cover, e.g. by using aftercrops and catch crops;
- increase in the capacity for carbon storage in the soil[3].

[3] The process of organic carbon storage in the soils depends not only on the quantity of organic matter supplied to the soil, the used cultivation treatments, intensity of land-use, but also on climatic conditions and soil type. It is a long-term process. Improvement in its efficiency can be obtained by e.g. applying soil cultivation methods keeping the organic matter oxidisation processes in the soil at as low level as possible.

Reduction of GHGs emission can be achieved by changes in the agricultural production technologies consisting in:

– use of land cultivation methods reducing the frequency and intensity of treatments;
– changes in the livestock breeding and keeping systems as well as in animal waste management to reduce the emission of methane and other greenhouse gasses and ammonia;
– reduction in energy-intensity of agricultural production processes;
– reduction in doses of mineral fertilisers, especially nitrogen fertilisers and their more precise and on-time application;
– keeping soil plant cover for as long as possible;
– proper maintenance of fallow land and rehabilitation of degraded soils.

Most of the above-mentioned solutions enables also greater carbon storage capacities in soils, which is favoured by a growth in crop rotation of plants intended for hay and generating large quantities of post-harvest residues (Horovitz and Gottlieb, 2010; Paustian et al., 2006).

Replacement of traditional land cultivation, characterised by regular use of tillage which is an energy-intensive and strongly invasive treatment, with methods that are less energy-intensive and less interfering with the soil structure (no tillage system, different types of minimum tillage systems) reduces emission of carbon dioxide during work performance, and also slows down oxidation processes of organic substance in the soil. The use of conservation tillage, which consists in shallow tillage with a multifunctional cultivation unit and a rotary ripper, developed in the Mazovia Research Centre of the Institute of Technology and Life Sciences, instead of the traditional cultivation with tillage, causes lower fuel consumption for field works in five-year rotational period: wheat – sugar beet – maize – rye – winter rape, from 240.1 to 105.7 $l \cdot ha^{-1}$, and energy inputs per area unit – from 1197 to 575 $MJ \cdot ha^{-1}$ (Golka and Ptaszyński, 2014). According to Sørensen et al. (2014) total carbon dioxide emission per unit of obtained production was for: traditional tillage at 915 $g \cdot kg^{-1}$, minimum tillage – 817 $g \cdot kg^{-1}$, no tillage system – 855 $g \cdot kg^{-1}$. Higher emission level per production unit in case of using the no tillage system compared to minimum tillage system was caused by lower crop yielding by an average of 10%. Mineralisation of organic substance in the soil causes approx. 50-60% of emission of greenhouse gases; hence tillage should crate soil conditions limiting mineralisation and oxidisation of organic substance.

Animal production is a serious source of GHGs emission: carbon dioxide, methane and nitrogen. Emission of these gasses depends e.g. on the animal species, system of their keeping and method of waste storage which are also a source of harmful emissions. Research held in Wielkopolska region on a high bedding fattening farm showed that daily value of methane emission ratio referred to livestock unit (LU) amounted to 199.8 $g \cdot LU^{-1}$, and the average value of nitrogen monoxide emission ratio (8.6 g·LU^{-1}) was much higher than on fattening farms run in the no bedding system (Mielcarek et al., 2014). In this case, replacement of bedding system of animal breeding with no bedding system ensures lower emission values. This is, however, linked to worse heat balance in the building when the weather gets cold. For instance, acidification of slurry or its separation and use of covers at places of manure storage favours reduction in GHGs emission from animal faeces.

The implementation of the precise agriculture system enables to limit GHGs emission linked to plant fertilisation and animal feeding. Using fertiliser doses as needed in a spatial system, we make it possible to increase the efficiency of their use by field crops and decrease the harmful emission per unit of obtained production. A similar effect in animal production may be achieved by relevant regulation of the micro-climate in livestock buildings, thus guaranteeing high efficiency of inputs in the form of feed. What also favours reduction in GHGs emission is in-ground application of slurry on fields and shorter time of keeping fertilisers on the surface of soils. The type of selected mineral fertilisers for application is also important.

It is crucial to keep – as far as possible – a rather continuous plant cover on farmland, and also on fallow land and reclaimed land. Plants, during vegetation, capture carbon dioxide, thus, contributing to its lower content in the atmosphere and, at the same time, by absorbing fertilisation elements from the soil they reduce emission of nitrogen monoxide. In case of fallow land and reclaimed land, the most beneficial method is their afforestation, which ensures a large mass of plants taking part in photosynthesis. At this place, it is expedient to mention the phenomenon of grass burring in spring time – dangerous, but still popular in Poland. Burning causes, on the one hand, direct emission of carbon dioxide and other harmful substances to the atmospheres, and on the other, temporary elimination of plants absorbing carbon dioxide from the atmosphere. If apart from grass and other low-stem plants burning affects bushes and trees, the negative effects are long-term.

Agriculture may also indirectly affect reduction in emission of greenhouse gases in other sectors of the national economy, e.g. by production of biofuels being the substitute for fossil fuels. The very production of fuels from biomass in agriculture is linked to emission of CO_2 and other GHGs (Hryniewicz and Grzybek, 2013; Namyślak, 2012; Wójcicki, 2015), and complete assessment of environmental effects of the use of biofuels requires assessment of the balances of carbon dioxide in their production at the farm-gate level (Dodder et al., 2015).

The actions causing reduction of GHGs emission, briefly discussed above, require relevant capital expenditures and influence the level and cost of agricultural production.

Estimation of economic effects of using technologies reducing GHGs emission in agriculture

The capital expenditures involved in technology modernisation to reduce the emission of greenhouse gasses

Estimating the value of capital expenditures linked to modernisation of agricultural production technologies which ensure reduction of emission of greenhouse gasses and air polluting substances in the field of plant production on the farm-gate scale, it is necessary to consider incomplete use of processing capabilities of the so far used technical buildings when their age is shorter than their theoretical lifecycle. This affects the costs of depreciation and, in case of taking out a loan during investment implementation – also for the costs of capital interests. Capital expenditures, considering incomplete depreciation of facilities used so far, may be estimated with the use of the following:

$$Ni_m = \sum_{i=1}^{k} Cm + \sum_{i=1}^{k} Cs\left(\frac{n_s - w_s}{n_s}\right) + \sum_{i=1}^{k}\left(\frac{n_s - w_s}{n_s}\right) \cdot \frac{Ks \cdot r_s}{100}_s + \sum_{i=1}^{k} \frac{Km \cdot r_m}{100} \qquad (1)$$

where:

Ni_m – capital expenditures involved in modernisation of agricultural production technology ensuring reduced GHGs emission (PLN);

C_m – prices of technical facilities used in agricultural production technologies ensuring reduction of GHGs emission (PLN);

C_s – prices of technical facilities used so far in agricultural production technologies (PLN);

n_s – lifecycle of technical facilities used so far in the agricultural production technologies (years);

w_s – age of technical facilities used so far in the agricultural production technologies (years);

K_s – value of loans taken out in relation to investments in the so far used technical facilities (PLN);

r_s – interest rate of loans taken out in relation to investments in the so far used technical facilities (%);

K_m – value of loans taken out due to modernisation of agricultural production technology ensuring reduced GHGs emission (PLN);

r_m – value of loans taken out due to modernisation of agricultural production technology ensuring reduced GHGs emission (%).

Macro-scale analysis does not allow for consideration of the value of incomplete depreciation of the so far used technical facilities and costs of servicing the taken out loans. Then, the formula in a simplified form is used to estimate capital expenditure:

$$Ni_m = \sum_{i=1}^{k} Cm \tag{2}$$

Costs and effects of agricultural production technologies modernisation

The calculation of costs for agricultural production technologies ensuring reduction of GHGs emission and air polluting substances is based on values of capital expenditures estimated with the use of (1) and (2) and costs of repairs, maintenance, technical service and used direct energy carries, costs of own and hired labour as well as costs of used seed materials, fertilisers, plant protection products in case of plant production or breeding materials, feed, medicines, etc. in case of animal production. Sums of these costs for technologies used so far and modernised may be referred to unit value of the gross margin obtained in the conditions of using such technologies.

As a result of replacement of the so far used agricultural production technology with technology reducing emission of substances threatening the natural environment is a change in the level of production costs per gross margin unit. This difference can be estimated with the following:

$$Em = \frac{Ni_m\left(\frac{1+k_m}{n_m}\right) + \sum_{e=1}^{i} Ke_m + \sum_{r=1}^{i} Kr_m + \sum_{n=1}^{i} Kn_m + \sum_{o=1}^{i} Ko_m + \sum_{p=1}^{i} Kp_m}{Nb_m} - \frac{Ni_s\left(\frac{1+k_s}{n_s}\right) + \sum_{e=1}^{l} Ke_s + \sum_{r=1}^{l} Kr_s + \sum_{n=1}^{l} Kn_s + \sum_{o=1}^{l} Ko_s + \sum_{p=1}^{l} Kp_s}{Nb_s} \tag{3}$$

where:

E_m – decrease or increase in unit agricultural production cost as a result of technology modernisation (PLN year^{-1});

k_m – ratio of repairs, maintenance and reviews of technical facilities applied in agricultural production technology, which ensures reduction in GHGs emission;

n_m – lifetime of technical facilities used in agricultural production technologies ensuring reduction of GHGs emission (years);

K_{em} – annual cost of energy carriers in agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});

K_{rm} – annual cost of own and hired labour in agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});
K_{nm} – annual cost of seed material (in case of plant production) or breeding material (in case of animal production) in agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});
K_{om} – annual cost of plant protection products (in case of plant production) or veterinary medicines (in case of animal production) in agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});
K_{pm} – annual cost of other means or services of agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});
N_{bm} – annual values of gross margin obtained in the conditions of using agricultural production technology ensuring reduction of GHGs emission (PLN year^{-1});
N_{is} – capital expenditures incurred on technical facilities currently used (PLN);
k_s – ratio of repairs, maintenance and reviews of technical facilities currently used;
K_{es} – annual cost of energy carriers in the so far used technology (PLN year^{-1});
K_{rs} – annual cost of own and hired labour in the so far used technology (PLN year^{-1});
K_{ns} – annual cost of seed material (in case of plant production) or breeding material (in case of animal production) in the so far used technology (PLN year^{-1});
K_{os} – annual cost of plant protection products (in case of plant production) or veterinary medicines (in case of animal production) in the so far used technology (PLN year^{-1});
K_{ps} – annual cost of other means or services in the so far used technology (PLN year^{-1});
N_{bs} – annual value of gross margin obtained so far (PLN).

Practical use of the proposed calculation procedures requires access to data on capital expenditures and costs involved in implementation of technologies enabling reduction of GHGs emission.

In order to estimate the above-mentioned expenditures and costs, multi-variant models will be prepared, which will enable reduction of GHGs on a farm or in agriculture on a country scale. Based on economic assessment, out of the considered variants only variants ensuring the highest efficiency of inputs will be chosen for practical use.

Upon assessment of the efficiency, what are considered are positive and negative sides of using the plant production technology enabling reduction of GHGs emission. Precise and on-time use of nitrogen fertilisers will be connected to a decrease in costs of their use. Reduction of the energy inputs due to replacement of tillage with less energy-intensive methods of land cultivation and use of multifunctional cultivation units which will reduce the costs of consumption of diesel oil. Savings on that account will partly compensate for a growth in the costs of operation following from the use of new generation technical facilities.

Efficiency of use of plant production technologies enabling reduction of GHGs can be estimated using the following:

$$Erm_{GHG} = \frac{Rim_{GHG} - \Delta pm}{\Delta cm - Ocm} \tag{4}$$

where:

Erm_{GHG} – efficiency of reduction of greenhouse gasses as a result of using *m*-th variant of agricultural production technology (kg CO_2e PLN^{-1}),
Rim_{GHG} – reduction of emission of *i*-th greenhouse gas as a result of using *m*-th variant of agricultural production technology (kg CO_2e),
Δpm – change in emission of other greenhouse gasses as a result of using *m*-th variant of agricultural production technology (kg CO_2e),
Δcm – change in costs of operation of technical facilities as a result of using *m*-th variant of agricultural production technology (PLN),
Ocm – change in costs of consumption of the means of production as a result of using *m*-th variant of agricultural production technology (PLN).

The formula (4) considers the side effects of reduction of GHGs, consisting in actions which cause reduction of emission of one of the polluting factors but increase in the emission of another one or ones. This phenomenon is termed in English as pollution swapping and is quite common in agriculture (Franks and Hadingham, 2012; Monteny, Bannink and Chadwick, 2006; Oenema and Velthof, 2007; Stevens and Quinton, 2008, 2009). An example thereof is reduction of CO_2 emission in case of using no tillage system and, at the same time, probable growth in emission of nitrogen oxides and methane.

The present state of knowledge does not allow yet to fully consider the side effects of reduction in GHGs emission in the form of interrelations between varied factors of their emission. There are also discrepancies regarding research findings. According to some authors the use of no tillage system causes increase in the emission of nitrogen compounds to the atmosphere, other authors present contrary results (Monteny, Bannink and Chadwick, 2006). Hence, it is necessary to conduct further comprehensive studies which will provide more precise data.

The scope of the method application, in the form presented above, is confined to the farm-gate level. Its use on the scale of the whole agriculture would require, on the one hand, omission of incomplete depreciation of technical facilities, and on the other – taking into account the emission transfer between production sectors and resulting from foreign trade.

Emission transfer takes place between respective economic entities, sectors of the national economy inside the country and on the international scale. Its balance is a sum of emissions cumulated in purchased products, decreased by emissions cumulated in sold products. Upon consideration of this balance it may turn out that the decrease in emission on a scale of a farm, agriculture or a country causes increased emission on a global scale (Franks and Hadingham, 2012; Moran et al., 2011).

Conclusions

Implementation of plant and animal production technologies ensuring reduction in GHGs emission, requires additional investments on agricultural farms. Whereas at least some part of so far used and now useless, because of the new technology, technical means was not fully depreciated. Because of all the above, unit costs of agricultural production will rise as a result of technology modernisation, despite some savings as regards energy carriers or mineral fertilisers. This is partly evidenced by the works of foreign authors, who opt for introduction of subsidies aimed at encouraging farmers to use environment-friendly production technologies.

In the light of the above facts, it is necessary to develop a method for estimation of economic effects of reduction of GHGs emission. The method proposed in this paper takes into account incomplete depreciation of technical means used under the conditions of crop and animal production technologies applied to date. In the presented form, the scope of its application is limited to respective farms, to enable its application across the entire agriculture the incomplete depreciation of technical facilities should be omitted and the emission transfer between production activities and following from foreign trade should be considered.

With the use of the proposed method it is possible today to estimate capital expenditures and costs of using technologies enabling reduction of GHGs emission on a farm. But lack of relevant data, and especially controversies concerning the impact of different solutions on the level and even direction of changes in emission of individual types of GHGs, hinders assessment of efficiency of environmental activities.

The use of the proposed method to the full scope requires relevant data which today are incomplete and often contrary to each other. Further comprehensive research is necessary which will provide more precise information on the measurable effects of different solutions reducing the GHGs emission.

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ZAŁOŻENIA METODYCZNE DO OCENY EKONOMICZNYCH SKUTKÓW REDUKCJI EMISJI GAZÓW CIEPLARNIANYCH W ROLNICTWIE

Abstrakt

W artykule przedstawiono metodę oceny ekonomicznych skutków zastosowania w gospodarstwach rolnych technologii powodującej redukcję emisji gazów cieplarnianych do atmosfery. Proponowana metoda uwzględnia niepełne zamortyzowanie obiektów technicznych, wykorzystywanych w warunkach stosowania dotychczasowych technologii produkcji roślinnej i zwierzęcej. Zakres jej stosowania w formie przedstawionej w niniejszej pracy ogranicza się do poszczególnych gospodarstw rolnych. Zastosowanie w skali całego rolnictwa wymagałoby z jednej strony pominięcia niepełnego zamortyzowania obiektów technicznych, z drugiej zaś – uwzględnienia transferu emisji między działami produkcji oraz w wyniku obrotów handlu zagranicznego.

Słowa kluczowe: emisja gazów cieplarnianych, redukcja, gospodarstwo rolne, koszt, ocena, metoda.

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