Centre for Climate and Energy Analyses

ASSESSING CLIMATE POLICY IMPACTS IN POLAND'S AGRICULTURE - OPTIONS OVERVIEW -

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LIFEClimateCAKEPL

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CAKE	Centre for Climate and Energy Analyses
CAP	Common Agricultural Policy
CDR	Agricultural Advisory Center
CH_4	Methane
CGE model	Computable General Equilibrium model
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
CU	Currency Unit
GWP	Global Warming Potential
d-PLACE model	Dynamic version of PLACE model (CGE model created in Polish Laboratory for the Analysis of Climate and Energy)
EC	European Commission
EPICA model	Evaluation of Policy Impacts – Climate and Agriculture Model
ESR	Effort Sharing Regulation
EU	European Union
EU ETS	European Union Emissions Trading System
EU28	European Union of 28 Member States
FADN	Farm Accountancy Data Network
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GHG	Greenhouse Gases
Gt	Gigatonne
GUS	Central Statistical Office of Poland
IEA	International Energy Agency
IOS-PIB	Institute of Environmental Protection – National Research Institute
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
KOBiZE	National Centre for Emissions Management
LU, LSU	Livestock Unit
MEESA	Model for European Energy System Analysis
MJ	Megajoule
NEL	Net Energy Lactation
N_2O	Nitrous Oxide
N	Nitrogen
P	Phosphorus
NECP(s)	National Energy and Climate Plan(s)
RES	Renewable Energy Sources
TR^3E model	Transport European Emission Economic Model
UAA	Utilised Agricultural Area
UNFCCC	United Nations Framework Convention on Climate Change

Abstract

Agriculture being one of the key sectors contributing to GHG emissions needs evidence-based approaches in order to estimate and verify the impacts of climate policies and corresponding GHG mitigation measures. For this purpose the EPICA model has been developed as a tool for analysis of agricultural sector and its responses to potential policy measures directed towards reduction of GHG emissions.

The EPICA model represents the agricultural sector of Poland and incorporates the assumption of the farm income maximisation driving the farm behaviour in the choice of production and respectively applied techniques, therefore influencing the overall agricultural supply structure and output, as well as accompanying GHG emissions.

This report presents the concept of the EPICA model, its functionalities and assumptions, as well as provides a set of modelling results followed by their analyses and key conclusions. Performed analyses involve various approaches to reduction of GHG emissions from agricultural sector, including: 1) induced general reduction targets for agricultural GHG emissions and capturing the following farm responses in production structure, 2) introduction of taxation in regard to application of nitrogen-based fertilisers in crop production, and 3) introduction of price on emissions from agriculture in accordance with the EU ETS approach.

There are in total 8 scenarios developed with the use of the EPICA model presented in this report, one being the reference (baseline) scenario and seven representing particular shocks.

Keywords: climate policy, agriculture modelling, agricultural production analysis, farming practices, greenhouse gas emissions.

Key policy insights:

- **Total GHG emissions in Poland's agriculture reach 30 Mt yearly.** Two sources have the largest shares in agricultural emissions: **agricultural soils – 42.9%** and **enteric fermentation – 41.9%.** It is the main source of N_2O in the country, responsible for 78% of this GHG's and – following the energy sector – the second biggest source of the CH_4 emissions, with 30% share.
- **Forcing the GHG reduction by 20% leads to decline in value of produced market commodities by ca. 9.5% and farm income by ca. 14%** (even 70% in small cattle farms). Any attempt to introduce more ambitious reduction causes more than proportional decrease of farm income.
- **Decline in production** following the forced GHG emission reduction to the greatest extent affects the production of **cattle for beef** (by 35%), **milk** (by 16%), **maize for grain** (by 21%), and **sugar beets** (by 21%).
- **Similar to the forced reduction of GHG emissions effects can be achieved through implementation of "fiscal" measures, however this is less efficient regarding reduction of emissions and strongly affects farmers' income.** Farms with less profitable activities become unprofitable after taxation what is not the case within the analyses performed at the national average profitability level.
- **Assuming implementation of the EUR 20 emission tax**, the potential emission **costs would rise up to PLN 2.78 bln** at country scale, which would mean an expense of over PLN 1,960 per average farm and PLN 195 per ha of Utilised Agricultural Area (UAA). **This is more than 11% of the average farm income earned in Poland's agricultural sector**.
- **Introducing the N-tax** and accordingly rising the N-fertiliser prices by 20% (the N20 scenario) **leads to increase of fertiliser costs by 3.95%** and 10.3% decline in their use, while the model shows a reduction of GHG emissions from agriculture by 1.6% only and decrease of farm income by 5.5%.
- **Under the assumption of currently utilised technologies, achieving ambitious emission reduction targets in agriculture is difficult.** Application of more ambitious mitigation goals doesn't just lead to decline of farm income, yet also to relatively high drop in production volumes, which would potentially lead to increase of price levels.
- **The relation of emissions to farm income seems to be a crucial indicator.** One of the oldest, however still implemented aims of the EU's Common Agricultural Policy is supporting farmers to maintain viable income. The results of the analysis shows that this should be aligned with the future Climate Action measures.
- The analysis shows, that achieving climate neutrality addressed in the European Green Deal, needs much more than strengthening traditional climate policy measures in agriculture. Expected **results require wider, deeper and more efficient changes in technologies**.

1. Introduction

1. Agriculture is one of key contributors to climate change through greenhouse gases being emitted along its production activities, affecting the local environment and global climate. Overall it emits a variety of GHG, primarily the nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Main agricultural activities driving the GHG emissions are the production of crops (mainly nitrous oxide from use of fertilisers on agricultural soils) and livestock (mainly methane from enteric fermentation of live animals and manure management). At the same time agriculture is crucial to ensure food provision to the society by utilising various natural resources such as land and water closely linked to the natural and climate conditions. Complexity of agricultural input towards the GHG emissions creates the necessity to model the current state and estimate the influence of acting and potential policies dealing with agricultural production and changes in agri-food supply.

2. Nitrous oxide (N_2O) is a greenhouse gas with atmospheric lifetime of over 100 years and is nearly 300 times better at trapping heat than carbon dioxide. Nitrous oxide in agriculture is generated from organic and mineral fertilisers containing nitrogen, which are applied to fields either as synthetic fertilisers such as urea or anhydrous ammonia, or as organic fertilisers such as manure. Nitrogen from the added fertilisers not taken up by plants is lost either as nitrate to the groundwater or released to the atmosphere in the form of gases N_2O, NO or NH_3 depending on the soil chemistry. The existing studies show that only nearly half of applied nitrogen is being taken up by the crop[1].

3. Methane (CH_4) is generated from animal digestion processes, animal manure management, rice cultivation and biomass burning[2]. The amount of methane generated by a specific manure management system is affected by the extent of anaerobic conditions present, the temperature of the system, and the retention time of organic material in the system. When manure is stored or treated as a liquid (e.g. in lagoons, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. When manure is handled as a solid (e.g. in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced[3,4].

4. Carbon dioxide (CO_2) emissions are generated by the application of urea and other carbon-containing fertilisers, as well as from the fuel combustion by the agricultural machinery.

[1] Millar N., Doll J., Robertson P. (2014). Management of nitrogen fertilizer to reduce nitrous oxide (N_2O) emissions from field crops, Climate Change and Agriculture Fact Sheet Series – MSU Extension Bulletin E3152, see: https://www.canr.msu.edu/uploads/resources/pdfs/management_of_nitrogen_fertiler_(e3152).pdf.

[2] The last two are not typical for Poland.

[3] IPCC (2006), IPCC Guidelines. Chapter 10: Emissions from Livestock and Manure Management.

[4] JRC (2017). Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs.

5. As there are numerous types of activities (types of production) in agriculture, the volumes of their emissions strongly vary. Intensive crop production differs from the extensive types, generally resulting in higher GHG emissions due to more frequent application of fertilisers. Intensive animal production leads to higher emissions through large quantity of animals and their fermentation processes and manure management. Higher productivity in both crop and animal production, aimed at by farmers, require adequate farming practices, which in conventional farming usually lead to greater pollution.

6. The European Union (EU-28) emitted a total of 4.5 Gt CO_2eq in 2017 with the share of agriculture reaching 9.8% (0.44 Gt CO_2eq)[5]. While the global GHG emissions have a growing trend, the EU GHG emissions originating from agriculture follow a steady decline since the 1990[6]. There is still a reduction potential due to new technologies and innovative processes available for implementation by the agricultural producers. As the scientists stress "major productivity gaps remain that could be exploited to supply more food on existing agricultural land and at lower costs"[7].

7. While there is a clear understanding of the need to mitigate the GHG emissions from agriculture, it has to be achieved in a balanced manner in order to maintain the delivery of key functions by agricultural sector. In order to pursue further reduction specific measures introduced through systems of incentives or taxation are required, which would motivate farmers and businesses in agricultural sector to invest in technologies and implement production practices that are more efficient in terms of environmental protection and mitigation of GHG emissions. Introduction of such measures need to be based on evidence regarding their potential effects, in generation and verification of which the approaches based on modelling can assist.

2. Description of the EPICA model

8. The model 'Evaluation of the Policy Impacts – Climate and Agriculture' (EPICA) is one of the models developed and currently used within the LIFE Climate CAKE PL project in the National Centre for Emissions Management (KOBiZE), which is a part of the Institute of Environmental Protection – National Research Institute (IOS-PIB). The main objective of this project is to build a sustainable and comprehensive system of creating and exchanging information and knowledge, supporting the development of cross-sectional analyses of the effects of various solutions in the field of climate and energy policy.

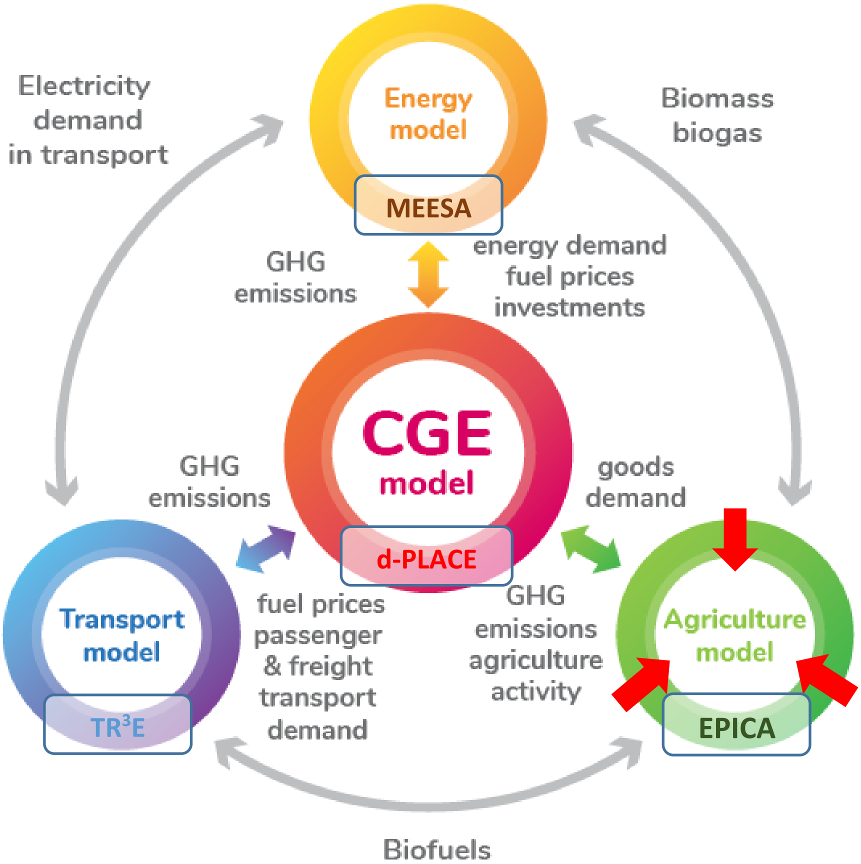
[5] Eurostat (2020). Greenhouse gas emissions by source sector (env_air_gge).

[6] European Commission (2017). Modernising and simplifying the CAP, https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/env_background_final_en.pdf.

[7] Valin H., Havlík P., Mosnier A., Herrero M., Schmid E., Obersteiner M. Agricultural productivity and greenhouse gas emissions: trade-offs or synergies between mitigation and food security? https://iopscience.iop.org/article/10.1088/1748-9326/8/3/035019.

The project's objectives are consistent with supporting the implementation of the EU climate change policy, support the implementation of the energy and climate package 2020 and the EU climate policy framework until 2030, also in the perspective of the long-term strategy until 2055. The project is developing an analytical workshop consisting of a global general equilibrium model (CGE) d-PLACE[8] and cooperative sectoral models including: MEESA for energy[9], TR^{3}E[10] for transport and EPICA for agriculture (Figure 1).

Figure 1. General scheme of models developed in the framework of LIFE Climate CAKE PL project and their interconnections



Source: CAKE/KOBiZE

9. The EPICA model (marked with red arrows on the Figure 1) aims at estimation and support of analyses of policy inflicted changes in agricultural production (including farm

[8] Gąska, J., Pyrka, M., Rabiega, W., Jeszke, R. (2019). The CGE model d-PLACE, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[9] Tatarewicz, I., Lewarski, M., Skwierz, S. (2019). The MEESA model documentation, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[10] Gąska, J., Rabiega, W., Sikora, P. (2019). The TR3E Model, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

structure and farm practices) with evaluation of its influence upon climate change through greenhouse gas emissions. Key feature enabling the EPICA model to stand out among other modelling approaches is the implemented assumption of farm income driving the farm behaviour in the choice of production and respectively applied techniques. The choices therefore include the type(s) of products (referred to as *farm activities*) and production intensity with relevant production processes and practices. The fundamental EPICA model assumption states that farmers aim to maximise their income by adjusting production structure to the present (expected) market conditions and political situation. Similar approach has been applied by Louhichi et al. (2015) arguing that models, which are currently available, are implemented with high aggregation level and are not able to fully capture the impacts of policy measures at farm level.

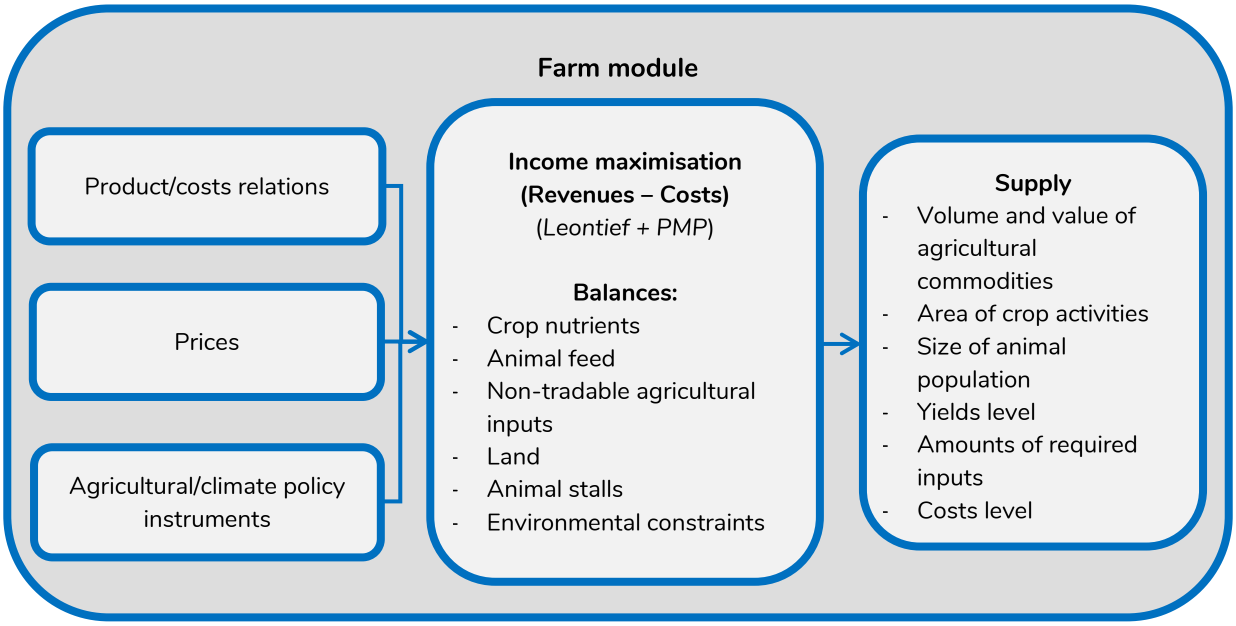
10. The EPICA model simultaneously utilises several approaches to modelling and combines a partial equilibrium with linear farm activity optimisation programming in order to assure a proper supply-demand balance, as well as provides a highly detailed disaggregation of analysed farm activities. Due to high detail level of agricultural activities the EPICA model and its dataset are currently built to represent solely the agricultural sector of Poland. The baseline dataset implemented in the EPICA model represents year 2015. The choice of Poland as a country to reflect in the EPICA model is substantiated by the fact that Polish agriculture is one of the major contributors to the GHG emissions among EU-28 countries (based on 2017 data), being the 6th largest emitter with the share of 7.2% of total EU-28 GHG emissions from agriculture[11]. While a steady decline in GHG from agriculture was present in Poland since the 1990, from the beginning of new millennia these emissions have been oscillating around the current level, showing only minor annual growth or decline shifts, therefore there's a need to implement policy measures aimed to assure a steady decline in the future.

11. The EPICA model consists of two modules: farm module and market module[12]. The EPICA's farm module is a supply (production) side implemented as a linear programming model calibrated using PMP (Positive Mathematical Programming, Howitt 1995) approach, representing outlined farm types optimising their income subject to resource and technological constraints (Figure 2). Its purpose is to define responses of agricultural sector at the micro-level (being the farm) with the ability to capture the policy induced changes in terms of hectares, livestock units, currency units, therefore giving a detailed picture of shifts in particular farm activities, supply of agricultural products and corresponding GHG emissions.

[11] Eurostat (2020). Greenhouse gas emissions by source sector (env_air_gge).

[12] For the purposes of this report it was not necessary to use all options of the market module.

Figure 2. EPICA's farm module operation concept



Source: CAKE/KOBiZE own study

12. The farm module's objective function is the farm income maximisation constrained by availability of primary production factors and production inputs. The farm module is based on three key factors being exogenous to farm activities (as shown in Figure 2): 1) product/costs relations, 2) price levels, 3) agricultural and climate policy instruments. These three factors are not under the influence of the farm. Farms objective is to adapt to them in the business process. Following these factors, the income maximisation function itself is constrained by several balances, which force it to maintain in realistic boundaries of available resources.

13. These balances include: 1) crop nutrients, 2) animal feed (separately for cattle, pigs and poultry), 3) non-tradable agricultural inputs, 4) land 5) number of animal stalls, and 6) environmental constraints (e.g. maintaining the permanent grassland area above 95% of the current level, according to the CAP requirements).

14. The outcome of the farm module is the updated supply based on the new farm activities' structure. The updated data includes the volume and value of agricultural commodities, area of crop activities, size of animal population, level of yields, amounts of required inputs, level of costs, and farm income.

15. The EPICA's market module being a partial equilibrium combines supply from the farm module and demand for products of agricultural origin from the main CGE core model (d-PLACE). The main CGE model utilises a highly aggregated dataset, where all agri-food sectors are represented by the following three: CRO (primary crops), ANI (primary products of animal origin, including agricultural and fishing products), and FOS (forest

products). Yet it is highly important to note that all estimations and analyses conducted in this report are based on static version of the EPICA model, without the implementation of the dynamic market responses of the core CGE d-PLACE. Such approach was taken to understand immediate supply responses to induced shocks, while the EPICA's models interconnections with the CGE and other satellite CAKE models are under development.

3. EPICA modelling assumptions

16. In the most basic understanding the *Farm income* is derived from *Total revenues* subtracted by *Total costs*. Farm revenues are calculated (Figure 3) based on farm gate prices of crop and animal commodities multiplied by either yield per hectare based on the devoted area (for crop production) or production output per LU in regard to current number of animals (for animal production). These are estimated for both extensive and intensive types of production. On the farm costs side:

    1) crop production is defined by the fertiliser inputs (purchased mineral and own organic, according to modelling assumptions), crop residuals and other inputs (seeds, planting materials, pesticides and other), while
    2) animal production costs include feed (purchased concentrate and own roughage, according to modelling assumptions) and other inputs (veterinary services, medicines, insemination, milk yield control, etc.).

    On top of revenues and costs the available payments within the Common Agricultural Policy (CAP) are taken into account to ensure the most comprehensive picture of farming.

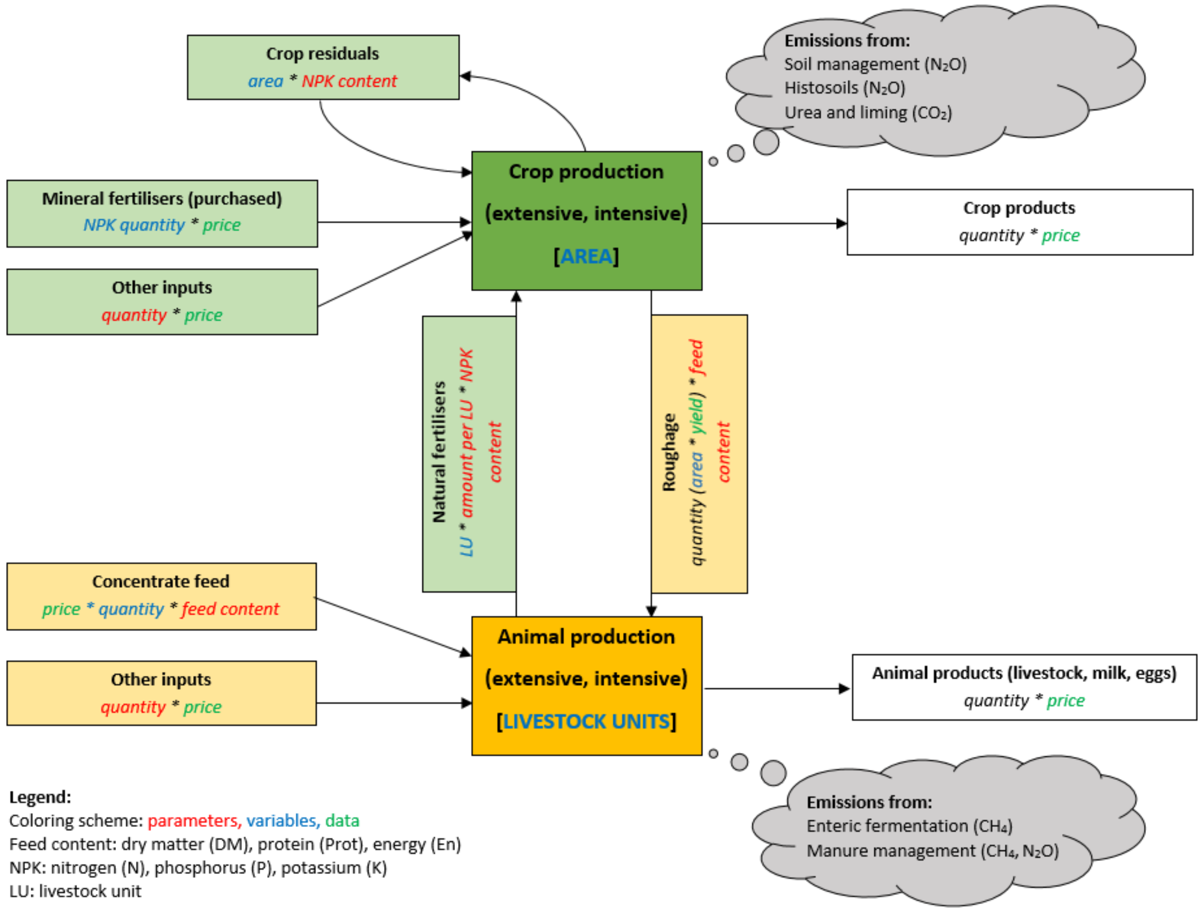
17. The EPICA model goes deep into assessment of specific agricultural (farm) activities. There are in total 23 activities singled out distributed between 17 crop and 6 animal farm activities, each having their distinctive input-output assumptions with consideration of two types of production intensity (extensive and intensive, regarded in the model as *technology*) with the final output of primary products and accompanying GHG emissions. The outlined crop activities can be grouped according to the purpose of these products. These are:

    1) general crops (including wheat, other cereals, oilseeds, sugar beets, potatoes, proteins (for grain), maize (for grain), fruits (short term <5 years), vegetables (short term <5 years), fruits & vegetables (>5 years);
    2) fodder crops (proteins (fodder), maize (for sillage), permanent grassland, grass on arable land and other fodder crops;
    3) energy crops;
    4) other crops; and

5) fallow land (Ecological Focus Area).

Animal activities are distributed into the following: cattle for beef, dairy cattle, pigs for meat, poultry for meat, poultry for eggs, other animals.

Figure 3. EPICA's farm module detailed input-output concept



Source: CAKE/KOBiZE own study

18. All farms in agricultural sector are aggregated into 19 types, according to specialisation and size criteria. Six agricultural specialisations include:

1) cereals,
2) crops (all excluding cereals),
3) cattle,
4) granivores,
5) mixed, and
6) other.

Each of these 6 types are split according to their size into small, medium, and large, resulting in overall of 18 types. There is also an additional farm type singled out in order to represent the rest of the agricultural sector, namely the semi-subsistence farms, which are not considered as producers of marketable products, yet represent nearly half of the overall farm population in physical terms.

19. Yields are an important parameter used in the EPICA model defined as the volume of production of the main commodity harvested on the given area[13] or the production per one livestock unit (LU). Yields in the model are endogenous. Each of the activities is represented by the mix of two technologies one of which is highly extensive (representing the lowest expected level of intensity), while the other one is representing highly intensive production (with the yields above the typical levels observed in the most intensive farm types). Changes in shares of those two technologies within each farm activity are indicating if modelled impacts are in favour of increasing or decreasing intensity of production for considered activities.

20. Yields for crop activities in the base year are estimated using FADN data on production and area used for particular activities independently for each farm type modelled. The yields are estimated based on produced quantities and the area of land used by each farm activity. For activities representing the number of different crops e.g. fruits and vegetables the yield is estimated as the value of produced crops, otherwise physical values are used (tonnes/ha).

21. In case of animal activities the yield is the production output collected per LU on the farm (e.g. volume of milk, number of eggs, or number of live animals sold for further processing). Large differences exist depending on the production intensity: if the animals are kept in more intensive production system the fattening period is shorter and the production per LU is greater. In case more than one commodity is produced on a farm due to animal production activity (e.g. both milk and beef in case of dairy cows), the yield of both commodities is estimated for these activities.

22. To ensure flawless exchange of data and comparability between parts of the model several assumptions have been made in regard to units used in the model. Thus crop nutrients are reflected by the chemical content of nitrogen (N), phosphorus (P) and potassium (K), which aside of being purchased in the form of mineral fertilisers, are also supplied to crops in form of natural fertilisers, crop residuals and other natural sources. For the animal nutrients the assumed elements include the dry matter (DM), energy (En) and crude protein (Prot), supplied by the production of fodder crops and purchase of feed concentrates.

23. GHG emissions as the key estimation target in the EPICA model are evaluated based on each farm activity output, for crop production as CO_2eq/ha and for animal production as CO_2eq/LU. As in the case with other economy sectors, agriculture produces a unique variety of GHG, all of which have a different potential towards impact on global

[13] A hectare of land is used as a reference unit in Europe.

warming. This potential depends on the particular GHG's atmospheric lifetime and Global Warming Potential (GWP) substantiated by IPCC. The EPICA model utilises conversion of all analysed GHG to CO_2eq based on the IPCC Forth Assessment Report[14] values for the 100-year time horizon. These values equal: for the N_2O – 298, for the CH_4 – 25, and for the CO_2 – 1.

24. Emissions from crop production include such sources as:

- soil management (N_2O),
- histosoils (N_2O), and
- urea and liming (CO_2).

25. Emissions from animal production cover:

- enteric fermentation (CH4), and
- manure management (CH4, N2O).

26. Emissions are calculated based on the IPCC methodology[15]. Key equations regarding the GHG emissions include:

1) enteric fermentation emissions (IPCC equation 10.21, Tier 1+2),
2) manure management direct CH4 (IPCC equation 10.23),
3) manure management direct N emission (IPCC equation 10.25),
4) manure management indirect N losses volatilisation (IPCC equation 10.26),
5) manure management indirect N losses due to leaching (IPCC equation 10.28),
6) emissions from soil - N from crop residuals returned to soils (modified IPCC equation 11.6 [Corrigenda for the 2006 IPCC GLs]16),
7) emissions from urea application (IPCC equation 11.13, Tier 1 method),
8) emissions from agricultural lime application (IPCC equation 11.12, Tier 1 method).

27. In regard of the data used in the model, the farm module database covers primary production factors, inputs and outputs. Data are expressed in both physical and monetary terms. Mutual consistency is ensured between quantities, values and prices. Data are sourced from the harmonized datasets of Polish FADN and GUS, as well as

[14] Forster, P., Ramaswamy V., Artaxo P., Berntsen T., Betts R., Fahey D.W., Haywood J., Lean J., Lowe D.C., Myhre G., Nganga J., Prinn R., Raga G., Schulz M. and Van Dorland R. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[15] IPCC (2006). Guidelines for National Greenhouse Gas Inventories.

[16] Poland's National Inventory Report 2019, GHG Inventory for 1988-2017, KOBiZE. https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_POL_2019_23.05.2019.pdf.

verified on the basis of publicly available data of regional Polish Agricultural Advisory Centres.

28. Primary data regarding agricultural production in Poland was derived from the publications of State Statistical Office of Poland. It was aggregated in order to ensure consistency between the FADN sample data and the national statistics, as well as to verify the module assumptions. Data used includes the utilised agricultural land area, areas under particular crops, production volumes and values of crops, quantity of farm animals, animal production in terms of quantity and value. Data derived from these sources was aggregated according to the structure of farm activities set in the farm module.

29. Another key source of data was the FADN[17] - Farm Accountancy Data Network, being an instrument for evaluating the income of national agricultural holdings and the impacts of the Common Agricultural Policy. Each EU Member State collects relevant farm information based on selected sample. While there were overall 1,506,620 farms in Poland in the 2015, only the farms with standard output (SO)[18] of 4,000 EUR and over were considered by the FADN. Therefore the number of such farms accounted to 730,879, which were responsible for 93.03% of the total production value in agricultural sector, cultivated 85.07% of agricultural land, kept 96.9% of farm animals, while employing 66.46% of agricultural labour resources[19]. Representing these farms a total of 12,100 farms were selected as the Polish FADN sample, data of which serves as the basis for assessment of Polish agriculture in the farm module of the EPICA model. Those farms cultivate 88% of agricultural area and produce 98% of farm animals.

30. In regard to crop activities, the Polish FADN sample records a total of ca. 150 various crops. Production of many of these crops has, however, only marginal meaning and for the sake of model optimisation were grouped into aggregates basically without any implications on the results of our analysis.

31. Data from Regional branches of Agricultural Advisory Centre in Poland provide detailed calculations for various types of agricultural production. This data includes detailed description and calculation of production costs, served as a verification basis for farm economic accounts (prices, yields, costs, nutrient inputs, payments) for both crop and animal production.

[17] FADN (2019). http://ec.europa.eu/agriculture/rica.

[18] The Standard Output (SO) is the average monetary value of the agricultural output at farm-gate price of each agricultural product (crop or animal) in a given region. The SO coefficients are expressed in euros and the economic size of the holding is measured as the total standard output of the holding expressed in euros. Source: FADN (2019). Field of survey, https://ec.europa.eu/agriculture/rica/methodology1_en.cfm.

[19] Polish FADN (2013). Plan wyboru próby gospodarstw rolnych Polskiego FADN od roku obrachunkowego 2014, https://fadn.pl/wp-content/uploads/2013/10/Plan-wyboru-od-2014.pdf.

4. Agriculture of Poland and its emissions in the baseline year

32. Agriculture of Poland has been developing in rather beneficial climate and soil conditions, having a relevant input into the national GDP. In the past decades agriculture in Poland has been dynamically developing due to enabling institutional environment aimed at restructuring of Poland's economy during the process of accession to the EU and the following support of farmers and their income through the EU's Common Agricultural Policy. Agricultural sector of Poland is one of the largest among the European Union member states. According to the 2015 data[20] it ranked 7th among the EU-28 with the value of agricultural production of EUR 22.3 bln calculated at basic prices being ca. 5.36% of the EU-28 agricultural output.

33. While the agriculture, forestry and fishing combined represent approximately 2.4% of the total gross value added of Poland (as of 2015)[21], it is a crucial economic activity ensuring food security, rural employment and income generation sources. In Poland itself, the agricultural sector comprises of 1.4 million farms and is responsible for the management of ca. 46.5% of the land area[22].

34. Crops and animal sectors are contributing nearly evenly to the gross output of Poland's agriculture, with the crops sector having produced 50.7% of total gross output of agriculture and the animal sector – 49.3%[23]. In the gross agricultural output the largest shares have the following crop products: cereals (16.6%), vegetables (10.0%), industrial crops (6.8%), potatoes (3.1%). As for the animal products, the key ones are: animals for slaughter (28.0% with the largest shares presented by poultry, pigs and cattle (excluding calves)), cow's milk (14.9%) and hen eggs (5.0%). On the scale of European Union (EU-28), Poland is ranking as the largest producer of apples (28.6% of EU-28 output) and oats (17.1%), 2nd largest in production of tobacco (16.6%) and potatoes (15.8%), 3rd largest in sugar beets (12.2%) and rape and turnip rape (11.3%). It is also a major producer of meat (10.1% of EU-28 output), cows' milk (8.4%), hen eggs (8.2%) and wheat (7.6%)[24].

35. Production of crops is a land-intensive activity. Overall, Poland is the 5th largest country according to utilised agricultural area (UAA) in the EU-28 (after France, Spain, United Kingdom and Germany) with the share of 8.04%[25]. Poland has a total of 14545

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[20] Eurostat (2020). Output of the agricultural industry (basic prices).
[21] GUS (2016). Produkt krajowy brutto i wartość dodana brutto według województw i podregionów w latach 2010-2015, https://stat.gov.pl/download/gfx/portalinformacyjny/pl/defaultaktualnosci/5482/3/4/1/produkt_krajowy_brutto_i_wartosc_dodana_brutto_wedlug_wojewodztw_i_podregionow_w_latach_2010-2015.xlsx.
[22] GUS (2016). Rolnictwo w 2015 r., Warszawa.
[23] GUS (2016). Mały rocznik statystyczny 2016, Warszawa.
[24] GUS (2017). Rocznik statystyczny rolnictwa, Warszawa.
[25] Eurostat (2020). Utilised agricultural area by categories.

thousand ha of agricultural land[26]. The sown area equals 10753 thousand ha, permanent meadows - 2658 thousand ha, permanent pastures – 435 thousand ha, permanent crops – 391 thousand ha, fallow land – 134 thousand ha. The sown area is distributed between different types of crops, the most substantial being the cereals covering 7512 thousand ha (being 69.9% of the total sown area). The key cereals are: wheat – 2395 thousand ha, triticale – 1516 thousand ha, barley – 839 thousand ha, cereal mixed for grain – 813 thousand ha, rye – 725 thousand ha, maize for grain – 670 thousand ha and oats – 461 thousand ha. These are followed by industrial crops (1191 thousand ha) consisting of oilseeds (994 thousand ha), sugar beets (180 thousand ha), then by feed crops (1056 thousand ha) including maize for feed, perennial legumes and root plants. The rest includes pulses for grain (407 thousand ha), potatoes (292 thousand ha) and other crops (295 thousand ha). The area utilisation according to the EPICA aggregation of crop activities is presented in Table 1.

Table 1. Area under crop activities in the baseline year (according to EPICA aggregation)

Crop farm activities	Area, ha
Wheat	2,395,451
Other cereals	4,446,102
Oilseeds	884,199
Sugar beets	180,119
Potatoes	300,355
Proteins (grain)	403,913
Proteins (fodder)	249,195
Maize (grain)	670,295
Maize (sillage)	555,168
Fruits (short term <5 years)	52,139
Vegetables (short term <5 years)	175,701
Fruits & Vegetables (>5 years)	248,627
Permanent grassland	3,092,000
Grass on arable land and other fodder crops	252,339
Fallow Land - Ecological Focus Area	134,000
Other crops	79,487
Energy crops	11,636

Source: CAKE/KOBiZE own study based on GUS data

36. Animal numbers in Poland in 2015 (as of June) have been the following: cattle – 5960.7 thousand heads (in which cows – 2444.5 thousand heads), pigs – 11639.8 thousand heads (in which sows – 947 thousand heads), sheep – 227.6 thousand heads (in which ewes – 143 thousand heads). As for the poultry, its numbers at the end of 2015 were

[26] GUS (2016). Rocznik statystyczny rolnictwa, Warszawa.

the following: 139588 thousand heads of hens (in which 49536 thousand heads being the laying hens), 1213 thousand heads of geese, 9008 thousand heads of turkeys, 3401 thousand heads of ducks and others.

37. GHG emission from the Poland's agricultural sector in 2015 amounted ca. 7.7% (excluding energy and LULUCF – Land use, land-use change, and forestry), where the N_2O emissions equalled 50.0%, CH_4 – 47.4% and CO_2 – 2.6%[27].

38. Total emissions of GHG in Poland's agriculture sector presented as CO_2eq in the year 2015 amounted to 29.6 Mt. Agriculture in Poland is the largest emitter of N_2O in the country, producing 78.0% of this GHG, although in the total GHG emissions of Poland in 2015 N_2O amounted to only 4.9%. Concerning the CH_4 emissions the agriculture is the source of 29.8% being the second largest emitter after the Energy sector (methane having a 12.2% input to the total GHG in Poland). In case of CO_2 the output of agriculture (and emissions from agricultural machinery and equipment) is at the level of 0.25%, while the share of the CO_2 in the total GHG of Poland equalled 80.5%. Important to note that the emissions from the agricultural machinery and equipment are reported separately in the Fuel combustion subcategory of the national inventory.

39. Two sources have the largest shares in agricultural emissions of GHG in Poland[28]: agricultural soils – 42.9% and enteric fermentation – 41.9%. Manure management is responsible for about 12.5% of GHG emissions, liming and urea application similarly for 1.3% Share of CH_4 and N_2O emissions from field burning of agricultural residues are minor – only about 0.1%.

40. Nearly 85.8% of N_2O emissions in agriculture come from the section of agricultural soils. Overall, in regard to the area of utilised agricultural land is a steady declining trend. In the structure of sown area during the 2000-2015 a relatively permanent area was utilised under the cultivation of wheat (being at the same time the key type of cereal produced in Poland), the rye, oats and potatoes have a declining trend, while the corn and some of the industrial crops (oilseeds and rape) have shown an increase. Level of GHG emissions depends on the type of agricultural land utilisation (type of crops) and the level of production intensity and applied techniques, primarily the rates of fertilisation. The overall rates of fertiliser (NPK) consumption in Poland had a growing trend over the 2002-2015 reaching the level of 174.1 kg per ha in 2015, being higher from the EU's average by 13.8 kg per ha of arable land[29].

[27] Poland's National Inventory Report 2017, GHG Inventory for 1988-2015, KOBiZE. http://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_2017_POL_May.pdf.
[28] Poland's National Inventory Report 2017, GHG Inventory for 1988-2015, KOBiZE. http://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_2017_POL_May.pdf.
[29] World Bank (2020). Fertilization data based on Food and Agriculture Organization, https://data.worldbank.org/indicator/AG.CON.FERT.ZS?locations=PL-EU.

41. Animal feed management (including feed composition) is a key issue for enteric fermentation processes being the cause of 88.3% of overall CH_4 emissions from agriculture in Poland[30]. Properly balanced and timely delivered feed is beneficial to provide proper amounts of vitamins, minerals, protein and fibre and limit the excreted manure[31]. Based on research in Poland methane emissions vary between 93.8 kg/year/cow in case of annual productivity of 4,000 kg of milk to 146.9 kg/year/cow in case of 12,000 kg[32], therefore farming intensity plays a key role in emissions' rate. The amount of methane emitted by animals is estimated from the number of heads and an emissions rate per animal. The emission rates mainly depend on the type of digestive system of the animal, its age, weight and energy consumption, as well as the quality and quantity of its feed intake[33].

42. Manure management is the cause of 11.5% of CH_4 and 14.1% of N_2O emissions coming from agriculture in Poland, being the third sector after the agricultural soils and enteric fermentation by magnitude of GHG emissions. Most of the manure is generated by cattle (57%) and pigs (34%)[34].

5. Scenarios considered in the analysis

43. The study considers scenarios aimed at reduction of GHG emissions from agriculture induced with implementation of three key approaches: 1) setting (forcing) reduction targets for the level of agricultural GHG emissions and capturing the following farm responses in production structure, 2) introduction of taxation in regard to application of nitrogen-based fertilisers in crop production, and 3) introduction of price for emissions from agriculture in accordance with the EU ETS approach. There are in total 8 scenarios developed with the use of the EPICA model presented in this report, one being the reference (baseline) scenario and seven representing particular shocks:

- **reference scenario (BAS)** - no emission reduction goal is set, the baseline is built for calibration purposes. The production structure, levels of inputs used, production outputs and GHG emissions are equal to those observed in Poland in 2015.

[30] Poland's National Inventory Report 2017, GHG Inventory for 1988-2015, KOBiZE. http://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_2017_POL_May.pdf.

[31] Climate Change Connection (2015), Feed management, https://climatechangeconnection.org/solutions/agriculture-solutions/livestock-production/feed-management/#Feed.

[32] Podkówka Z., Podkówka W. (2011). Emisja gazów cieplarnianych przez krowy, http://ptz.icm.edu.pl/wp-content/uploads/2011/12/PH_3_2011_Podkowka.pdf.

[33] Eurostat (2019). Agri-environmental indicator - greenhouse gas emissions, https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_greenhouse_gas_emissions.

[34] Poland's National Inventory Report 2017, GHG Inventory for 1988-2015, KOBiZE. http://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_2017_POL_May.pdf.

- **forced GHG emission reduction (three "RE" scenarios)** – while such administrative regulations aimed at forced reduction of GHG emissions at farm level would be too difficult to implement, these scenarios are constructed to reveal the vulnerability of Polish farms to emission restrictions and understand potential changes in agricultural production structure, as well as level of production output and demand for inputs. The three chosen GHG reduction levels applied to agricultural sector were assumed to maintain comparability with other existing analyses (e.g. EcAMPA 2, 2016)[35]. The reduction has been applied on national level and proportionally in every farm type analysed. Therefore the following three scenarios have been tested:
    a. **RE5 – reduction of GHG emission from agriculture by 5%** - the reference scenario for this exercise is the BAS, the total emissions (N_2O, CH_4, CO_2) being reduced to 95% of the 2015 level calculated in CO_2 equivalent.
    b. **RE10 - reduction of GHG emission from agriculture by 10%** - the reference scenario for this exercise is the BAS, the total emissions (N_2O, CH_4, CO_2) being reduced to 90% of the 2015 level calculated in CO_2 equivalent.
    c. **RE20 - reduction of GHG emission from agriculture by 20%** - the reference scenario for this exercise is the BAS, the total emissions (N_2O, CH_4, CO_2) being reduced to 80% of the 2015 level calculated in CO_2 equivalent.
- **N fertiliser tax (two "N" scenarios)** – as land use is an important factor for carbon (C) and nitrogen (N) dynamics of ecosystems, it can have a great effect on GHG emissions from soils (Forster et al. 2007)[36]. Agriculture emits the vast majority of the total anthropogenic emission of nitrous oxide (N_2O) (Thomas et al. 2011)[37], which is primarily due to field management practices such as application of synthetic N fertiliser (Bouwman et al. 2002)[38], performed to enrich the soil with nutrients to the levels adequate to expected yields. As nearly half of GHG emissions in Poland

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[35] Pérez Domínguez I., Fellmann T., Weiss F., Witzke P., Barreiro-Hurlé J., Himics M., Jansson T., Salputra G., Leip A. (2016). An economic assessment of GHG mitigation policy options for EU agriculture (EcAMPA 2), JRC Science for Policy Report, EUR 27973 EN, 10.2791/843461.

[36] Forster, P., Ramaswamy V., Artaxo P., Berntsen T., Betts R., Fahey D.W., Haywood J., Lean J., Lowe D.C., Myhre G., Nganga J., Prinn R., Raga G., Schulz M. and Van Dorland R. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[37] Thomas J., Thistlethwaite G., MacCarthy J., Pearson B., Murrells T., Pang Y., Passant N., Webb N., Conolly C., Cardenas L., Malcolm H., Thomson A. (2011). Greenhouse gas inventories for England, Scotland, Wales and Northern Ireland: 1990-2009. Report to the Department for Energy and Climate Change, The Scottish Government, The Welsh Government and The Northern Ireland Department of Environment. Report number: AEAT/ENV/R/3222 Issue 1. ISBN: 978-0-9565155-5-1. Access 25 June 2015.

[38] Bouwman A.F., Boumans L.J.M., Batjes N.H. (2002). N2O and NO emissions from fertilized fields. Summary of available measurement data. Glob Biogeochem Cycl 16:1080. doi:10.1029/ 2001GB00181.

(Poland's... 2017[39]) are the result of soil management the following two scenarios aim to analyse the consequences of reduction in volumes of applied synthetic N fertilisers. As proportional reduction of N fertilisers for each crop seems highly unrealistic and might cause inefficient distribution of inputs it was decided to test the effects of synthetic N fertilisers' price increase, performed through introduction of Nitrogen tax. Two scenarios assuming different tax rates were tested:

a. **N10 – introduction of 10% tax on nitrogen-based fertilisers** - the reference scenario for this exercise is the BAS, the price of N synthetic fertilisers was increased by 10% compared to the BAS scenario.

b. **N20 - introduction of 20% tax on nitrogen-based fertilisers** - the reference scenario for this exercise is the BAS, the price of N synthetic fertilisers was increased by 20% compared to the BAS scenario.

- **EU Emissions Trading System (ETS) expansion (two "ETS" scenarios)** - introduced to analyse possible shifts in supply of agricultural products under a GHG emission reduction pressure. Unlike in RE scenarios the constraints on GHG reduction have not been enforced in all farms, however similarly to the N fertiliser tax scenarios the GHG emissions have been charged with additional costs. For this purpose an assumption of additional costs due to set prices for emission allowances (derived from the existing EU ETS scheme) have been utilised (as an assumption of potential EU ETS expansion towards inclusion of agriculture in the future). Two EU ETS emission price levels were used in the simulations to capture the supply responses: the lower price level from beginning of year 2015[40] and the higher price level from the same period in 2020[41]. Such approach allows to analyse economic vulnerability of different types of agricultural production following the induced economic implications on emitted GHG. Therefore the ETS scenarios include:

  a. **ETS15 – an introduction of obligatory price for GHG emitted from agriculture according to EU ETS approach in 2015** – in this scenario emission from agricultural activities calculated in line with IPCC methodology has been charged with additional costs at the rate of EUR 6.99 per tonne of CO_2eq (with exchange rate of EUR/PLN 4.3078 applied).

[39] Poland's National Inventory Report 2017, GHG Inventory for 1988-2015, KOBiZE. http://www.kobize.pl/uploads/materialy/materialy_do_pobrania/krajowa_inwentaryzacja_emisji/NIR_2017_POL_May.pdf.

[40] KOBiZE (2015), Report from the CO2 market, no. 34, January 2015, https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/raport_co2/2015/KOBiZE_Analiza_rynku_CO2_styczen_2015.pdf.

[41] KOBiZE (2020), Report from the CO2 market, no. 94, January 2020, https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/raport_co2/2020/KOBiZE_Analiza_rynku_CO2_styczen_2020.pdf.

b. **ETS20 - introduction of payments induced upon GHG emitted from agriculture according to EU ETS approach in 2020** - in this scenario emission from agricultural activities calculated in line with IPCC methodology has been charged with additional costs at the rate of EUR 24.24 per tonne of CO_2eq (with exchange rate of EUR/PLN 4.2571 applied).

44. Scenarios considered are aiming both to test model capabilities and examine reaction of agricultural sector for wide scope of potential actions regarding limitation of GHG emission. The results assume that market and economic environment of the modelled farms remains the same as in the base year.

6. Results

45. The model has been run in two variants: 1) aggregated at the level of the whole country (further called "national" approach), and 2) for the particular farm types (representing different farms currently existing in the Polish farm sector, further called "farm type" approach). National version of the model is based on the assumption that all farms in Poland are homogenous units and all resources available for agricultural production could be used by the sector. Such assumption is especially important in case of inputs, which are produced by agriculture itself (e.g. animal feed, natural fertilisers etc.). Thus in the national variant all inputs originating from agricultural sector are allocated in the most optimal way (in regard to overall farm income at national level). This could be interpreted as optimal allocation of all resources and what is even more important - most optimal distribution of abatement measures among all agricultural activities and between all different farms existing in reality in the sector.

46. In reality the agricultural sector consists of highly diversified farms. Each farmer aims to maximise its own economic result, even at the cost of neighbouring farms. Thus applying "farm type" variant (assuming coexistence of different farm types) we assume that allocation of resources could take place only within a given farm type. For example, the excess of fodder in small cattle farms, which are reducing herd size due to the GHG reduction scenario, would be further obsolete and not used by other farm types. Such mechanism tends to reflect barriers in flow of non-tradable commodities across the farms and allows to estimate effects of constructed scenario from the perspective of different farm types.

47. Both variants of the model have been calculated for all constructed scenarios. Following indicators have been analysed to present changes in the farming sector:

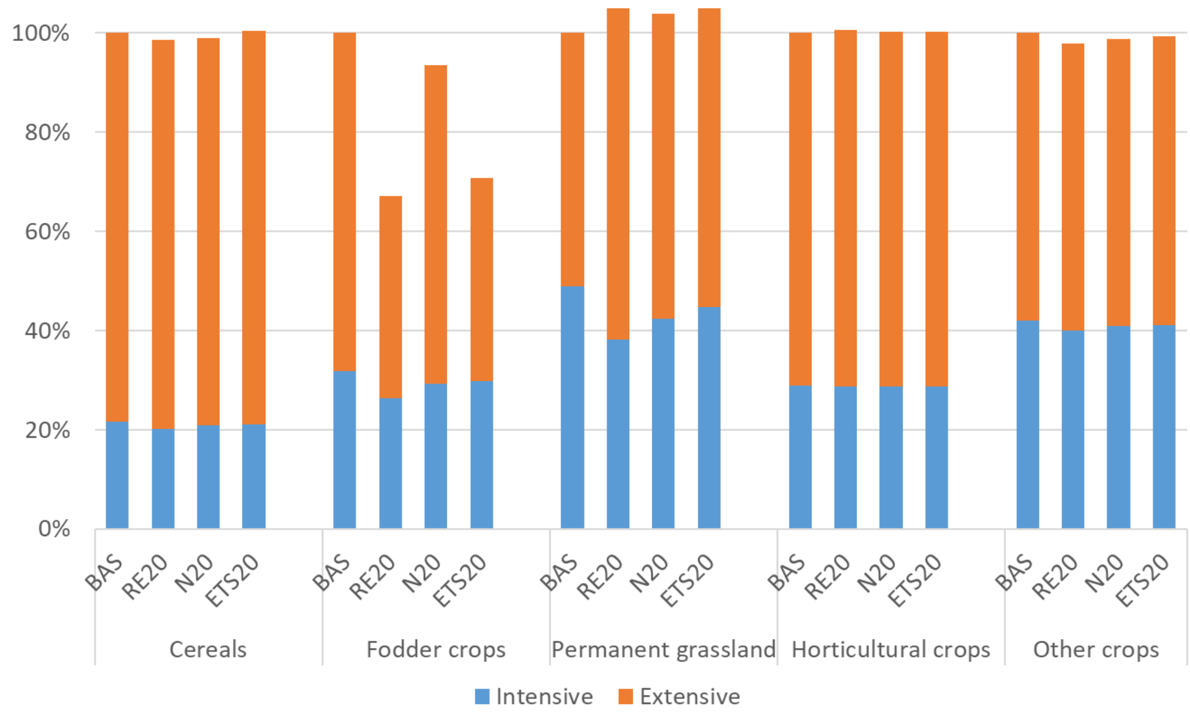
- agricultural production structure:
  - ✓ shares of crop areas (including the share of fallow land),
  - ✓ numbers of animals.
- yields' change resulting from changes in the structure of production techniques,
- emissions of main GHG and their CO2 equivalent,
- values of produced commodities,
- farm income.

48. Results for considered scenarios are presented in the following sections.

6.1. National approach results

49. Introduction of assumptions in constructed scenarios affects the scale of production activities. In case of crop production the model results show differences in scale of adjustments depending on the crop cultivated. The biggest impact could be observed in case of fodder crops cultivated on arable land. Reduction in animal production causes decrease of demand for fodder crops, while production on permanent grassland is rather subject of extensification: share of intensively grown permanent grassland is reduced, while the arable land no longer needed for marketable crops is converted to unmanaged grassland. Detailed results are presented below (Figure 4).

Figure 4. Area of main crops in selected scenarios [%]



Source: CAKE/KOBiZE own study

50. Figure 4 depicts changes in area utilised under main groups of crops in selected scenarios. Area of cultivated cereals in scenarios decrease following the forced reduction of emissions. The highest decrease of area under cereals is observed in the RE20 scenario. Important to note the area of intensively grown cereals remain almost unchanged, whilst the area of extensive production is changing depending on scenario.

51. It needs to be emphasised that division of assumed mixed intensive and extensive techniques of production is just a technical concept implemented in the model, constructed to reflect changes in input-output relations, including the GHG emissions, which are treated as undesired output. In reality agriculture is a very diversified sector

with high number of differentiated technologies and techniques. Presented results should not be interpreted as changes of shares between two technologies existing in a country, region or even a farm, but rather as an overall indicator of intensity of production in the sector.

52. It might be noticed that other crops, consisting mainly of potatoes, sugar beets and oilseeds (usually being more profitable than cereals) are less reduced, even in the RE20 scenario, which forces the highest GHG emission reduction. Horticultural crops, which are certainly the most profitable (at least in relation to the area of utilised land) seems to be invulnerable for emission restrictions. Areas of main groups of crops are presented in Table 2.

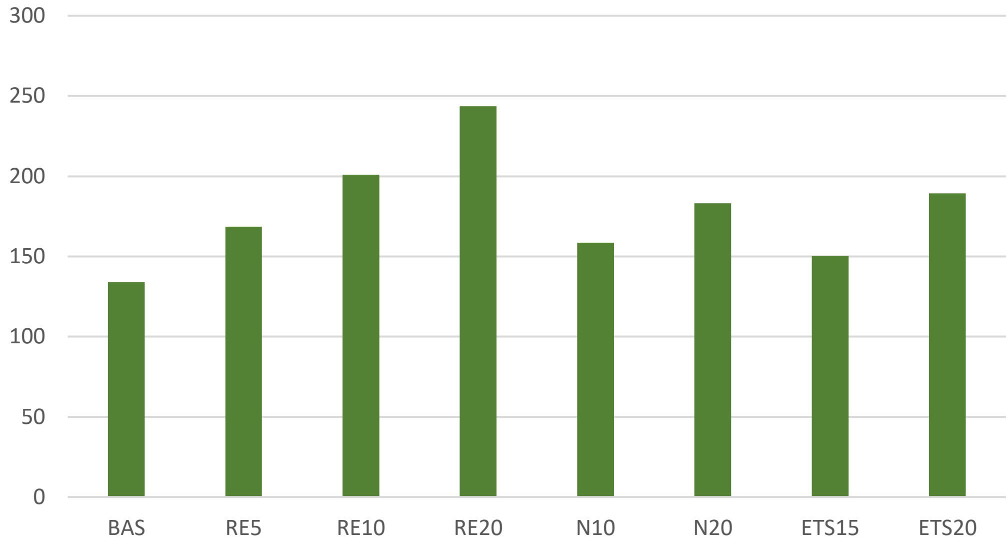
Table 3. Area of main crop groups within scenarios [thousand ha]

Scenario	Technique	Cereals	Fodder crops	Permanent grassland	Horticultural crops	Other crops	Fallow land
BAS	Intensive	1714.4	336.8	1511.3	163.1	679.6	134.0
	Extensive	6201.4	719.9	1581.5	402.8	939.9	
RE5	Intensive	1686.8	322.7	1432.4	163.0	671.8	168.5
	Extensive	6249.2	541.4	1802.8	404.1	942.0	
RE10	Intensive	1657.4	308.1	1349.8	162.9	663.7	200.9
	Extensive	6279.7	403.3	2010.6	405.3	943.1	
RE20	Intensive	1592.7	279.4	1180.1	162.7	647.5	243.6
	Extensive	6217.1	430.9	2285.2	406.8	938.8	
N10	Intensive	1682.8	322.9	1410.2	163.0	671.7	158.6
	Extensive	6191.1	700.0	1741.7	403.7	939.0	
N20	Intensive	1651.2	309.0	1309.0	162.9	663.7	183.2
	Extensive	6180.9	680.2	1901.9	404.7	938.0	
ETS15	Intensive	1701.5	330.2	1474.4	163.1	675.9	150.1
	Extensive	6223.8	636.4	1685.1	403.4	940.9	
ETS20	Intensive	1670.2	314.2	1384.8	163.0	667.1	189.3
	Extensive	6278.1	433.7	1936.4	404.9	943.2	

Source: CAKE/KOBiZE own study

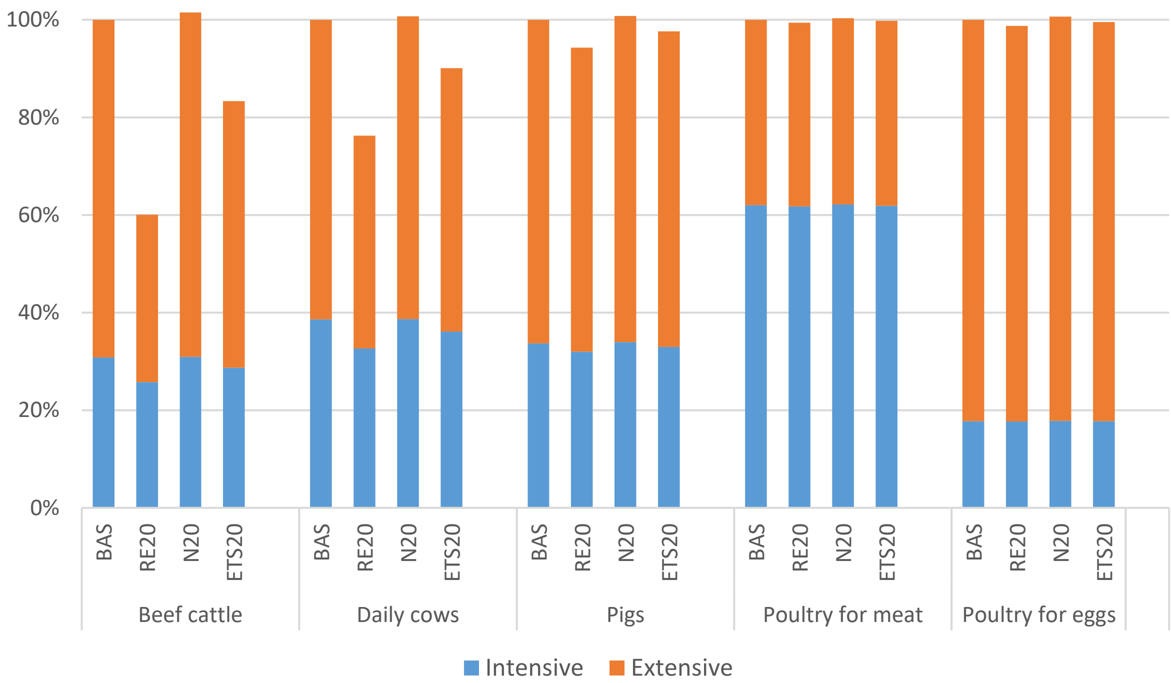
53. Reduction under the "RE" scenarios in terms of area of cultivated crops leads to significant increase of fallow land in modelled results (Figure 5). However it needs to be mentioned that prices for agricultural products in all considered scenarios were fixed at the unchanged level. In such case model reaction to the increase of fallow land area can be interpreted as maximum value. In case of flexible approach (implemented market reaction and increase of prices for at least several agricultural commodities), the increase of fallow land area would be limited.

Figure 5. Area of fallow land within scenarios [thousand ha]



Source: CAKE/KOBiZE own study

Figure 6. Changes in size of animal activities in selected scenarios [BAS=100%]



Source: CAKE/KOBiZE own study

54. Animal production plays an important role in GHG emissions from agriculture. The most significant impact of emission reduction measures in regard to existing herd sizes is made on cattle. Therefore the largest impact reflected by the herd size decrease can be observed in case of extensive beef cattle, which has significant share in the GHG

emission, being rather low profitable animal activity, usually maintained on marginal land areas.

55. As the volumes of extensive beef cattle are reduced, the share of beef produced with intensive production increases. The reason is that the intensive production generates less GHG emission per unit produced. In the most restrictive RE20 scenario the overall number of beef cattle is reduced by ca. 40%. Due to this reduction the share of intensive beef cattle is increasing to 43% (compared to the 31% in baseline scenario – Table 3).

56. Similar pattern of changes could be observed in case of dairy cattle. Number of dairy cows is reduced slightly over 20% in RE20 scenario, also primarily due to reduction of extensive production.

Table 4. Scale and structure of animal activities [thousand LU]

Scenario	Technique	Beef cattle	Dairy cows	Pigs	Poultry for meat	Poultry for eggs
BAS	Intensive	684.4	920.1	970.9	614.4	114.1
	Extensive	1535.8	1463.3	1910.2	376.7	527.7
RE5	Intensive	655.0	882.7	957.9	613.8	114.0
	Extensive	1332.9	1352.5	1880.0	375.7	525.7
RE10	Intensive	625.5	845.1	944.8	613.2	113.8
	Extensive	1128.6	1240.9	1849.6	374.7	523.8
RE20	Intensive	572.3	777.4	921.3	612.1	113.4
	Extensive	761.3	1040.3	1795.0	373.0	520.2
N10	Intensive	685.9	921.2	974.2	615.0	114.3
	Extensive	1551.1	1470.4	1917.8	377.6	529.6
N20	Intensive	687.4	922.3	977.5	615.6	114.5
	Extensive	1566.3	1477.5	1925.4	378.6	531.5
ETS15	Intensive	670.7	902.7	964.9	614.1	114.1
	Extensive	1441.5	1411.7	1896.4	376.2	526.9
ETS20	Intensive	637.5	860.3	950.4	613.5	113.9
	Extensive	1212.6	1286.6	1862.8	375.2	524.8

Source: CAKE/KOBiZE own study

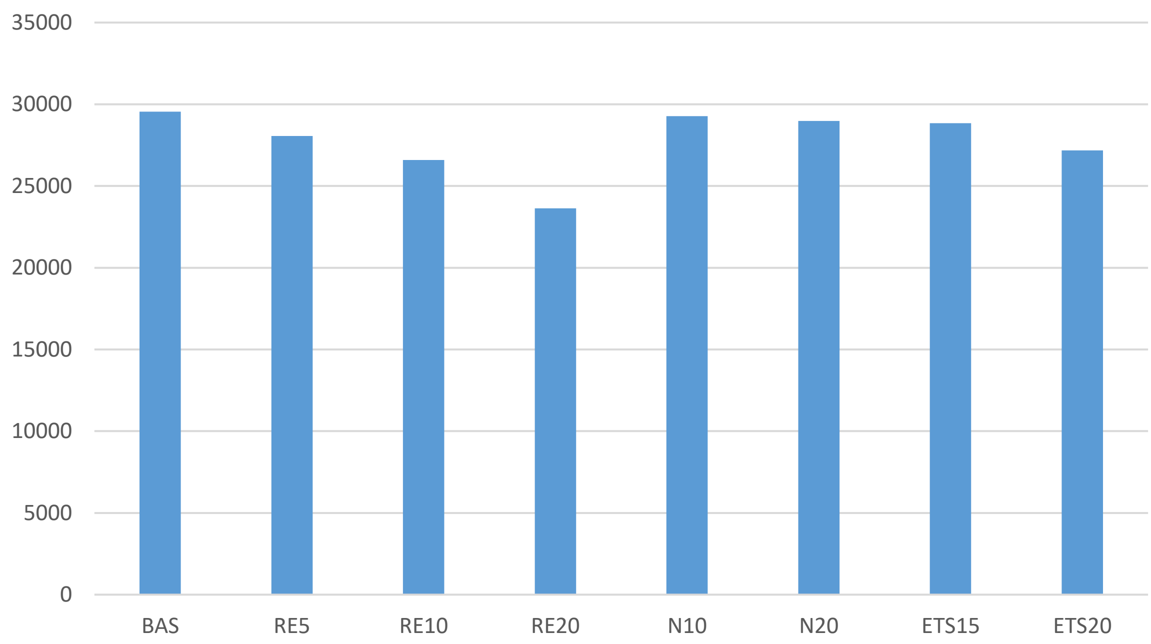
57. In case of N20 scenario, which assumes introduction of fertiliser tax, a small increase of animal production can be observed. This is explained by slight increase of profitability due to higher value of natural fertilisers, which could serve as substitutes for the purchased mineral fertilisers.

58. In case of pig production the changes follow the pattern observed in case of cattle and dairy, yet are hardly noticeable and even in case of GHG reduction by 20% (RE20) the herd size drops less than 5%. GHG emission generated by poultry production are

relatively low, especially when compared to value of production, thus in all scenarios poultry herd size remains unchanged. As it was mentioned in the previous section in regard to crop production, the scales in all scenarios have been solved using the price levels. However it might be expected that in case of increased demand for poultry products, resulting in higher prices, the herds could become even slightly larger than in the baseline year.

59. The overall effects of measures implemented within constructed scenarios on total volumes of GHG emissions are presented in the Figure 7.

Figure 7. Total volumes of GHG emissions from agriculture within all scenarios [kt CO_2eq]*



* based on IPCC methodology

Source: CAKE/KOBiZE own study

60. As it was expected the highest reduction of emissions is observed in RE20 scenario, where it was constrained by scenario assumptions. In case of overall greenhouse effect such assumption seems quite effective, however it should be noted that it would be difficult to implement, as carrying out detailed calculations according to IPCC guidelines in all existing farms would entail significant bureaucratic burden.

61. Scenarios introducing economic measures aimed at GHG emission decrease like the nitrogen tax (N10, N20) and emission tax (ETS15, ETS20) are less efficient in regard to such mitigation. Even if it would be assumed the agricultural sector could be treated similarly to other ETS sectors with effective charging of farmers for emitted GHG, it

would still lead to reduction of emissions less significant compared to RE20 scenario. This proves that significant reduction of GHG emissions in agriculture (measured based on IPCC methodology) is a relatively difficult task.

62. Also, applying economic pressures to achieve GHG reduction (introduction of N taxes, ETS payments) would drive the increase of food prices, which could void the expected effects of these measures. Detailed analysis of this issue is not captured within the presented results.

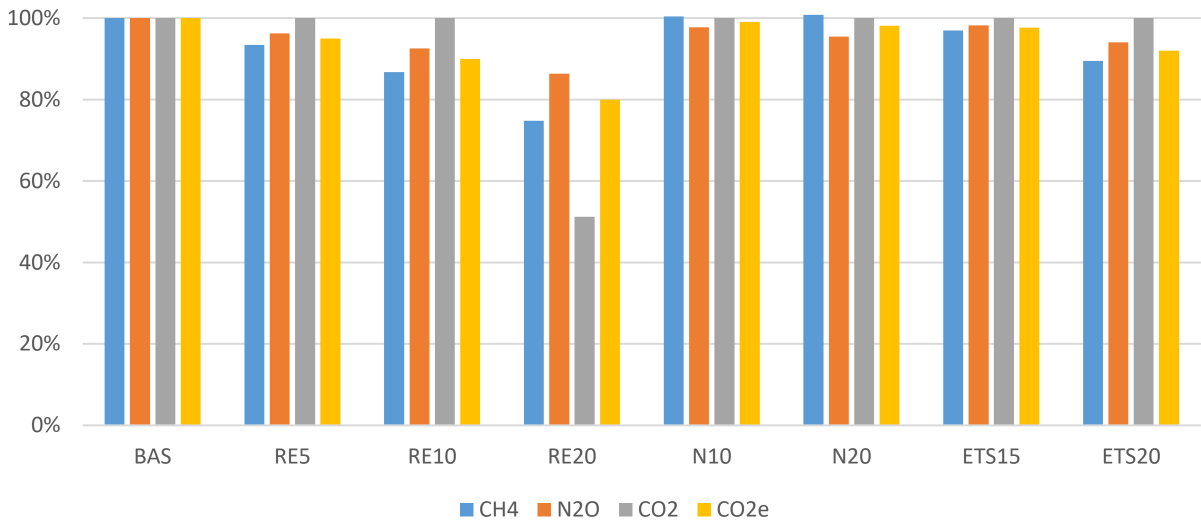
Table 5. Sources of GHG emissions within all scenarios [kt CO_2eq]

Scenario	Total	Enteric fermentation	Manure management	Soil management	Other
BAS	29540.1	12407.2	3635.5	12754.4	743.0
RE5	28063.1	11547.4	3463.3	12309.4	743.0
RE10	26586.1	10682.0	3289.9	11871.2	743.0
RE20	23632.1	9125.6	2978.0	11147.9	380.5
N10	29264.5	12460.7	3649.5	12411.2	743.0
N20	28988.9	12514.2	3663.5	12068.1	743.0
ETS15	28851.8	12007.0	3555.5	12546.3	743.0
ETS20	27181.8	11036.2	3361.2	12041.4	743.0

Source: CAKE/KOBiZE own study

63. It needs to be mentioned that reduction in the emissions of particular GHG, and thus the structure of GHG from agriculture strongly depends on introduced scenarios, which is clear from the results presented in Figure 8 and Table 5.

Figure 8. Reduction of main GHG emissions within all scenarios [BAS in kt CO_2eq; other: BAS=100%]



Source: CAKE/KOBiZE own study

64. In case of nitrogen tax introduction the highest decrease could be observed in case of N_2O emissions, as applying mineral fertilisers is one of its major drivers.

Table 6. Emissions of main GHG within scenarios [kt]

Scenario	CH_4	N_2O	CO_2	CO_2eq
BAS	559.9	49.7	743.0	29540.1
RE5	523.0	47.8	743.0	28063.1
RE10	485.8	46.0	743.0	26586.1
RE20	418.9	42.9	380.5	23632.1
N10	562.3	48.5	743.0	29264.5
N20	564.6	47.4	743.0	28988.9
ETS15	542.7	48.8	743.0	28851.8
ETS20	501.0	46.7	743.0	27181.8

Source: CAKE/KOBiZE own study

65. The RE5 and RE10 scenarios with constrained reduction have similar pattern of reduction of particular GHG. In both cases model is trying to minimise the costs incurred due to emission mitigation, thus activities providing highest income per unit of emission are preferred by farmers. Only in the RE20 scenario model results indicate reduction of urea use, which leads to decrease of CO_2 emission. Yet total withdrawal of urea from agricultural production sounds rather unrealistic in present conditions, it can serve as

an indicator that achievement of more ambitious reduction goals could potentially lead to decrease of urea use.

66. Overall, the CO_2 emissions in agriculture have rather marginal role (2-3% of total GHG emitted in agriculture measured in CO_2eq). Therefore except the RE20 scenario, in all the other scenarios the carbon dioxide emissions are fixed. Primarily those emissions are the results of calcium carbonate and urea application. The first, as it could be considered as a kind of fixed cost aimed at maintaining the soil condition, due to quite significant acidification of soils in Poland, should not be reduced in practice[42]. The second source (urea application) could in theory be substituted by nitrates, however due to relatively low GWP of CO_2 and strong economic and agrotechnical reasons for using urea, it is not considered efficient. Therefore, in most scenarios it remains unchanged.

67. Yields change calculated by the model reflect changes according to the change of structure of production techniques. Under the conditions analysed within constructed scenarios the pressures on production efficiency regarding amount of production per unit of emission leads toward changes in yields. Expected changes of yields in considered scenarios are presented in the Table 6. In the baseline scenario the reference values are given in physical units, yet for the rest of the scenarios they are presented by indices showing changes in the yield levels.

Table 7. Relative changes of yields in comparison to BAS scenario [%]

Indicators	BAS	RE5	RE10	RE20	N10	N20	ETS15	ETS20
		Change in relation to BAS [%]						
GHG emissions	29540.09	-5.00	-10.00	-20.00	-0.93	-1.87	-2.33	-7.98
Milk yield [hl/LU]	53.95	1.23	2.65	5.79	-0.12	-0.24	0.55	2.04
Cattle meat yield [kg/LU]	441.53	2.20	5.02	12.63	-0.17	-0.33	0.96	3.77
Wheat yield [dt/ha]	45.70	-0.35	-0.68	-1.17	-0.26	-0.53	-0.16	-0.56
Other cereals yield [dt/ha]	31.24	-0.30	-0.57	-0.93	-0.21	-0.42	-0.14	-0.48
Sugar beats yield [dt/ha]	520.00	-0.47	-0.99	-2.01	-0.44	-0.91	-0.22	-0.78
Corn yield [dt/ha]	47.10	-0.60	-1.22	-2.37	-0.47	-0.98	-0.28	-0.98

Source: CAKE/KOBiZE own study

68. The changes in the yields presents a clear picture of the way in which mitigation measures are likely to be applied in the agricultural sector. In scenarios constraining overall emission (RE) and introducing additional costs connected with the emission (ETS) the cattle production (both dairy and beef) is shifting towards being more

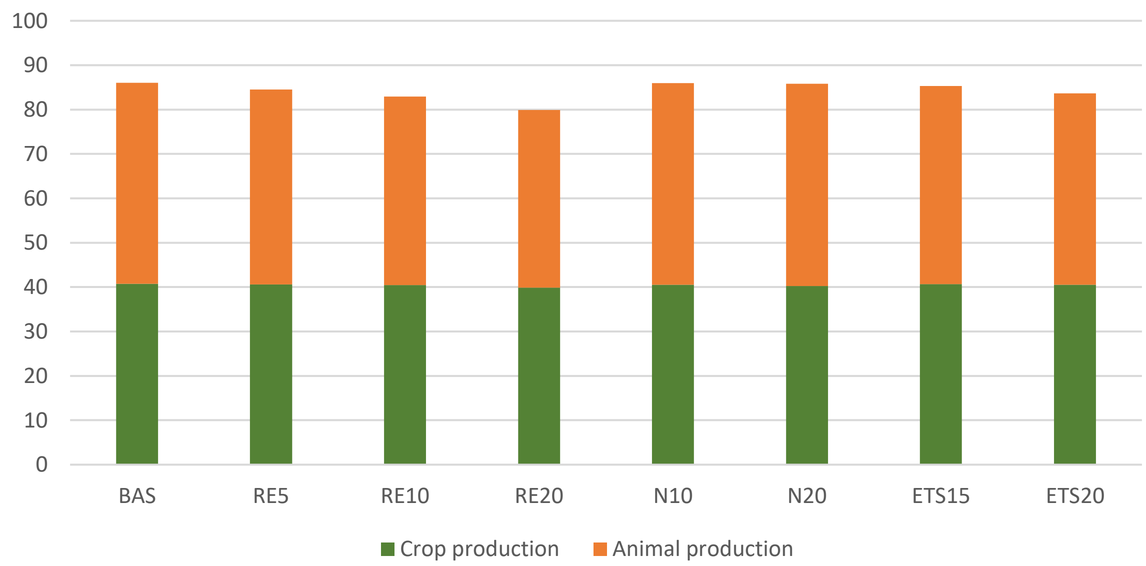
[42] MAFE Expertise - citation

intensive. Additionally, what was presented on Figure 6, the physical number of animals is reduced. However, the drop of production is less significant than the drop of emissions. It is clearly visible in case of dairy production. In case of nitrogen tax scenarios (N10, N20) the direction of changes is opposite. More expensive purchased mineral fertilisers might be at least to some extent substituted by manure, thus the value of the manure is increasing in comparison to the baseline. As this scenario does not constrain the GHG emission from animal production, it is leading to slight increase in share of extensive animals, which are producing relatively high amounts of manure.

69. In case of crop production the changes are not that significant, but their pattern clearly indicates some regularities. The yields of fertiliser intensive crops like sugar beets, corn and to some extent wheat are strongly decreasing (compared to other crops) within all scenarios. The reason is the pressure toward reduced use of mineral nitrogen-based fertilisers, which are one of the key drivers of agricultural GHG emissions. This is not as visible in case of other crops, which are usually grown with much lower doses of fertilisers (e.g. other cereals).

70. Decrease of crop area and yields leads to reduction in amount of GHG emitted along with the quantity of produced commodities, which are also decreasing. This is expressed by decrease in value of produced agricultural commodities. The model used in this version of analysis does not include a market module, so the prices of commodities are assumed to be fixed in all scenarios, thus value of production is reflecting overall changes in volumes produced. This is presented in the Figure 9 and in Table 7.

Figure 9. Total value of agricultural production [bln PLN]



Source: CAKE/KOBiZE own study

71. The largest decrease of production could be observed in RE20 scenario. It clearly shows that process of emission reduction in agriculture using presently known and used technologies is highly complex and inevitably leads to overall decrease in produced volumes. However it should be noted that emissions generated by agricultural sector decrease at faster pace compared to the production processes.

Table 8. Value of production and its changes for main groups of agricultural products [BAS in bln PLN, other scenarios BAS=100%]

	BAS	RE5	RE10	RE20	N10	N20	ETS15	ETS20
Cereals	17.28	99.69	99.17	96.87	99.07	98.14	99.85	99.50
Other field crops	9.62	99.34	98.62	97.01	99.24	98.47	99.69	98.94
Horticultural crops	13.83	100.05	100.09	100.10	100.02	100.04	100.02	100.08
Crop production	40.73	99.73	99.35	98.00	99.43	98.86	99.87	99.56
Beef cattle	5.94	91.36	82.67	67.03	100.60	101.20	95.98	86.23
Dairy cows	14.16	94.94	89.84	80.68	100.22	100.45	97.64	91.92
Pigs	10.09	98.53	97.04	94.37	100.37	100.74	99.32	97.68
Poultry	15.13	99.82	99.64	99.32	100.18	100.35	99.92	99.74
Animal production	45.32	96.90	93.78	88.16	100.29	100.58	98.56	95.06

Source: CAKE/KOBiZE own study

72. The crop production is much less vulnerable in case of constraints applied towards emissions. Only in the N20 scenario (20% increase of prices for nitrogen-based fertilisers) the drop in crop production was noticeable, however rather low (~1%).

73. Other crop activities are invulnerable to the restrictions regarding GHG emissions. The most evident is the example of horticultural crops, which are characterized by high economic value added and relatively low emission.

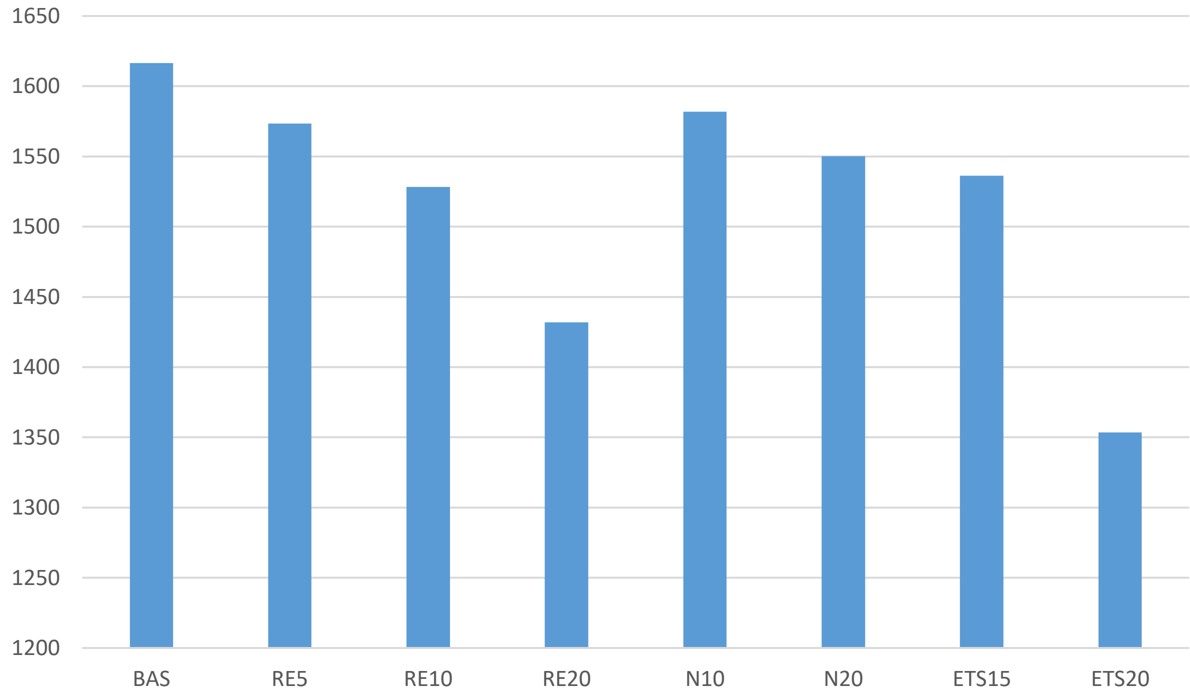
74. The sharpest drop in production could be observed in case of beef cattle and dairy cattle. In case of the most restrictive scenario (RE20) assuming 20% GHG reduction, the beef cattle production is decreasing by 33%, while the milk production – by 20%.

75. The most invulnerable to GHG reduction measures is the poultry production, and to some extent the production of pigs. In these cases the production is not decreasing significantly along with the set reduction of GHG emissions. Generally, the GHG emissions from the poultry production are relatively low, as the enteric fermentation is minimal and manure management does not lead to GHG emissions due to low water content in the poultry manure. The overall emissions from pig production is higher compared to poultry, however relatively lower compared to beef and dairy cattle. It is also important to notice than due to the drop in cattle production in the scenarios strongly constraining emissions, the demand for the manure is increasing, thus poultry

and pig production help to compensate this misbalance by avoiding excessive purchases of nitrogen-based mineral fertilisers.

76. All of the changes in production and emissions presented above are driven by economic factors. The model is aiming to find optimised structure of production activities, which should provide maximum economic output in given conditions. Thus the changes of income need to be analysed in order to assess economic costs of emission reductions. The average income per 1 ha of UAA within all developed scenarios are presented in Figure 10.

Figure 10. Average agricultural income in relation to UAA [PLN/ha]



Source: CAKE/KOBiZE own study

77. Introducing any restriction in optimisation model is likely to decrease the value of objective function. The effect of this statement can be observed on presented diagram (Figure 10). The stronger the constraints the higher income decrease is expected. In case of the RE5 scenario the reduction of GHG emissions by 5% causes drop of the farmers' income by 2.7%, while 4 times higher reduction (implemented through RE20) results in 11.4% drop of income. It reveals that small reduction could be achieved relatively easy, while any attempt to introduce more ambitious reduction causes more than proportional decrease of farm income (more in Table 8).

Table 9. Income (per farm and per ha) within all scenarios

	BAS	RE5	RE10	RE20	N10	N20	ETS15	ETS20
Per farm [thousand PLN]	16.4	15.9	15.5	14.5	16.0	15.7	15.6	13.7
Per ha [PLN/ha]	1616.6	1573.3	1528.2	1432.0	1581.8	1550.2	1536.4	1353.6
BAS=100%	100%	97.3%	94.5%	88.6%	97.8%	95.9%	95.0%	83.7%
GHG emission [BAS=100%]	100%	95.0%	90.0%	80.0%	99.1%	98.1%	97.7%	92.0%

Source: CAKE/KOBiZE own study

78. Scenarios constructed assuming reduction of GHG emission through introduction of economic measures show even higher impact on farm profitability. Introduction of nitrogen-based tax results in relatively small GHG reductions (~2.5% in N20), while income drop is higher than in the RE5 scenario (which is assuming twice as high emission reduction). This dependency is even more evident in case of ETS scenarios. In the last scenario analysed (ETS20) the reduction of the emission by slightly more than 10% causes decrease of farm income by 18%.

79. Both "tax scenarios" (N10, N20 - introducing increased costs of fertilisers) and ETS scenarios (ETS15, ETS20 - introducing charges for emission allowances) induce some adjustments, including decreasing production volumes or production intensity, but also inevitably leading to increase of costs. In case of the N20 scenario the expenditures for fertilisers are growing from PLN 4.266 bln in BAS to PLN 4.336 bln, with simultaneous reduction of purchased fertilisers by 15%. This leads to sharp decrease of produced volumes of commodities.

80. This effect is even more evident in case of two last scenarios (ETS15 and ETS20). Apart of costly implementation process, the farmers would need to pay additional fee for the excess emitted GHG. In the less restrictive ETS15 scenario, the agricultural holdings, after adjusting production and reducing emissions, would still have to annually spend PLN 0.85 billion on purchase of emission allowances, which gives on average ca. 60 PLN per ha and ca. PLN 600 per average Polish farm.

81. In a more restrictive scenario (ETS20), the potential amount of expenditures on emission allowances would rise to PLN 2.69 bln at country scale, which would mean an expense of PLN 1,900 per average farm and PLN 190 per ha of UAA. These are close to nearly 10% of average farm income earned in Polish agricultural sector.

6.2. Farm type approach results

82. Results presented in the previous section, as it was emphasized, assumes perfect allocation of all resources and optimal allocation of abatement measures. However, taking into consideration different sizes and level of specialisation of farms in Poland such perfect adjustment is rather unlikely in short-run (possible in long-term). To model more realistic reaction on assumed constraints in the scenarios, the model has been also calculated for different farm types. Delimitation of farm types based on criteria used in FADN system, such as type of farming and economic size. The total population of Polish farms were divided into 18 types of commercial farms and 1 type representing all semi-subsistence and hobby farms. Number of farms represented by each of the distinguished farm types (Table 9).

Table 10. Number and size of farms within analysed EPICA farm types

Farm size/type of farming	Cereals	Other crops	Cattle	Mixed	Granivores**	Other
Semi subsistence (SO* < 4 ths EUR)	689110					
Small (SO 4-25 ths EUR)	55136	95719	140049	195451	42321	51715
Medium (SO 25-100 ths EUR)	8309	12892	55074	23023	18986	13730
Large (> 100 ths EUR SO)	2693	1548	1989	2660	6442	3149

* SO standard output – estimated value of agricultural production.

** animals fed with cereals (mostly pigs and poultry).

Source: CAKE/KOBiZE own study

83. It needs to be stated that even though semi-subsistence farms number is close to 700 thousand (which is nearly half of farms in Poland), they cover less than 10% of crop production and ca. 5% of animal production. Due to relatively low intensity of production the emission of GHG generated even by such number of farms is not significant.

84. On the opposite, the 1.3% of largest farms is responsible for 35% of total production, covering 20% of land and keeping over 30% of animals. These are responsible for ca. 23% of GHG emissions form agricultural sector in the baseline year.

85. Short characteristics of land resources, structure of main crops and number of animals kept in across defined farm types are presented in the Table 10.

Table 11. Main crop area and number of animals in defined farm types [ha or LU per average farm]

Farm type	Crop production [ha]						Animal production [LU]				
	Cereals	Other field crops	Horticultural crops	Fodder crops	Permanent grassland	Total	Beef cattle	Dairy cows	Pigs	Poultry	Total
Cattle large	27.58	8.18	0.02	35.82	36.48	**108.07**	44.10	76.40	7.35	0.00	**127.86**
Cattle medium	8.46	0.58	0.05	6.90	12.24	**28.23**	10.65	19.73	1.87	0.04	**32.28**
Cattle small	4.03	0.23	0.03	1.48	5.16	**10.93**	3.99	4.05	1.04	0.15	**9.24**
Cereals large	273.95	111.37	0.12	3.63	14.20	**403.27**	5.83	3.87	3.42	0.00	**13.13**
Cereals medium	44.04	15.62	0.12	0.44	1.87	**62.09**	0.80	0.08	1.22	0.06	**2.16**
Cereals small	11.24	2.14	0.04	0.08	0.84	**14.34**	0.16	0.03	0.20	0.06	**0.44**
Other crops large	68.42	42.60	15.55	3.49	7.67	**137.73**	2.67	0.89	6.09	0.32	**9.97**
Other crops medium	16.66	8.05	4.97	1.11	2.65	**33.44**	1.41	0.30	1.25	0.12	**3.08**
Other crops small	5.17	1.57	1.16	0.30	0.87	**9.07**	0.28	0.10	0.50	0.07	**0.94**
Mixed large	195.76	73.15	2.54	23.81	63.43	**358.70**	54.45	76.12	82.92	0.00	**213.50**
Mixed medium	19.60	5.20	0.35	2.18	4.38	**31.71**	6.44	3.71	12.23	0.22	**22.60**
Mixed small	6.09	0.66	0.13	0.42	2.23	**9.52**	1.86	0.89	2.33	0.17	**5.25**
Other large	6.60	1.97	12.79	0.11	0.37	**21.85**	0.18	0.02	0.30	0.00	**0.50**
Other medium	2.68	0.68	5.33	0.14	1.64	**10.47**	0.56	0.13	0.13	0.05	**0.87**
Other small	1.00	0.29	3.30	0.09	1.02	**5.70**	0.40	0.04	0.02	0.00	**0.47**
Granivores large	34.11	4.42	0.03	1.84	2.54	**42.95**	1.53	0.49	80.45	221.84	**304.31**
Granivores medium	13.91	1.13	0.05	0.95	2.25	**18.30**	3.17	0.87	30.98	4.86	**39.88**
Granivores small	5.24	0.19	0.02	0.23	1.71	**7.39**	1.42	0.48	7.86	0.71	**10.47**
Semi-subsistence	1.91	0.21	0.04	0.13	0.70	**2.98**	0.13	0.06	0.17	0.01	**0.37**

Source: CAKE/KOBiZE own study

86. Applying the farm type approach allows to present result changes for each considered farm type, but also in the aggregated form on the national level. The data in Table 11 presents results of the farm type approach at the aggregated national level.

Table 12. Area of main crop groups within all scenarios – aggregated area of all farm types [thousand ha]

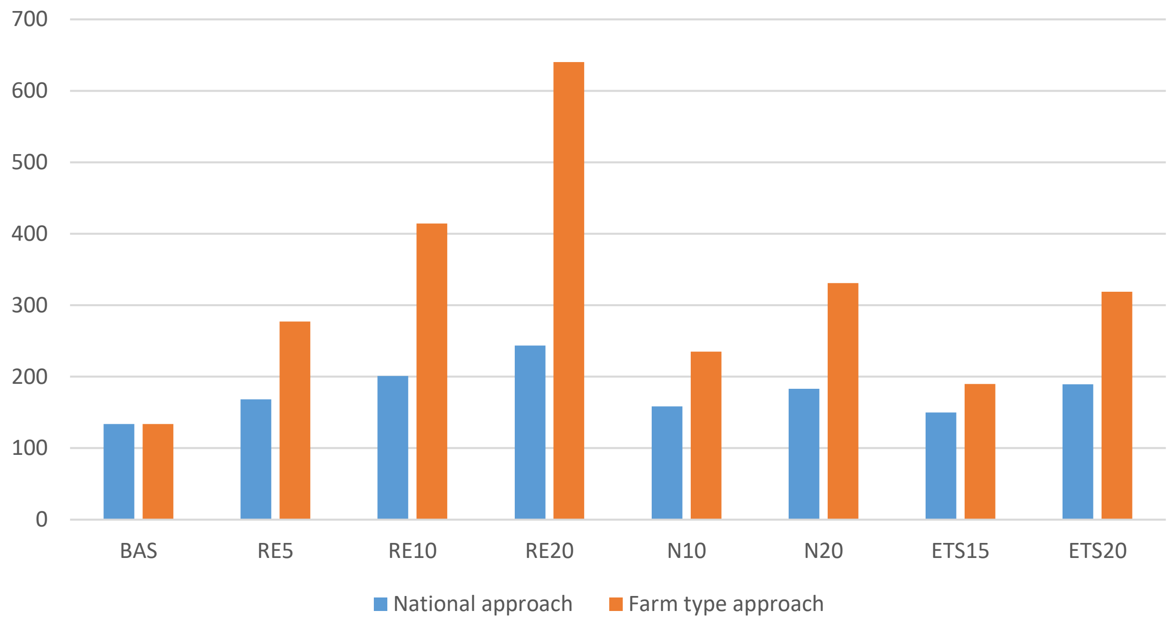
Scenario	Technique	Cereals	Fodder crops	Permanent grassland	Horticultural crops	Other crops	Fallow land
BAS	Intensive	1714.3	336.8	1511.3	163.1	681.0	133.8
	Extensive	6201.3	717.8	1581.4	402.8	941.1	
RE5	Intensive	1668.2	326.3	1443.8	162.9	669.4	277.4
	Extensive	6105.6	682.5	1717.0	402.9	928.8	
RE10	Intensive	1625.9	315.4	1376.8	162.6	659.0	414.5
	Extensive	5998.0	670.9	1836.9	403.0	921.7	
RE20	Intensive	1532.0	286.3	1233.4	162.0	634.6	640.3
	Extensive	5833.3	644.1	2100.0	403.2	915.6	
N10	Intensive	1677.4	322.8	1407.0	163.0	671.9	235.3
	Extensive	6124.0	753.1	1697.6	402.9	929.7	
N20	Intensive	1640.2	308.7	1326.9	162.8	662.8	331.0
	Extensive	6038.0	769.0	1818.6	403.0	923.6	
ETS15	Intensive	1697.5	329.9	1471.9	163.0	676.6	189.7
	Extensive	6175.3	692.0	1652.2	402.9	933.7	
ETS20	Intensive	1657.9	308.4	1353.9	162.8	666.3	319.1
	Extensive	6094.5	686.6	1805.2	403.0	926.9	

Source: CAKE/KOBiZE own study

87. Comparing pattern of changes with the national approach results (Table 2) it should be noticed that the impact of the scenario regarding GHG emission reduction is slightly stronger. In general the area of cultivated crops in each scenario is a bit smaller due to a higher share of fallow land (Figure 11).

88. The higher are the assumed emission reductions within the scenarios, the higher are the differences between the approaches. In the RE20 scenario the fallow land area in farm type approach is ca. 5 times higher compared to baseline, while in the national approach it is only 2 times higher. It is the most visible result of applying 20% emission reduction on the farm type level. The scale of possible adjustments in a particular farm type (which is, for example, specialising in certain production to a lower extent compared to national average) can differ, as within more ambitious emission targets the pressure for fallowing unused land is stronger.

Figure 11. Area of fallow land within all scenarios (aggregated for all farm types) [thousand ha]



Source: CAKE/KOBiZE own study

Table 13. Structure of animal activities and aggregated numbers of animals within all farm types [thousand LU]

Scenario	Technique	Beef cattle	Dairy cows	Pigs	Poultry for meat	Poultry for eggs
BAS	Intensive	684.4	920.1	970.9	615.6	114.2
	Extensive	1535.8	1463.3	1910.2	377.9	527.8
RE5	Intensive	657.6	894.0	949.0	613.5	113.6
	Extensive	1297.8	1364.9	1821.4	373.7	518.7
RE10	Intensive	630.4	868.1	926.7	611.4	112.9
	Extensive	1063.9	1267.6	1731.3	369.4	509.4
RE20	Intensive	580.2	810.4	878.8	607.0	111.5
	Extensive	677.8	1093.5	1543.6	360.8	490.8
N10	Intensive	685.9	921.0	973.7	615.7	114.3
	Extensive	1567.0	1472.3	1918.3	378.0	528.2
N20	Intensive	687.4	921.8	976.5	615.8	114.3
	Extensive	1597.5	1481.2	1926.4	378.0	528.5
ETS15	Intensive	670.5	900.3	962.4	615.1	114.1
	Extensive	1297.8	1395.6	1880.0	376.9	525.5
ETS20	Intensive	636.9	858.4	941.6	613.8	113.7
	Extensive	1016.8	1273.7	1806.8	374.3	519.9

Source: CAKE/KOBiZE own study

89. Changes in scale and structure of animal activities are presented in the Table 12. Regarding the animal production the pattern of changes is in general similar to the one observed within the national approach. A strong decrease of cattle activities (mostly beef, but also dairy) is noted.

90. However the decrease of beef cattle within the farm type approach is even stronger than within the national approach. The cattle farms usually have relatively simple structure. Focusing of animals the supplementing crop production is typically concentrated on growing permanent grassland and fodder crops (in some cases only this approach is feasible), therefore the adjustment of such farm activity is limited to shifts (decrease) of animal production. However, in spite of stronger decrease of beef cattle the number of dairy cows is decreasing slightly slower in farm type approach compared to national approach. This could be explained by surplus of fodder left after giving up beef cattle production, which otherwise has no use. It needs to be pointed out that income per unit of emission from dairy cattle is higher compared to beef cattle. Spare resources acquired due to giving up beef cattle production in few farm types are utilised by dairy cattle. This is what causes the reduction of dairy cows quantity in farm type approach being slower compared to the national approach.

91. Another reason to analyse effects of constructed scenarios separately for the farm types is that the GHG emissions are not equally distributed among them. Thus the effects of assumed reduction measures would be different in each farm type. The data on distribution of the GHG emission among farm types along with the summary of their resources and economic performance are presented in the Table 13.

92. Nearly half of GHG emissions is coming from the cattle farms, primarily the medium ones, which are emitting equivalent of 7 kt CO_2eq, which is more than quarter of overall emissions from Polish agriculture. Those farms have relatively low share in number of units, however due to the production scale (ca. 28 ha and 32 LU per farm) they occupy over 10% of agricultural land and keep ca. 20% of animals. Their emissions are relatively high in relation to used resources and generated income.

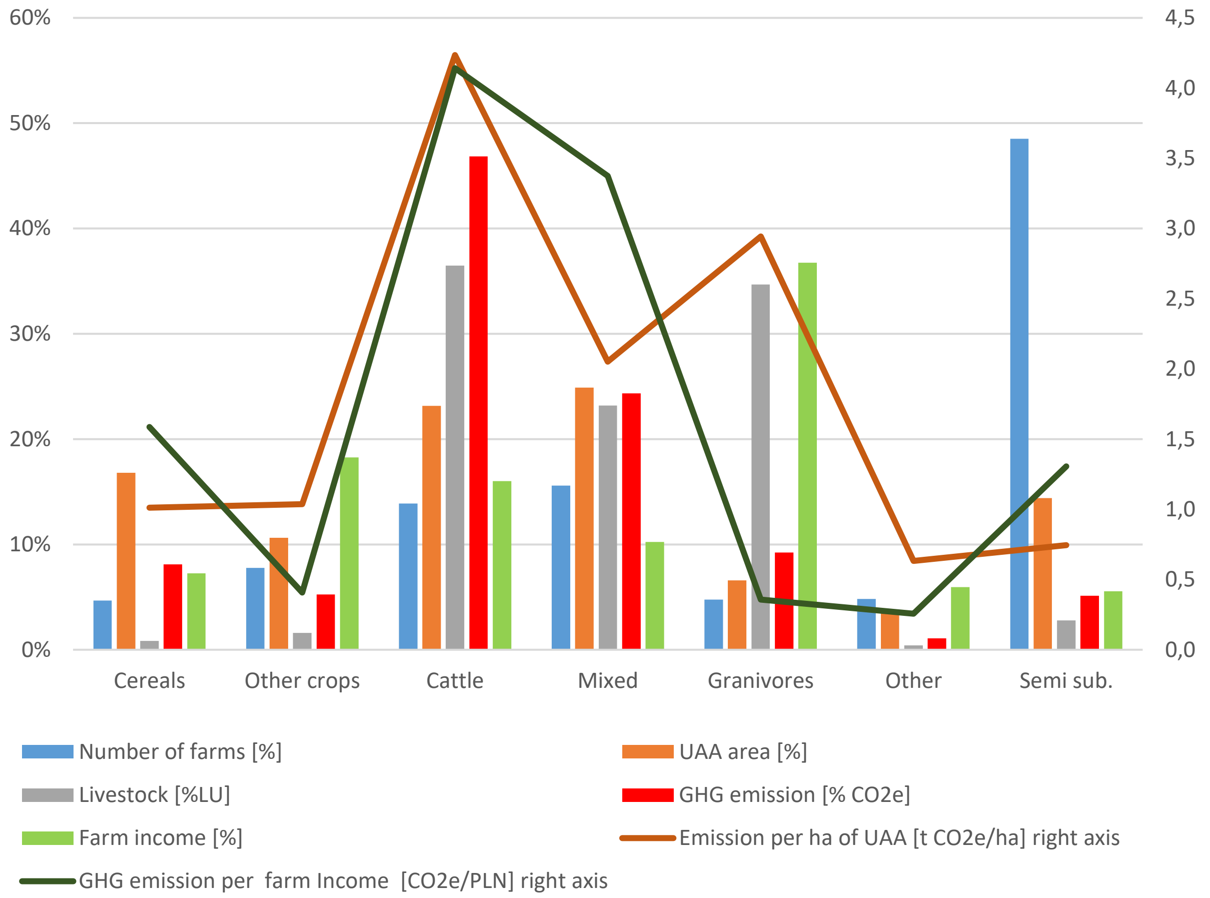
93. The cattle farms also represent high emissions per hectare of land, which is an obvious consequence of cattle production. Even in the large scale milk production, which is usually perceived as a profitable activity, the level of emissions calculated per PLN of income is certainly the highest in the cattle farms due to high overall emission. Also the large mixed farms fit this characteristic, as they keep significant numbers of cattle. These farms, along with generation of one PLN of income, also emit ca. 4 kg of CO_2eq. The shares in number of farms, land area, animal numbers and income are presented in the Figures 12 and 13.

Table 14. Characteristics of farm types (divided according to size) regarding their shares in land area, animal numbers, income and emissions in the baseline year

Farm type	Shares in, %					GHG emissions	
	Number of farms	Land area	Animals [LU]	GHG emission	Farm income	Land UAA [t CO_2eq/ha]	Farm Income [kg CO2e /PLN]
Cattle large	0.14	1.5	2.8	4.4	1.3	6.04	4.72
Cattle medium	3.88	10.9	19.5	26.4	10.5	5.07	3.58
Cattle small	9.86	10.7	14.2	16.1	4.3	3.13	5.35
Cereals large	0.19	7.6	0.4	4.2	3.8	1.14	1.55
Cereals medium	0.59	3.6	0.2	1.8	2.4	1.02	1.03
Cereals small	3.88	5.5	0.3	2.2	1.0	0.83	3.05
Other crops large	0.11	1.5	0.2	1.0	3.3	1.38	0.42
Other crops medium	0.91	3.0	0.4	1.7	7.4	1.17	0.32
Other crops small	6.74	6.1	1.0	2.6	7.5	0.88	0.48
Mixed large	0.19	6.7	6.2	8.9	3.0	2.77	4.23
Mixed medium	1.62	5.1	5.7	5.3	2.6	2.17	2.87
Mixed small	13.76	13.1	11.3	10.2	4.6	1.63	3.11
Other large	0.22	0.5	0.0	0.2	1.9	0.99	0.17
Other medium	0.97	1.0	0.1	0.3	1.7	0.71	0.28
Other small	3.64	2.1	0.3	0.5	2.3	0.51	0.31
Granivores large	0.45	1.9	21.5	4.3	30.7	4.69	0.20
Granivores medium	1.34	2.4	8.3	2.9	4.7	2.47	0.87
Granivores small	2.98	2.2	4.9	2.0	1.3	1.92	2.15
Semi-subsistence	48.53	14.4	2.8	5.1	5.6	0.74	1.31
POLAND	100.00	100.00	100.00	100.00	100.00	2.09	1.42

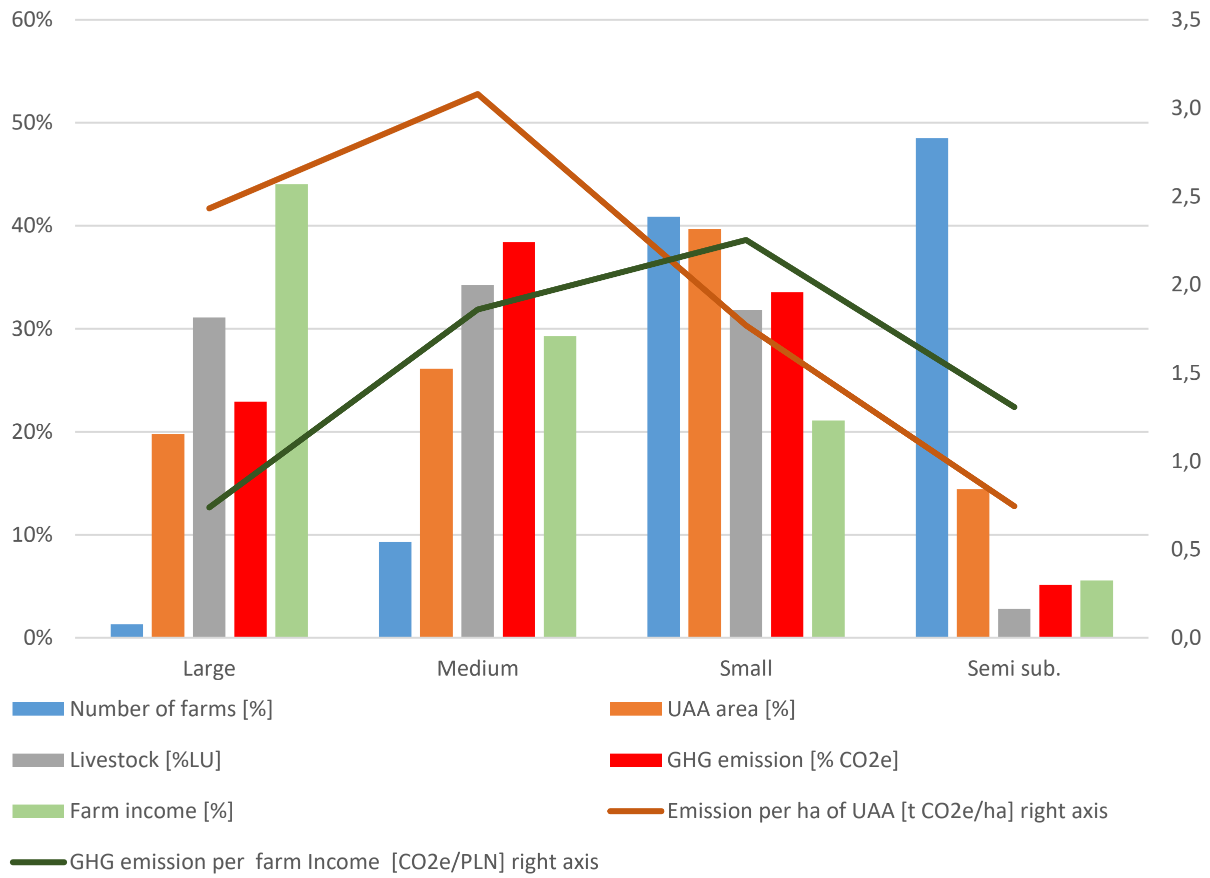
Source: CAKE/KOBiZE own study

Figure 12. Characteristics of aggregated farm types regarding their shares in land area, animal numbers, income and GHG emissions in the baseline year



Source: CAKE/KOBiZE own study

Figure 13. Characteristics of farm types regarding their shares in land area, animal numbers, income and GHG emissions in the baseline year (by farm size)



Source: CAKE/KOBiZE own study

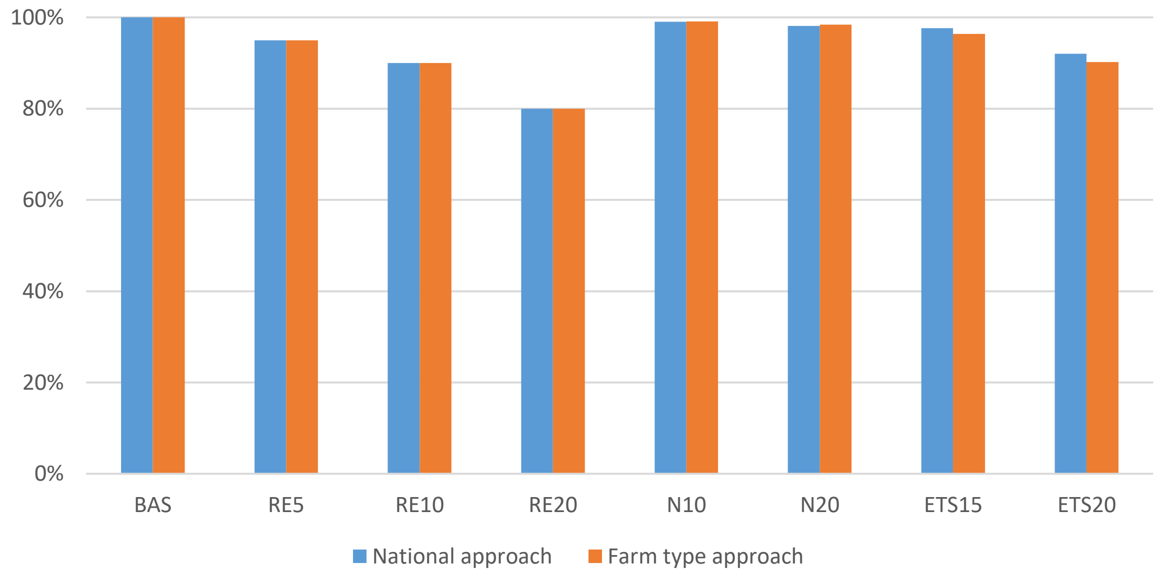
94. Much lower emissions could be observed in crop farms (cereals, other crops) and other farms. This is mostly due to low number of animals kept in those farms. However, even in the granivore farms, where animal production is important and the share of total animals in Poland is ca. 33%, the GHG emissions are relatively low compared to cattle and mixed farms. In granivore farms generation of one PLN income causes only 0.4 kg of CO_2eq, which is comparable with cereal farms.

95. Analysing differences based on economic size of the farm it could be observed that in larger farms the GHG emissions per unit of income is much lower than in small farms. While highest emissions per ha of land could be observed in medium farms, due to higher livestock density.

96. Relation of the farm income to the emissions is crucial to find the compromise between one of the main goals of Common Agricultural Policy, which is providing viable income for farmers, as well as Climate Action, which aims to reduce GHG emissions.

97. Similarly as within the national approach, the overall emissions measured within the farm type approach are decreasing in all considered scenarios (Figure 14). In the "RE" scenarios the level of the reduction is a result of scenario assumptions, where each of the farm types is forced to decrease emissions by 5%, 10% and 20% respectively. In scenarios assuming introduction of tax (N10, N20) in both approaches the reduction level is similar, however in the N20 scenario within the farm type approach the reduction is slightly lower. It is an effect of not fully optimised use of manure, which is assumed to be utilised within the same farm type where it was produced, which causes higher GHG emission. In case of ETS scenarios the reduction of GHG emission in the farm type approach is greater than in case of national approach. It is a result of stronger impacts of taxation of GHG emission in farm types with less profitable activities. Those activities become unprofitable after taxation and need to be reduced, which is not the case within the analyses performed at the national average profitability level.

Figure 14. Changes of GHG emission from agriculture [BAS=100%]* – changes in analysed scenarios within national and farm type approaches



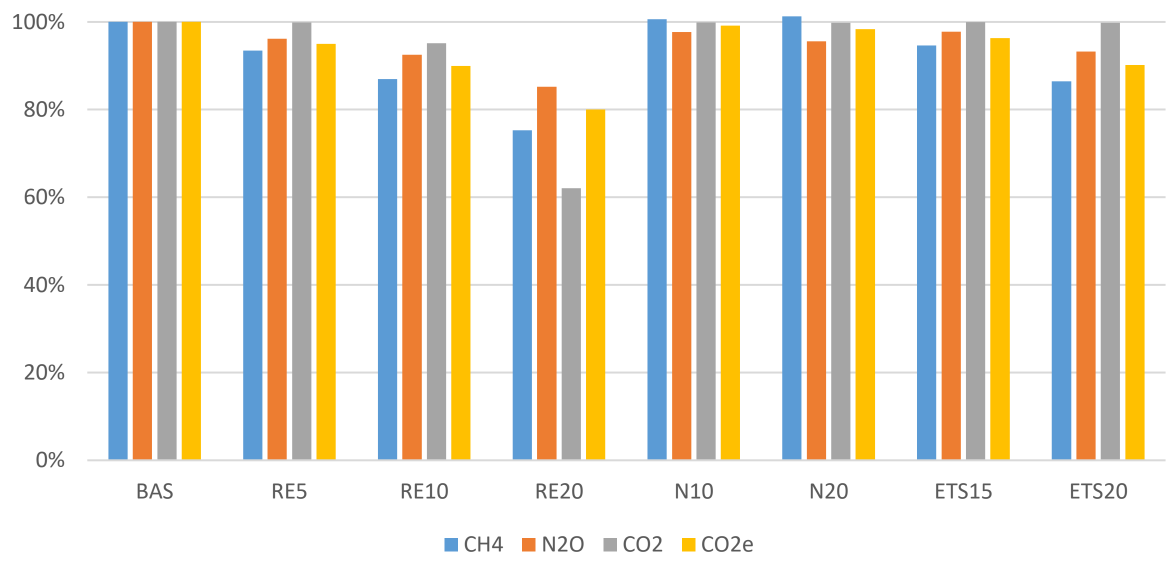
* based on IPCC methodology

Source: CAKE/KOBiZE own study

98. Not only the amount of GHG emissions in farm type approach is slightly different compared to national approach, but also there are some noticeable differences in their structure (Figure 15). In the national approach forcing the reduction of emissions (RE20 scenario) resulted in total withdrawal of urea and its substitution by nitrates. In farm

type approach some drop in CO_2 emissions could be observed already in the RE10 scenario, which was caused by partial substitution of urea in few of the farm types. The number of farms applying this mitigation measure is certainly greater in RE20 scenario, but even than some of farms are using urea. Even though the emissions from application of the urea are not the most significant source of the GHG emissions in Poland, this example shows differences between reactions of particular farm types to specific mitigation measures.

Figure 15. Reduction of emissions of main GHG within all scenarios [BAS in kt CO_2eq; other: BAS=100%]



Source: CAKE/KOBiZE own study

99. Using farm type approach could also provide results of emission reduction in each of analysed farm types. The N10 and N20 scenarios can be considered ineffective regarding reduction of GHG emission in large farms with intensive animal production, as their nitrogen from mineral fertilisers could be easily substituted by animal manure. So based on the nitrogen balances incorporated in the model it could be stated that increase of N prices in considered range in those farms do not lead to reduction in GHG emissions. On the other side in small cereal farms, which due to low scale and low productivity are not very profitable, and due to their marginal character of animal production they cannot substitute N fertilisers by animal, therefore their drop of GHG emissions in the N20 scenario is over 6.4%. This proves that taxation of N fertilisers could be only partially effective and would not always result in decrease of nitrogen use in each of the farm types.

100. In the ETS scenarios the result of taxation is different, which even in case of high price of allowances (ETS 20) does not necessarily lead to significant reduction in the national approach, it however could lead to significant reduction of GHG emissions in particular farm types. In case of large cattle farms and large mixed farms, which also keep high number of cattle, the model shows the reduction reaching 20% of GHG emissions.

Table 15. GHG emissions from different farm types within all scenarios [BAS in kt CO2e, other: BAS=100%]

Farm type	BAS [kt CO_2eq]	RE5	RE10	RE20	N10	N20	ETS15	ETS20
Cattle large	1285.7	95.0%	90.0%	80.0%	100.0%	100.0%	87.4%	78.1%
Cattle medium	7805.6	95.0%	90.0%	80.0%	99.4%	99.1%	97.4%	91.0%
Cattle small	4743.0	95.0%	90.0%	80.0%	99.0%	98.0%	96.9%	89.3%
Cereals large	1227.2	95.0%	90.0%	80.0%	98.9%	97.7%	98.8%	95.9%
Cereals medium	520.0	95.0%	90.0%	80.0%	96.8%	93.7%	98.2%	93.8%
Cereals small	649.6	95.0%	90.0%	80.0%	96.8%	93.6%	98.2%	93.8%
Other corps large	291.1	95.0%	90.0%	80.0%	98.2%	96.4%	98.7%	95.7%
Other corps medium	501.1	95.0%	90.0%	80.0%	97.5%	95.0%	98.2%	93.9%
Other corps small	760.2	95.0%	90.0%	80.0%	97.8%	95.7%	98.3%	94.5%
Mixed large	2615.5	95.0%	90.0%	80.0%	100.0%	100.0%	88.8%	80.5%
Mixed medium	1569.5	95.0%	90.0%	80.0%	99.3%	98.6%	97.8%	92.3%
Mixed small	3010.2	95.0%	90.0%	80.0%	98.9%	98.0%	97.3%	91.5%
Other large	67.5	95.0%	90.0%	80.0%	98.1%	97.0%	98.5%	96.8%
Other medium	101.1	95.0%	90.0%	80.0%	97.9%	96.7%	97.4%	93.7%
Other small	149.1	95.0%	90.0%	80.0%	97.5%	95.9%	97.1%	90.9%
Granivores large	1284.5	95.0%	90.0%	80.0%	100.0%	100.0%	98.7%	95.7%
Granivores medium	851.0	95.0%	90.0%	80.0%	99.7%	99.4%	97.4%	91.1%
Granivores small	594.5	95.0%	90.0%	80.0%	99.8%	99.5%	96.5%	88.1%
Semi-subsistence	1513.8	95.0%	90.0%	80.0%	98.5%	97.1%	98.3%	94.5%
POLAND Farm types average	29540.1	95.0%	90.0%	80.0%	99.1%	98.4%	96.3%	90.2%
POLAND whole country	29540.1	95.0%	90.0%	80.0%	99.1%	98.1%	97.7%	92.0%

Source: CAKE/KOBiZE own study

101. On the other side there are farm types classified as "other", which consist mostly of horticultural farms, where emission taxation does not lead to serious reduction of emissions. This could be explained by two factors. Those farms are usually quite profitable, so introduction of additional cost of allowances has limited impact on the business process, but also the fact that their basic emission is relatively low, thus quite difficult to decrease in the first place.

102. The yields in crop and animal activities in general within the farm type approach are similar to ones observed in the national approach. However, in case of animal production stronger pressure towards GHG emissions' reduction put also more pressure on intensification of production. In case of crop production it is not so evident, as the differences are quite small, but still the farm type approach results in higher average yields in all scenarios compared to the national approach.

Table 16. Relative changes of yields of aggregated farm types in comparison to BAS scenario [BAS=100%]

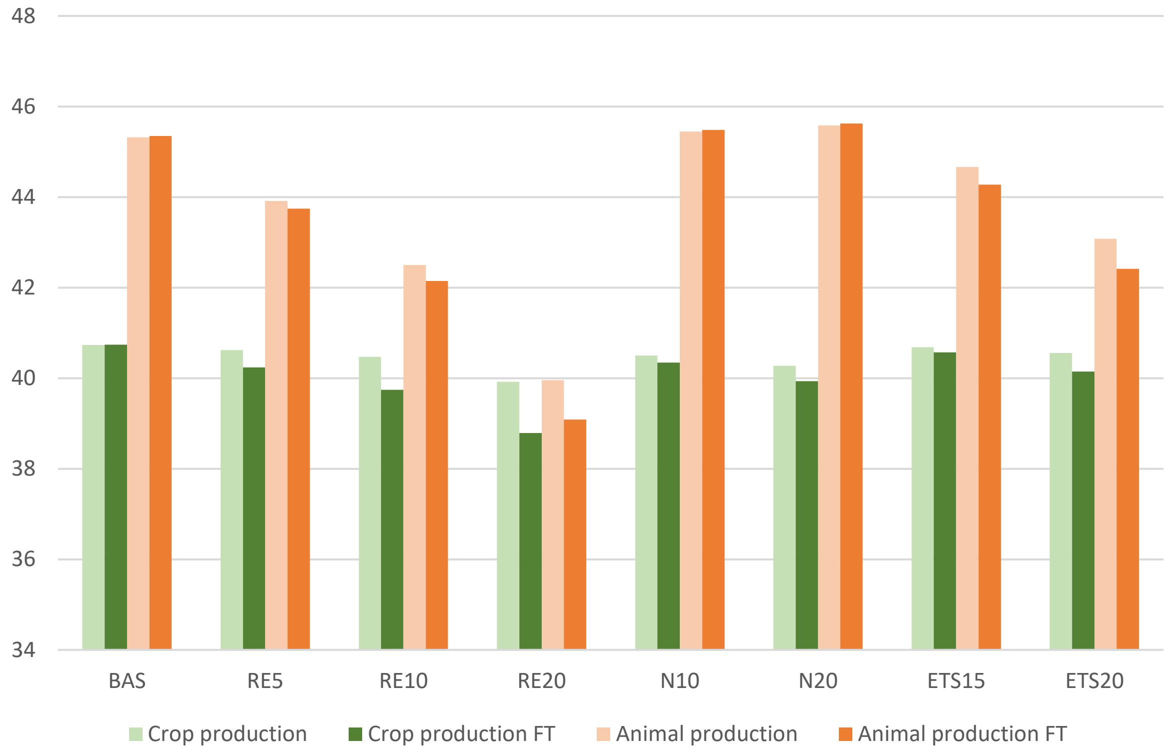
	BAS	RE5	RE10	RE20	N10	N20	ETS15	ETS20
GHG emission	29540.1	-5.00%	-10.00%	-20.00%	-0.85%	-1.62%	-3.65%	-9.79%
Milk yield [hl/LU]	53.95	1.35%	2.84%	5.50%	-0.17%	-0.34%	0.85%	2.30%
Cattle meat yield [kg/LU]	441.53	2.91%	6.65%	16.03%	-0.39%	-0.76%	3.37%	8.03%
Wheat yield [dt/ha]	45.70	-0.20%	-0.33%	-0.99%	-0.15%	-0.29%	-0.08%	-0.25%
Other cereals yield [dt/ha]	31.24	-0.12%	-0.20%	-0.48%	-0.11%	-0.21%	-0.07%	-0.19%
Sugar beats yield [dt/ha]	520.00	-0.57%	-1.10%	-2.79%	-0.47%	-0.97%	-0.23%	-0.80%
Protein crops yield [dt/ha]	17.70	-0.12%	-0.13%	-0.72%	-0.11%	-0.18%	-0.11%	-0.27%
Corn yield [dt/ha]	47.10	-0.74%	-1.48%	-3.42%	-0.45%	-0.94%	-0.26%	-0.95%

Source: CAKE/KOBiZE own study

103. Looking at the results of reduction measures application, the value of production cannot be omitted as well (Figure 16, Table 16). Reaction of the model results in farm type approach are stronger compared to the national approach. As each farm type needs to separately cope with the assumed reduction measures across the scenarios, possible adjustments are more limited. Thus even the farm type results show stronger pressure on intensification of production on one side, due to which a higher area of abandoned land could be noticed within the analysis data. As it was mentioned before, presented results were calculated with the price levels fixed for all scenarios, so the differences in production value reflect strictly the differences in quantity produced. It is an effect of

reducing the area of crop production (in RE20 scenario the sum of fallowed land within the farm type approach is more than 2.5 times higher than within the national approach). Also a decrease in number of animals kept in farms could be observed.

Figure 16. Total value of agricultural production [bln PLN] – national level approach and farm type approach (FT)



Source: CAKE/KOBiZE own study

104. Scenarios assuming reduction of overall emissions (RE and ETS) on average cause similar reduction in crop and animal production, while the N scenarios lead to downward shifts in crop production and slight increase of animal production values. Even though the pattern of changes in both approaches is very similar the results of the farm type approach indicate larger drops of production in comparison to the national approach.

Table 17. Relative changes in value of production for main groups of commodities in comparison to BAS scenario [BAS=100%] - results of aggregated farm types [bln PLN]

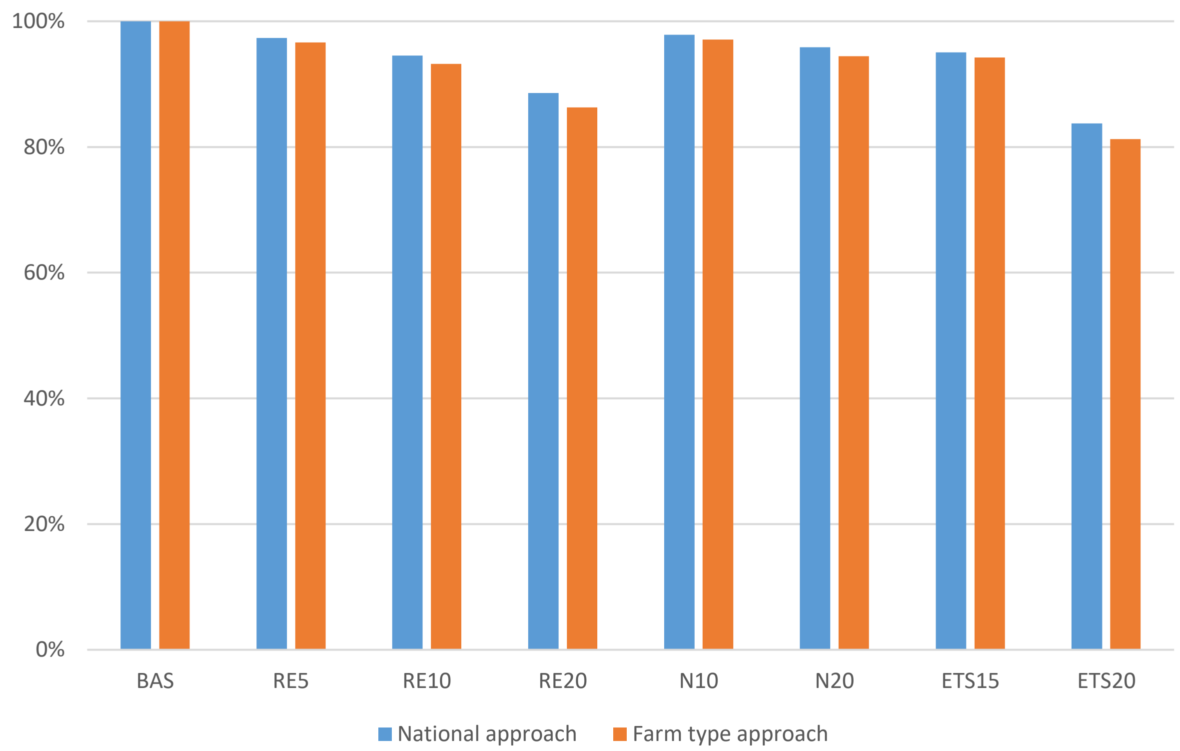
	BAS [bln PLN]	RE5	RE10	RE20	N10	N20	ETS15	ETS20
Cereals	17.3	97.9%	95.8%	91.8%	98.3%	96.6%	99.3%	97.5%
Other field crops	9.6	98.7%	97.6%	95.2%	99.0%	98.0%	99.5%	98.4%
Horticultural crops	13.8	99.9%	99.8%	99.5%	99.9%	99.9%	100.0%	99.9%
Crop production	40.7	98.8%	97.6%	95.2%	99.0%	98.0%	99.6%	98.5%
Beef cattle	5.9	90.4%	81.0%	65.0%	101.1%	102.2%	91.4%	79.9%
Dairy cows	14.2	96.1%	92.1%	84.3%	100.2%	100.5%	97.1%	91.5%
Pigs	10.1	96.4%	92.8%	85.1%	100.4%	100.7%	98.7%	95.6%
Poultry	15.2	99.3%	98.5%	97.0%	100.0%	100.0%	99.8%	99.4%
Animal production	45.3	96.5%	92.9%	86.2%	100.3%	100.6%	97.6%	93.5%

Source: CAKE/KOBiZE own study

105. Regarding the most important activities the sharpest decrease of production could be observed in case of beef cattle, which shows a drop of 35% in case of the RE20 scenario and 20% in the ETS20 scenario. Lower, but also significant drop of production could be observed in case of pigs and dairy cattle. The decrease of crop production and poultry is limited. It needs to be stated again that it was assumed there are no price reactions to the changes in production. Thus in case the price change would be modelled it might be expected that production decrease would be lower due to expected price increase.

106. Decrease of production and assumption of fixed prices leads inevitably to lower farm incomes. The decrease of farm income in the farm type approach is sharper than in national approach. Even though the GHG reduction is the highest in the RE20 scenario, the biggest income drop is observed in the ETS20 scenario. In the ETS scenario, apart of adjustments needed to reduce emissions, which are leading to some income lost, the remaining GHG emissions are covered by ETS scheme. The average income drop in this case could reach nearly 20% (ETS20).

Figure 17. Changes of average agricultural income [BAS=100%] – changes in analysed scenarios within national and farm type approaches



Source: CAKE/KOBiZE own study

107. However, the decrease of farm income at the level of several percent might be considered as an inevitable loss in global challenge to mitigate the climate change. It also needs to be stressed that this is an average drop of income, resulting from the number of income changes in different farm types (Table 17).

Table 18. Farm income changes in different farm types within scenarios [BAS in thousand PLN/farm, other scenarios BAS=100%]

Farm type	BAS [ths PLN]	RE5	RE10	RE20	N10	N20	ETS15	ETS20
Cattle large	138.4	97.9%	95.7%	87.7%	92.9%	86.8%	81.7%	46.8%
Cattle medium	40.0	91.2%	82.5%	65.9%	95.0%	91.1%	84.9%	50.7%
Cattle small	6.4	90.1%	80.2%	59.7%	93.4%	87.9%	78.3%	29.7%
Cereals large	297.9	96.3%	93.3%	82.3%	91.9%	84.0%	94.5%	81.7%
Cereals medium	61.2	95.6%	91.3%	84.2%	93.2%	86.8%	95.4%	84.6%
Cereals small	3.9	87.1%	74.3%	54.7%	81.2%	63.6%	86.4%	54.8%
Other corps large	450.7	98.6%	97.3%	94.0%	97.6%	95.3%	98.4%	94.6%
Other corps medium	120.9	98.6%	97.2%	94.8%	98.1%	96.2%	98.5%	95.2%
Other corps small	16.6	97.7%	95.4%	91.9%	97.4%	95.0%	97.8%	92.8%
Mixed large	234.6	97.9%	95.8%	86.6%	90.5%	81.7%	84.0%	52.2%
Mixed medium	24.0	93.6%	87.2%	75.1%	94.1%	88.5%	88.7%	62.9%
Mixed small	5.0	94.1%	86.8%	73.6%	95.9%	91.7%	88.2%	59.6%
Other large	128.5	98.6%	97.7%	93.7%	99.0%	97.9%	99.3%	97.5%
Other medium	26.2	99.2%	98.0%	96.2%	99.1%	98.1%	99.0%	96.2%
Other small	9.4	99.0%	97.9%	95.2%	99.3%	98.7%	98.5%	95.2%
Granivores large	1004.5	98.9%	97.7%	95.4%	100.0%	100.0%	99.1%	97.1%
Granivores medium	52.0	97.5%	95.0%	88.2%	99.3%	98.6%	96.2%	87.5%
Granivores small	6.6	95.3%	90.7%	78.5%	97.8%	95.8%	90.5%	69.5%
Semi-subsistence	1.7	96.3%	92.5%	86.7%	96.8%	93.7%	95.1%	83.4%
POLAND Farm type average	100%	96.6%	93.2%	86.3%	97.1%	94.5%	94.3%	81.3%
POLAND National aggregation	100%	97.3%	94.5%	88.6%	97.8%	95.9%	95.0%	83.7%

Source: CAKE/KOBiZE own study

108. Modelled farm types are differentiated based on farm specialisation and economic scale reflecting their activity. Thus the initial level of farm income is strongly differentiated. It is needed to mention that farm income is specific index of economic performance. It is a remuneration not only for capital invested in the farm, but also for own labour (farmer's and members' of the family). Thus the drop of farm income could be interpreted similarly as a drop of labour remuneration of an employee. Therefore if the farm income level is approaching the level of zero it will lead to ceasing of activities, as usually is not possible to keep the farm operating if the work of farmer is not compensated.

109. The highest farm income is achieved in large granivore farms. In BAS scenario it exceed PLN 1 mln per year per unit. On the other side are the semi-subsistence farms, which are able to annually generate only PLN 1,700. Certainly the semi-subsistence farms are not supposed to be the main source of income for their inhabitants and usually those farms are kept due to many reasons, beside economic ones. And in between there is a wide range of farms with different income levels. Small farms usually provide few thousand PLN of farm income, which is barely a minimal remuneration of one part-time worker. Medium sized farms, depending on their specialisation, could be perceived as family farms providing main income for the family members employed at the farm, however in some cases at the very low level of financial compensation. The large farms group consists of individual farms (the largest among family farms) and legal entities. The initial level of income is crucial for analysing potential economic effects of considered scenarios.

110. On average the pattern of changes is following the average values, but the impact of assumed scenarios on farm income level is strongly differentiated between farm types. "RE" scenarios cause the highest drop of income in farms with cattle production (cattle and mixed farms). The relatively highest income drop is observed in small farms, which are usually less extensive and have very low initial income value. Similarly as within the national approach, the scenarios assuming introduction of nitrogen or emission tax within the farm type approach results in higher income drop compared to the RE scenarios.

111. The sharpest income drop could be observed in small cattle farms. In the worst case, which is the ETS20 scenario, in this farm type the income drops below 30% of initial income level. For most of businesses it could be considered as a reason for shutting the production down. However, it needs to be noticed that in this case the drop of annual income, even though being high in relative terms, is in absolute value lower than average monthly remuneration in Poland. Therefore a conclusion can be made that this would certainly worsen economic situation of the farmer and could lead to significant adjustments on the farm (e.g. giving up animal production), but it is rather unlikely that it would lead to closing the farm in a short term.

112. Even though the drop of income in medium and large cattle and large mixed farms is relatively lower (~50% in the "worst" ETS20 scenario), it could strongly undermine economic bases of those entities. There is a threat the farmers would lose significantly, and not be able to compensate the losses from other sources.

113. Noticeable income drop in the ETS20 scenario could also be observed in other farms specialising in animal production. Relatively low farm income drop in biggest granivore farms could be explained by high share of poultry farms in this group, which are pretty invulnerable to introduction of mitigation measures due relatively high income and low GHG emissions from poultry production.

114. The nitrogen tax scenarios impact on income could be noticed in case of crop farms, while farms specialising in animal production are nearly invulnerable for this instrument. The sharpest farm income drop due to introduction of the N tax is observed in small cereal farms. This could be explained mostly by very low base value of income and relatively low overall profitability of those units.

115. To some extent differences in farm income could also be explained by additional costs in those scenarios, which assume nitrogen tax and paying for allowances in line with the ETS scheme (Table 18).

116. It is assumed that the nitrogen tax results in increase of nitrogen fertiliser's price, consequently leading to more efficient allocation of the nitrogen-based fertilisers. Thus its use decreases, as the fertilisation in some cases (especially extensive and low income crops), becomes economically unjustified. However, the volume of used nitrogen in both N scenarios is lower than expenditures in most farm types, therefore the reduction in application of N fertilisers is smaller than the price increase. Value of purchased fertilisers under the N10 and N20 scenarios is lower only in case of two types: 1) small cereal farms, and 2) other small farms. At the same time the large granivore farms, due to having excess manure, do not need to purchase more N fertilisers, as the nutrients from natural manure covers nutrition needs of their cultivated crops.

117. There are differences in expenditures for emission allowances in ETS scenarios (Table 18). Amount paid for the GHG emission allowances depends on the structure of activities and their scale. In the ETS15 scenario the expenditures for allowances starts from nearly unnoticeable annual payment of PLN 70 per farm in case of semi-subsistence farms, to nearly PLN 27 thousand per farm in case of the large mixed farms. While in the ETS20 it could reach even PLN 82 thousand in case of the mixed large farm type, which is over 30% of farm income in BAS scenario.

Table 19. Amount and value of purchase N fertilisers and potential cost of ETS emission allowances in different farm types in considered scenarios

	Amount of N purchased in mineral fertilisers			Value of purchased N mineral fertilisers			Expenditures on emission allowances	
Scenario	BAS	N10	N20	BAS	N10	N20	ETS15	ETS20
Farm type	kg/farm	BAS=100%		thousand PLN/farm	BAS=100%		thousand PLN/farm	
Cattle large	17000	93.40%	88.20%	71.09	102.74%	105.72%	17.19	52.67
Cattle medium	3715	93.90%	90.00%	15.51	103.29%	107.88%	4.2	13.45
Cattle small	863	91.50%	82.90%	3.58	100.43%	99.12%	1	3.15
Cereals large	44424	98.10%	96.20%	185.15	107.91%	115.32%	13.69	45.54
Cereals medium	5991	95.30%	90.70%	24.93	104.72%	108.72%	1.87	6.12
Cereals small	1022	94.70%	89.50%	4.23	104.06%	107.16%	0.35	1.15
Other crops large	19404	97.40%	94.80%	81.06	107.14%	113.76%	5.65	18.75
Other crops medium	3402	95.80%	91.60%	14.16	105.27%	109.80%	1.16	3.81
Other crops small	577	95.50%	91.10%	2.39	104.94%	109.08%	0.24	0.78
Mixed large	40829	95.00%	89.90%	170.23	104.39%	107.76%	26.55	82.47
Mixed medium	2763	96.20%	92.30%	11.48	105.71%	110.64%	2.03	6.56
Mixed small	474	93.50%	87.30%	1.95	102.63%	104.40%	0.46	1.47
Other large	2016	96.80%	95.20%	8.38	106.48%	114.12%	0.64	2.16
Other medium	369	92.90%	89.10%	1.5	101.97%	106.44%	0.22	0.72
Other small	38	74.60%	57.50%	0.15	82.06%	69.00%	0.09	0.27
Granivores large	-	-	-	-	-	-	5.99	19.89
Granivores medium	413	86.50%	72.90%	1.65	94.27%	85.68%	1.33	4.26
Granivores small	156	87.80%	75.50%	0.62	95.81%	88.92%	0.41	1.29
Semi-subsistence	101	94.70%	89.50%	0.41	103.95%	106.92%	0.07	0.22

Source: CAKE/KOBiZE own study

118. Comparison of expenditure on emission allowances at the aggregated country level between national and farm type approaches shows that the level of expenditures is slightly higher in the farm type approach. As it was already mentioned, the adjustment possibilities within the single farm type are limited thus the final GHG emission is slightly higher resulting in higher expenditures. In the less restrictive ETS15 scenario, the farm sector, after adjusting production and reducing emissions, would have to spend annually PLN 0.85 billion on the purchase of emission allowances, while in the farm type approach this would rise to PLN 0.87 bln, which gives on average ca. PLN 61 per hectare. Similarly in the more restrictive scenario (ETS20), the potential amount of expenditures on emission allowances in the national approach would rise to the amount of PLN 2.69 bln, while in case of the farm type approach it would at PLN 2.78 bln or 195 PLN/ha. This amount is higher than 11% of farm income earned on average in the Polish farm sector, but the financial burden is unevenly distributed between the farm types.

7. Conclusions and further work

7.1. Key conclusions

119. Under the assumption of currently utilised technologies the achievement of ambitious emission reduction goals in agriculture is difficult. Application of more ambitious mitigation goals doesn't just lead to decline of farm income, yet also to relatively high drop in production volumes, which would potentially lead to increase of price levels.

120. Considering high differentiation of farms across the farming system the use of the farm type approach provides a better insight into changes within the sector compared to the national approach, where the same analyses were performed based on average country values. The farm type approach shows that actual farm types differ significantly in regard to their emission reduction potential and economic results due to application of GHG mitigation measures. The aggregated indicators calculated as an average for all farm types show similar patterns as in national approach. However the farm type model allows to capture heterogeneity within the farming sector regarding the ways of addressing difficulties in GHG reduction, which might appear in particular farm types. The rest of the following conclusions refer to the results based on the farm type approach.

121. Forcing the GHG reduction by **20%** (with other conditions remaining the same) leads to decline in value of produced market commodities by ca. **9.5%** and farm income by ca. **14%** (~200 PLN/ha or PLN 2.8 bln within the whole country). However, the decrease of income in particular farm types can differ from 5% in large granivore farms to even 70% in case of small cattle farms.

122. Decline in production following the forced GHG emission reduction (**RE20**) to the greatest extent affects the production of cattle for beef (by **35%**), milk (by **16%**), maize for grain (by **21%**), and sugar beets (by **21%**).

123. Similar to the forced reduction of GHG emissions effects can be achieved through implementation of "fiscal" measures. However, this approach is less efficient regarding reduction of emissions and strongly affects farmers' income.

124. Introduction of N tax, which is assumed to result in increase of N fertiliser prices by **20%** (the **N20 scenario**) leads to decline in their application by **10.3%** with simultaneous increase of fertiliser costs by **3.95%.** In overall effect within the N20 scenario the model shows a reduction of GHG emissions from agriculture by ca. **1.6%** and decrease of farm income by **5.5%.**

125. Introduction of GHG allowance prices at the level equivalent to the EUA 2015 leads to reduction of GHG emissions from agricultural sector by **3.65%,** yet also means a decline in farm income by **5%.** Assumption of emission allowances at the prices of 2020 level could lead to emission reduction by **9.8%** and income by **16.5%.**

126. Due to simultaneous production decrease and necessity to pay for emission allowances (additional fiscal burden at the level of **PLN 0.87 bln** annually in ETS15 and **PLN 2.78 bln** annually in ETS20) the ETS scenarios are the most "expensive" from the farmers' standpoint.

127. Model results indicate that the emission reduction in some cases is possible through the change of production intensity. Yet it's important to realise that it could result in „agricultural carbon leakage". For example, use of such purchased fodder as soya cake in production of cattle could lead to reduction in emissions due to decreased domestic land areas under fodder crops, while generating emissions outside of Poland as the result of soya cake production.

128. Result analyses reveal that the standard IPCC method, utilising typical values of parameters in particular emission equations, which was used to define the volumes of GHG generated in agriculture, mainly reflects the scale and structure of agricultural activities, at the same time giving limited abilities to reflect technological solutions, which could be potentially implemented and in effect lead to reduction of emissions.

129. Consideration of potential implementation of new technologies requires the development of new emission coefficient values, being necessary to estimate GHG emissions coefficients, which could replace standard values calculated in line with presently used technologies and applied in line with IPCC methodology.

130. The relation of emissions to farm income seems to be a crucial indicator. One of the oldest, however still implemented aims of the EU's Common Agricultural Policy is supporting farmers to maintain viable income. The results of the analysis shows that this

should be aligned with the future Climate Action measures, as one of highly supported activities under the CAP are the beef and dairy production, which generate the highest GHG emissions per unit of farm income. At the same time scarcely supported poultry and pig production are much more climate friendly in this dimension.

131. The analysis clearly shows, that achieving climate neutrality addressed in the European Green Deal cannot be achieved through simple strengthening the "traditional" climate policy measures in agriculture, including taxation and implementing stronger emission standards. Such an attitude leads to negative effects in both production level and farmers' income in all scenarios assuming this kind of measures. Expected policy results require wider, deeper and more efficient changes in technologies and compensation measures to secure acceptable level of farmers income and the overall sector economic efficiency.

7.2. Comments on further work

132. EPICA model that has been presented and used to perform above analyses is still under development. Further works on model development will be continued in three directions:

- **adding the market module** (partial equilibrium) to the model, which will allow to capture expected changes of prices for agricultural commodities, which are likely to occur under analysed scenarios, especially in cases where strong decrease of production is observed. It will enable to observe potential increase of production of substitutes of commodities, understand which production activities contribute significantly to GHG emissions (e.g. increase of poultry meat production due to expected decrease of beef supply).
- **adding farm structure module** to capture possible changes in the farm structure. It is expected that due to policy changes assumed in analysed scenarios some of the farm types might become economically non-viable. In this case their resources (mainly land) will be taken over by those farm types, which are able to maintain satisfactory economic performance, while also reducing GHG emissions.
- **adding measures concerning technologies** to capture and analyse higher reduction potential in agriculture, that is unachievable through traditional policy measures in this sector.
- **linking the EPICA model with the d-PLace CGE model** to capture influence of complex changes throughout the economy onto the agricultural sector, while also capturing impact of availability and thus prices of agricultural inputs as fertilisers, fuel or energy. This would allow to capture impact of other mitigation measures on processes in agriculture.

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