https://doi.org/10.55343/CogSust.28

Hungarian agricultural pathways revealing climate-related challenges

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Abstract
The agricultural sector is highly exposed to the expected impacts of climate change, such as more frequent extreme weather events, prolonged and intensified heat waves, and water shortages, which present new challenges to farmers. Innovation is becoming increasingly important in European and Hungarian agricultural policy, and it plays a key role in the decarbonization of the sector. Innovative technologies improve the three dimensions of sustainability, and contribute to food security and increase the profitability of agricultural production. The research aims to analyze the greenhouse gas emission trends and forecast future emissions from the agriculture sector in Hungary and give a brief overview of the emission scenarios reported in the National Clean Development Strategy. Descriptive statistics are used to analyze emissions data. Chebyshev's inequality is used to predict future EU and domestic GHG emissions. Agriculture is one of the most conservative sectors from a climate perspective and it is already visible that the conventional approach will not be enough, but it has effective tools to achieve climate neutrality by 2050.

Keywords
Agricultural pathways, Climate change, Innovation, Scenarios, Greenhouse gas emission trends

1. Introduction

The paradox of the agricultural sector is that agriculture can decouple itself from the adverse effects of climate change by increasing the intensity of farming (irrigation, use of plant stress tolerance fertilizers, growth regulators, pesticides, large-scale livestock production, etc.), which, together with increasing the profitability of agricultural production and crop safety, increases GHG emissions. Achieving climate neutrality by 2050 will also require a contribution from the agricultural sector, and we can already see that we need to step out of our comfort zone to achieve this, as the traditional approach will not deliver the desired results. The goal for Hungarian agriculture is to produce more, realize its potential, and fulfill its historic mission in global food markets while reducing greenhouse gas and other pollutant emissions. This is the sustainable intensification of agricultural production and Hungary has all the tools at its disposal to achieve this. An integrated approach should be adopted, which requires assessing the negative externalities and potential adaptation trajectories for Best Available Techniques (BAT) (Ndue and Goda, 2022). Furthermore, we must base the development on innovation, and smart, energy-efficient, renewable energy-based, waste-free, and environmentally friendly agriculture must become a reality by 2030. Innovative solutions and businesses have a pivotal role in solving sustainability, climate change, and achieving low GHG emissions in the sector and precision farming and Agriculture 4.0 toolbox are the innovative tools in this process. The aim of precision farming is to reduce the use of pesticides, fertilizers, and water-use, and improve soil productivity. In livestock production, as in crop production, more sustainable management is based on targeted interventions.

Agricultural policy plays an important role in supporting Sustainable Development Goals (SDGs). SDG-2 aims to eliminate hunger in the world and in this regard, agriculture has a dual role: the Common Agricultural Policy (CAP) guarantees the availability of safe, nutritious, and sustainably produced food for all, and food exports contribute to food security, thereby promoting the growth of the domestic agro-industry. The agricultural policy also contributes to several other SDGs, including

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Goal 1 (no poverty), Goal 8 (decent work and economic growth), Goal 12 (responsible consumption and production), Goal 13 (climate action), and Goal 15 (life on land) (United Nations, 2015).

Innovative technologies and business are the key solutions to sustainability and climate change. Innovative tools contribute to solving social challenges, but they can also have negative externalities (Csete, 2022). Innovation improves the 3 scopes of sustainability: enhance incomes, decrease the risks and environmental pressures, and reduce critical labor deficit (Szőke et al., 2021). Sustainable management tools and solutions can be linked to business, innovation, and agriculture and the issues must consider maintaining or improving the quality of life and strengthening the processes of cognitive sustainability (Zöldy et al., 2022).

2. Literature review

2.1 Agriculture map

Hungary produced 2.1% of the EU's agricultural output in 2020, according to Hungarian Central Statistical Office (KSH) data (KSH, 2020). Hungary accounted for 4.9% of EU cereal production, including 11% of maize. In industrial crops, Hungary contributed 5.8% to the EU's output, mainly related to the production of oilseed crops. National poultry production accounted for 4.4% of total EU production in 2020. Among the countries with significant agricultural production, the Central and Eastern European and Southern European countries, including Greece, Romania, and Hungary, typically have the largest share of agriculture in gross value-added production, with a share of over 4%. In contrast, Germany and Belgium have shares of less than 1%. The different economic structures are also reflected in the fact that, although Germany and France together account for one-third of the EU's agricultural output, agriculture makes only a small contribution to their economic performance. The KSH carried out a comprehensive agricultural census in 2020. Data collection covering all municipalities in the country takes place every ten years, and last year was the eighth in the history of Hungarian agricultural statistics. According to the first preliminary data, the number of farms has fallen by two-thirds to 234,000 since 2010 (KSH, 2021). The concentration of holdings has increased, with the reduction in the number of holdings leading to an increase in the amount of land per holding in all cultivated branches, for example, in the case of vines, the area of land per holding has more than doubled. The use of digital tools is most common among young managers. The most frequently used tool is the crop health monitoring system. The results also show that the higher the farmers' education, the more often they use expert help (Juhász and Horváth-Csikós, 2021). Based on their main activities, two-thirds of farms were mainly engaged in crop production in 2020 a significant change compared to 2010, when the share of livestock and crop production was 41-46%. At the same time, the share of farms with a mixed profile has also decreased, thus increasing specialization (KSH, 2021).

2.2 Overview of the sector

Agricultural production is highly exposed to constantly changing weather patterns, average temperature increases, and changes in precipitation patterns due to climate change. Within Europe, the Carpathian Basin is the region most exposed to climate change, along with the southern countries (Gaál et al. 2014, Pálvölgyi and Csete, 2012; Biró and Csete, 2021b; Hadnagy et al. 2013). Climate change also has a significant impact on agriculture in our country because weather extremes, periods that are too cold or too hot, too wet, or too dry, and periods of excessive precipitation or drought, reduce the reliability of crops and production. In the short term, the average yields of our main arable crops may not yet be significantly threatened by climate change, but from 2050 onwards we can expect a significant reduction in yields of up to 30%, which will require adaptation techniques such as drip irrigation, construction of reservoirs, soil protection, drought-tolerant crops, use of stress-tolerant propagation materials, water-saving and low-GHG agro-techniques, climate-smart husbandry or the energy-efficient agrotechnological tools.

What we cannot currently estimate in the long term is the changing composition of disease and damage due to climate change, not only because the environment is changing, but also because the composition of the living communities surrounding our crops and livestock is changing, including new pathogens and vector organisms that pose a risk to plant and animal health. What we do know is that current trends in plant and animal health are not very promising for the future. Climate change is leading to the increasing emergence of pathogens and vectors from southern Europe and even tropical regions, but indigenous pathogenic organisms will not disappear in the short term.

2.3 Emission trends

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The agricultural sector is a major sector of the economy, but also a major emitter of GHGs. According to the National Inventory Report 2022 (UNFCCC, 2022), the energy sector is the largest emitting sector, contributing 71% of domestic GHG emissions, with agriculture accounting for 11.6%. A closer look at the trend of GHG emissions from agriculture shows that GHG emissions have been increasing in Hungary since 2010, mainly due to the significant increase in fertilizer use and beef cattle population, which is the result of the domestic agricultural support system. The European Green Deal, the European Commission's "Go 55%!" package of proposals, and the RRF introduced in the 2021-2027 programming period confirm the importance of this dissertation and show that this topic is a high priority in the green transition. The total greenhouse gas emissions in Hungary in 2020 were 62.8 million tonnes of CO_2-e without the Land Use, Land-Use Change and Forestry (LULUCF) sector (UNFCCC, 2022). Considering the largely decarbonizing processes in the LULUCF, Hungary's emission in 2020 was 56.0 million tonnes of CO_2-e. Hungarian emissions per capita are around 6 tonnes below the European average. Figure 1 shows the trend in net and gross GHG emissions in Hungary between 1985 and 2020. GHG emissions from agriculture decreased by 39% over the whole period 1985-2020, but increased steadily between 2010 and 2018, due to an increase in inorganic fertilizer use, cattle, and dairy production (UNFCCC, 2022). In 2020, Hungary's GHG emissions will fall by 2.7% compared to the previous year, back to 2016 levels. The reduction in travel restrictions under COVID-19, and tourism, and business travel have strongly contributed to the decrease in emissions. According to the National Inventory Report, the agricultural sector accounted for 11.6% of total domestic GHG emissions in 2020 (UNFCCC, 2022).

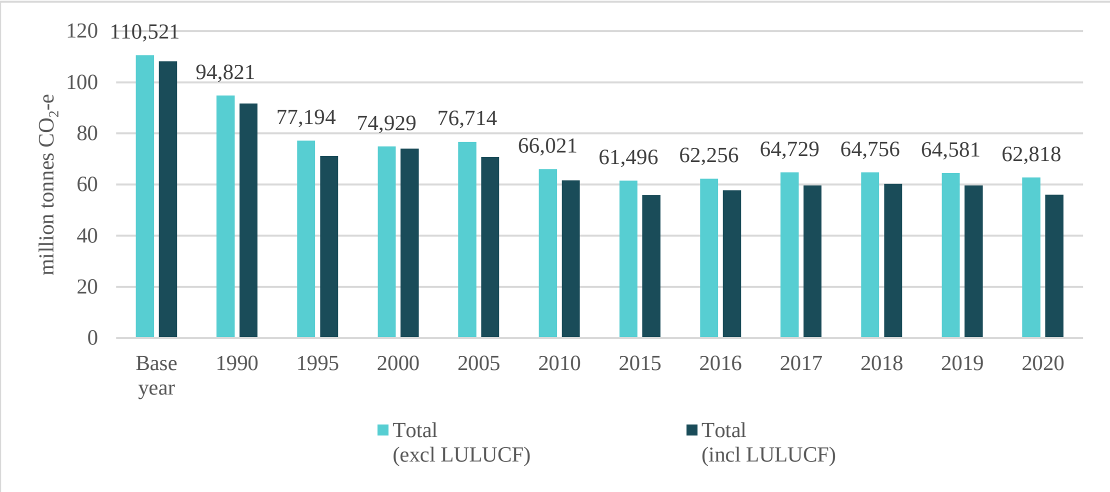

Figure 1 Total GHG emissions in Hungary 1985-2020 (including and excluding Land Use, Land-Use Change and Forestry (LULUCF)) (Source: data based on UNFCCC, 2022)

Agriculture mainly emits N_2O (from arable land, and manure management) and methane (from livestock production) into the atmosphere. Trends in aggregate GHG emissions can be assessed based on Global Warming Potential (GWP). Methane has a global warming potential (GWP) of 25 times (GWP_{CH4}=25), and nitrous oxide 298 times (GWP_{N2O} = 298) compared to carbon dioxide over the hundred-year period (IPCC, 2006). 86% of total N_2O emissions were from agriculture in 2020 (UNFCCC, 2022).

It can be concluded that agriculture is of great importance for our country in terms of the national economy, employment, and nature, but it is also a very sensitive sector exposed to climate change, so the application of mitigation and adaptation techniques are essential tools to preserve its role.

3. Methods

The research aims to analyze GHG emission trends in Hungary and forecast future emissions. Descriptive statistics are used to summarize and interpret GHG emissions data, which support inferences about a population by estimating the value of unknown population (population is the same as the sample) parameters using a single point and a graphical representation. The graphical representation is used to illustrate the relative magnitude of the data. The time series representation of GHG emission data is presented as a line graphs. Univariate analyses look at the distribution of cases according to a single variable

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to describe it. By variable, we mean a selected numerical property of the phenomenon under study. The size of the statistical population is usually large, so it is important to be able to characterize the data collected well with a few numbers. These numbers are called statistical indicators. Dispersion indicators show how much the data deviate from the mean, i.e., how much the data are skewed around the average. The following descriptive statistics were applied to the data series collected in the research:

- Average: one of the most popular statistical items that measure the central tendency of a sample of observations.

(1) $$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}$$

- Standard deviation: the mean squared deviation of each value from the average. It shows how much the values differ from the mean on average, i.e., how heterogeneous the sample is. A standard deviation is always a non-negative number (positive or zero).

(2) $$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}}$$

- Variance: emphasizes the variance because of the quadratic function.

(3) $$\sigma^2 = \frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}$$

- Skewness: is a measure of the degree of asymmetry of the frequency distribution. The skewness of a symmetric distribution is 0.
- Kurtosis: is a measure of the flatness of the frequency distribution. Positive values indicate a relatively peaked distribution, while negative values indicate a relatively flat distribution.

The skewness and kurtosis of a sample can be determined from equations (4) and (5) (Casella and Berger, 2002):

(4) $$sk(X) = E\left[\left(X - E(X)\right)^3\right] \cdot Var(X)^{-3/2}$$

(5) $$kr(X) = E\left[\left(X - E(X)\right)^4\right] \cdot Var(X)^{-4/2}$$

According to the definition of descriptive statistics, the expected value is the first moment of the probability variable, the variance is the second moment of the probability variable, the third moment measures skewness, i.e., how non-symmetric the distribution is, and the fourth moment measures flatness (kurtosis), i.e., how peaked the distribution is.

The Chebyshev inequality is used to estimate the range of values within which greenhouse gas emissions from agriculture are expected to range in the next ten years (2020-2030) and is examined at the EU and national levels. Chebyshev's inequality can use the expected value and standard deviation to estimate the probability that a probability variable will deviate from the expected value by more than a given amount. In other words, it can be used to estimate the probability that the time series treated as a probability variable will deviate from the expected value with a large standard deviation. Greater certainty will, of course, lead to greater variance. The Chebyshev inequality does not require knowledge of the distribution and can be applied to any probability variable with finite variance. Let X be a probability variable with variance σ(X). Then for any real number a > 0:

(6) $$P(|X - E(X)| \geq \varepsilon) \leq \frac{D^2(X)}{\varepsilon^2}$$

where,

X is the estimated value,
E(X) is the expected value of the probability variable X,
D2(X) is the variance,
ε is the probability of estimation.

The study presents EU and domestic agricultural emissions based on the EEA (2022) database, followed by a statistical analysis of the data. According to the National Clean Development Strategy, we also demonstrate the emission reduction scenarios to assess the measures to reduce the GHG emissions in Hungary.

4. Results and discussion

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On average, emissions in the agricultural sector have been decreasing year by year in EU member states, while our GHG emissions from agriculture have been increasing since 2010 (EEA, 2022) (Figure 2). The standard deviation of CO_2 emissions from agriculture is large, so the sample does not show a normal distribution. The kurtosis values are around 3, so the distribution is flat. The skewness values range from 1.7 to 2 (Table 1), i.e., the distribution curve is skewed to the right and the data are not normally distributed.

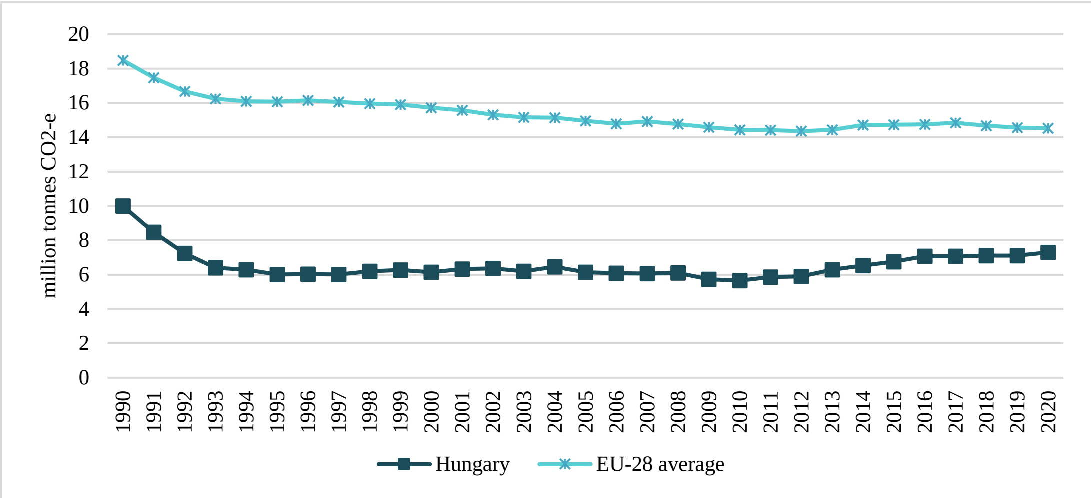

Figure 2 GHG emission trends from agriculture in the EU (average) and Hungary, 1990-2020 (Source: data based on Eurostat and EEA, 2022)

Table 1 Statistical analysis of EU greenhouse gas emissions from agriculture sector based on EEA database (million tonnes CO_2e)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Average	18,49	17,47	16,67	16,24	16,09	16,07	16,14	16,06	15,97	15,92	15,72	15,58	15,31	15,16	15,15	14,95
Standard deviation (σ)	21,43	20,41	20,05	19,85	19,92	20,03	20,26	20,21	20,29	20,38	20,42	20,23	19,78	19,54	19,45	19,20
Variance (σ^2)	459,25	416,75	401,86	393,99	396,66	401,37	410,35	408,30	411,58	415,14	416,95	409,06	391,30	381,82	378,20	368,77
Kurtosis	2,14	2,60	2,75	2,75	2,63	2,70	2,63	2,71	2,70	2,77	3,21	3,37	3,40	2,95	3,08	3,09
Skewness	1,66	1,74	1,78	1,78	1,76	1,77	1,77	1,78	1,79	1,81	1,89	1,92	1,92	1,85	1,87	1,87
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Average	14,79	14,92	14,77	14,58	14,44	14,42	14,36	14,43	14,71	14,73	14,76	14,85	14,68	14,56	14,52	
Standard deviation (σ)	18,99	19,19	19,05	18,97	18,73	18,65	18,63	18,62	19,07	19,01	18,85	18,93	18,64	18,40	18,14	
Variance (σ^2)	360,74	368,08	362,81	359,83	350,72	347,66	347,05	346,77	363,79	361,30	355,24	358,52	347,36	338,67	329,04	
Kurtosis	3,17	3,19	3,65	3,59	3,55	3,45	3,54	3,46	3,53	3,52	3,30	3,19	3,06	3,01	2,64	
Skewness	1,88	1,88	1,96	1,96	1,96	1,94	1,96	1,95	1,96	1,96	1,92	1,89	1,86	1,86	1,79	

The histogram (bar chart) shows the frequency of GHG emissions from the EU agricultural sector. The horizontal axis shows the emissions in million tonnes of CO_2 equivalent and the vertical axis shows the frequency (Figure 3). 868 values are included in the sample, so the data have been grouped. The histogram shows that nearly 80% of EU Member States emitted 16 million tonnes of CO_2-equivalent GHG from the agricultural sector in 2020.

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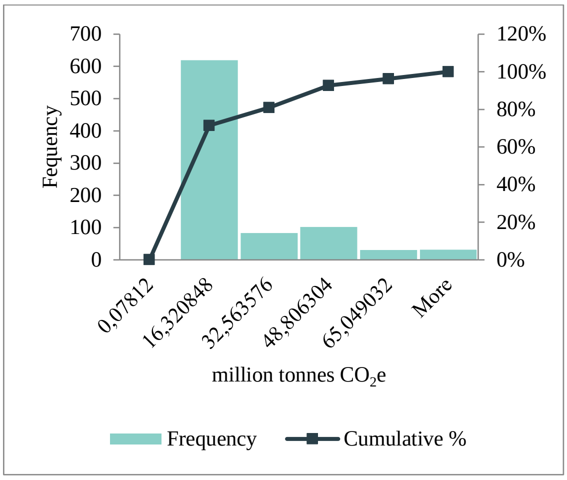

Figure 3 Histogram of EU GHG emissions from agriculture, 2020 (Source: based on EEA 2022 database)

Chebyshev's inequality was used to assess the values within which GHG emissions from agriculture can vary over time. The expected trend in GHG emissions for the EU (in million tonnes of CO_2 equivalent) between 2020 and 2030 with a confidence interval of 95%, based on the actual data and their standard deviation. EU GHG emissions are expected to be between 0 and 42 million tonnes of CO_2 equivalent in 2030 (Figure 4). Hungary's GHG emissions from agriculture are also projected between 2020 and 2030. Emissions are expected 2030 to be between 0-19 million tonnes of CO_2 equivalent with a confidence interval of 95% (Figure 5).

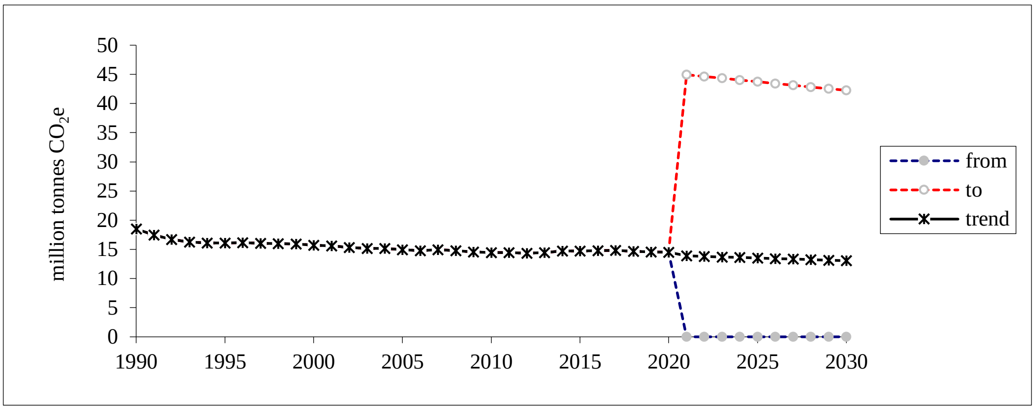

Figure 4 Projected GHG emissions from agriculture in EU, 2020-2030 (Source: based on EEA 2022 database)

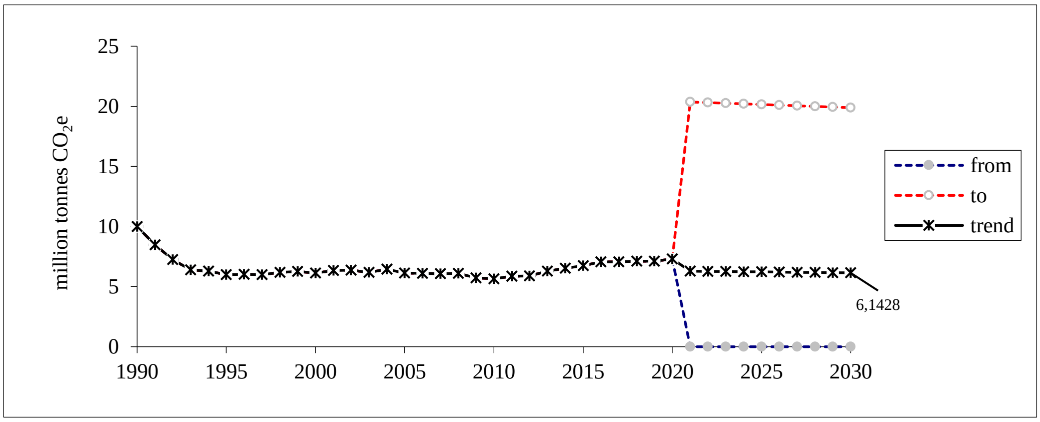

Figure 5 Projected GHG emissions from agriculture in Hungary, 2020-2030 (Source: based on EEA 2022 database)

The National Clean Development Strategy serves as a roadmap for achieving climate neutrality in Hungary by 2050, setting out sectoral targets and tasks. For agriculture, two different production and emission reduction scenarios (Business-As-Usual and the Early Action scenario) for the future were examined (ITM, 2021). The Business-As-Usual (BAU) scenario of the

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Strategy is based on the implementation of measures to reduce greenhouse gas emissions from agriculture in the past and by the end of 2020. The scenario assumes that the present free trade agreements stay in place, the embargo against Russia is ended in 2025 and there is no significant change in eating habits. The scenario is predicated on a gradual increase in livestock numbers on a market basis, together with the use of nitrogen fertilizers. The scenario projects a continuation of the slow, steady increase in emissions until 2050. Emissions projected for 2050 are expected to be 7.679 million tonnes of CO_2-e per a year which is still a lower value compared to 1985 emissions (Figure 6). Precision farming and Agriculture 4.0 tools are gaining ground through subsidies and market-based approaches. In livestock production, as in crop production, the tools of precision farming and Agriculture 4.0 are emerging. The Early Action (EA) climate neutrality scenario contains measures and innovative technologies that are at an investigational or experimental stage but could be implemented if appropriate EU and national legislation are in place. Such actions could be included restricting to the use of nitrogen fertilizers by increasing prices, eliminating subsidies for beef cattle, stricter regulation of fertilizer use, and subsidized cattle selection schemes. Also included campaigns to reduce meat and milk consumption and to raise awareness. According to Business-As-Usual, the sector's output would increase by 8% at the end of 2050 (Figure 6). In contrast, under the Early Action scenario, the sector's GHG emissions are projected to decrease by 70% until 2050 (ITM, 2021).

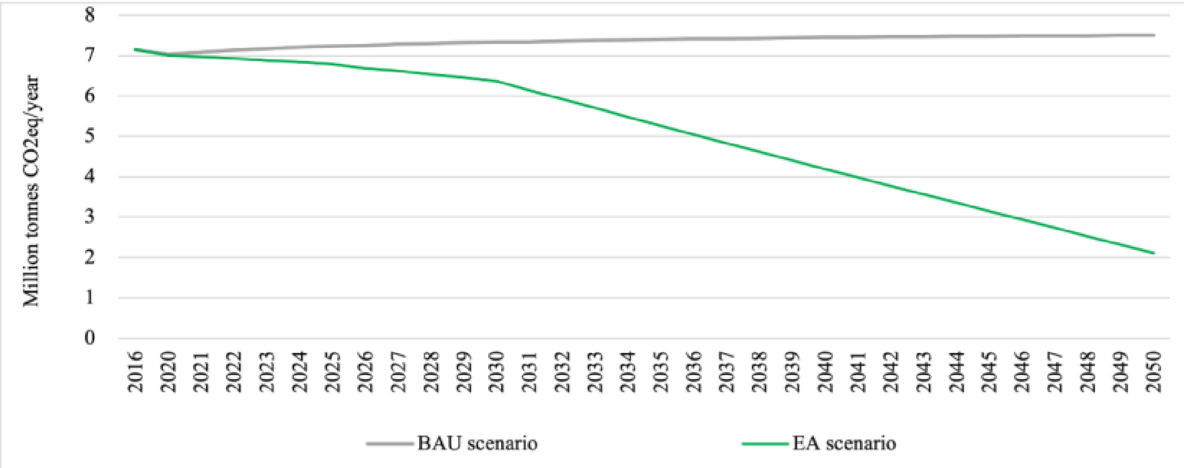

Figure 6 The projected GHG emissions in the agricultural sector under the two scenarios (CO_2-e/year) (Source: ITM, 2021)

In the Early Action scenario, the largest emission reductions are caused by a very significant structural transformation. 30% of the feed materials for feed production are planned to be produced in closed industrial fermenters using biomass and renewable energy, which will also help the livestock sector to produce feedstock by using carbon-neutral technologies. Further GHG emission reductions are expected in soil emissions. According to the Ministry of Agriculture, fertilizers are mainly needed on arable land to replenish nutrients. The right management of organic materials is an essential requirement for competitive and sustainable production, so it is important to know how farmers handle in practice the waste of production, such as manure. The impact of biomass energy use on soil nutrient replenishment has direct and indirect implications for farmers. If soil nutrient replenishment is not ensured, soil biological activity and biota are not maintained, and humus extracted by crop production is not improved, the soil will not be able to renew itself, and in the long-term yields will fall drastically as a result. The European Union's Farm to Fork strategy has set a target of a 20% reduction in fertilizer use by 2030, with demand for organic fertilizers in the sector expected to increase (European Commission, 2020). Within the agricultural sector, the smallest reduction in emissions can be expected in animal husbandry, but with precision farming and the use of Agriculture 5.0 tools, emissions can be reduced even with the growing number of animals.

It can be assumed that our perdition using Chebyshev’s inequality yields the values of the Early Action (EA) scenario outlined in the National Clean Development Strategy. The expected GHG emission trend will be around 6 million tonnes of CO_2 equivalent by 2030. This is a climate-neutrality vision, where innovative tools play a key role, leading to a profound structural transformation of the sector. From the early 2030s, we will increasingly see the dawn of the digital era of agriculture, with near-zero GHG and other pollutant emissions, circular material flows, and zero waste based on the use of Agricultural 5.0 tools such as robotics, drones, molecular farming, functional fertilizers, bio-pesticides. Innovation has the potential to increase the sustainability and intensification of agricultural production, thus growing the global food supply.

5. Conclusions

Thinking through the diversity of development paths that the agricultural sector could potentially take: all projections are wrong; the question is how wrong. The most optimistic scenario that Hungarian agriculture could realize would be to fully exploit the agricultural potential in the future. Conversely, the most pessimistic scenario would be to be locked into production and price competition with many developing agricultural countries, resulting in production far below what is possible. Anything between these two scenarios is possible. The research aimed to analyze GHG emission trends and forecast future emissions in Hungary. Descriptive statistics were used to analyze the emissions data, and they were presented in a time series. The result shows that the prediction using Chebyshev's inequality approximates the values of the Early Action (EA) scenario and a climate-neutral vision in which innovation has a major role. From a climate perspective, agriculture is perhaps the most conservative sector, with no marketable and significant emission reduction technologies yet in sight. Nevertheless, wherever we are in 2030, agriculture will have two powerful tools at its disposal to achieve climate neutrality: it can even reduce its current emissions by planting carbon-climate crops on marginal land and by basing agriculture on renewable energy.

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