Analysis of Greenhouse Gas Emissions in Bulgaria - Sources, Trends and Reduction Priorities

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Abstract: *The purpose of this study is to analyze the emissions of greenhouse gases in Bulgaria. The main sectors contributing to greenhouse gas emissions are identified and analyzed. A comparison of net greenhouse gas emissions in the country with the EU average is made and the contribution of the different sectors is analyzed. Special attention is paid to the Land Use, Land-Use Change and Forestry sector. Recommendations are formulated for measures for sustainable reduction of greenhouse gas emissions in Bulgaria in the context of achieving the country's goals by 2030 for net greenhouse gas removals in this sector.*
Keywords*: DOMESTIC NET GREENHOUSE GAS EMISSIONS, LAND USE, LAND-USE CHANGE AND FORESTRY, REFORESTATION, AFFORESTATION, GREENHOUSE GAS REMOVALS*

1. Introduction

One of the most serious problems of the modern world, which if not promptly resolved will threaten life on the planet, is global warming. It is expressed in a permanent trend towards an increase in the average temperature of the Earth and causes extreme climate changes and phenomena such as more frequent and severe storms, droughts, heat waves, floods, melting glaciers, rising sea levels, loss of biodiversity, changes in ecosystems. Increased temperatures lead to more frequent heat waves and fires. This has a negative impact on agriculture and food security. Extreme weather events become a threat to human life and cause damage to the infrastructure of settlements and carry potential health risks such as the spread of diseases and heat stress.

Global warming is mainly the result of increased greenhouse gas emissions caused by human activity – burning fossil fuels, deforestation, industry and agriculture.

Research objectives:

• To identify the main sectors contributing to greenhouse gas emissions in Bulgaria;
• To analyze the trends in emissions for the period 2014 ÷ 2023;
• To compare the net greenhouse gas emissions in the country with the EU average;
• To formulate recommendations for measures for sustainable emission reduction.

2. Greenhouse gas emissions

Greenhouse gases CO_2, CH_4, N_2O etc. F-gases (industrial greenhouse gases containing fluorine and having a very strong greenhouse effect) accumulate in the atmosphere. They retain the heat that is released from the Earth as a result of heating by the Sun and this leads to a change in the energy balance of the planet. This in turn leads to an increase in the average temperature of the Earth and causes extreme climate changes. Emission sources can be grouped into two main groups:

A. Sources caused by human activity:
• Energy: coal-fired power plants, fuels in transport;
• Industry: production of cement, steel, chemicals;
• Agriculture: fertilization in crop production, animal husbandry;
• Landfilling of organic waste;
• Deforestation.

B. Natural sources:
• Volcanic activity;
• Biological processes;

According to International Panel on Climate Change (IPCC) [1] the main greenhouse gases are:
• carbon dioxide (CO_2);
• methane (CH_4);
• nitrous oxide (N_2O);
• hydrofluorocarbons (HFCs);
• perfluorocarbons (PFCs);
• sulphur hexafluoride (SF_6);
• nitrogen trifluoride (NF_3);
• trifluoromethyl sulphur pentafluoride (SF_5CF_3);
•halogenated ethers (e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$);
• and other halocarbons not covered by the Montreal Protocol including CF_3I, CH_2Br_2 $CHCl_3$, CH_3Cl, CH_2Cl_2

Table 1 shows the main greenhouse gases causing global warming and climate change and the main sources that generate them.

Table 1: *Main greenhouse gases*

Greenhouse gas	Source
CO_2	Fossil fuel combustion, industry
CH_4	Livestock, landfills, natural gas/coal mining
N_2O	Fertilizers, waste, biomass combustion
F-gases	Refrigerators, air conditioners, industrial processes

3. Greenhouse gas measurement indicators

Greenhouse gas measurement indicators are specific indicators that track the amount of greenhouse gas emissions, their sources, trends over time, and the effectiveness of measures and policies. Table 2 shows the main indicators for greenhouse gas.

Table 2: *Main indicators for greenhouse gas emissions*

Indicator	Description
Total greenhouse gas emissions	The most important indicator - summarizing CO_2, CH_4, N_2O and F-gases
Emissions by sectors	The share of emissions from energy, transport, industry, etc.
Emissions per capita	Total greenhouse gas emissions per capita
Emissions per unit of Gross Domestic Product (GDP)	Amount of emissions emitted per unit of GDP – measures the carbon intensity of the economy
Removals by Land Use, Land- Use Change, and Forestry (LULUCF)	Amount of CO_2 absorbed by forests, soils, etc.
Net emissions (gross – removals)	Total carbon emissions for the country
Share of emissions covered by EU Emissions Trading System (EU ETS)	Percentage of emissions falling under the European Emissions Trading Scheme
Emissions from energy consumption	By fuel type or end user (households, transport, etc.)

Monitoring and accounting for greenhouse gases is a strictly regulated process based on international standards, scientific methods and technological tools. Table 3 shows the levels of monitoring and reporting of emissions of the main greenhouse gases and the bodies responsible for this.

Table 3: *Monitoring and reporting of the main greenhouse gases [6]*

Level	Bodies	Role
National	Ministry of Environment and Water / Environment Executive Agency	Collects and prepares the National Inventory Report [2]
European	European Environment Agency (EEA), Eurostat	Monitor compliance with regulations
International	United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC)	Review and adopt national reports, set methodology

The main emitting sectors in terms of CO_2 equivalent are shown in Table 4. Source sectors for greenhouse gas emissions (Common reporting UNFCCC format) [2].

Table 4: *Main emitting sectors (by CO_2 equivalent)*

Sector	Share of greenhouse gas emissions
Energy	60 ÷70 %
Transportation	15 %
Industry (industrial processes + etc.)	17 ÷ 20 %
Buildings and domestic heating	4 ÷ 10 %
Waste	2-3%
Agriculture	~10% (included above in industry and others sources)

Domestic net greenhouse gas emissions reducing standard units of measurement that reflect both the quantity of emissions and their climate impact. The most widely used unit is [tCO_2e] (tonnes of carbon dioxide equivalent). This means that all greenhouse gases (including methane, nitrous oxide and fluorinated gases) are recalculated according to their power to warm the atmosphere, compared to CO_2. [3] Thus different gases are combined into one comparable value. Domestic net greenhouse gas emissions. Domestic net greenhouse gas emissions can be calculated using the formula:

(1) ***Domestic net greenhouse gas emissions = Total emissions – Removals (LULUCF - by forests, soils, capture technologies + Memo Item)***

LULUCF (Land Use, Land-Use Change and Forestry) is a sector of climate accounting that accounts for how changes in land use affect greenhouse gas emissions and removals. It includes: forests and forest plantations, agricultural lands, built-up areas, pasture or wetland management, conversions (e.g. from forest to urban area or vice versa) [3], [11]

A. LULUCF may increase emissions:

• When forests are cut down (deforestation);

• In the case of drainage of peatlands;

• When converting green areas into built-up areas as a result of intensive urbanization;

B. LULUCF may reduce emissions (removals):

• In afforestation and forest restoration;

• With well-managed agriculture, which increases soil carbon sequestration;

• With good management of pastures and grasslands.

Under the Kyoto Protocol and the Paris Agreement, countries are required to report the balance of emissions and removals in the LULUCF sector. [11], [20] Usually they are measured:

• Removals of CO_2 (by forests and soils);

• Minus emissions of CO_2 (from deforestation and degradation).

In some years, the LULUCF sector can even offset part of the emissions from other sectors (negative emissions). In the context of greenhouse gas reporting, Memo Items are additional categories or emissions that are not part of the underlying national emissions total, but are reported separately because they are important for comparison, transparency, or international agreements. [13]. The main emitting Memo Items sectors are summarized in Table 5.

Table 5: *Main emitting memo items sectors (by CO_2 equivalent) [3]*

Memo Item	Description
International aviation	Emissions from international aviation flights
International navigation	Emissions from international shipping
CO_2 emissions from biomass combustion	Emissions from biomass combustion
Emissions from bunkers	Emissions indirectly generated in the production of fuels loaded for international transport
Indirect CO_2	CO, NO_x, NMVOC – not directly reported for, but impact carbon emissions
Non-energy CO_2	CO2, which is not the result of combustion (chemical processes, cement, etc.)
Military emissions	Military aviation, warships, etc.

International flights and ships are not covered by national targets but contribute significantly to global emissions. Biomass is considered neutral but in reality can have a carbon effect. Countries can have hidden emissions if Memo Items are not monitored carefully.[3]

According to data from European Environment Agency (EEA) [8] in the forestry and agricultural sectors, net removals have decreased, and the negative trend has accelerated in the last few years. The main reasons for the decrease in net removals include aging forests, increased timber production and the negative impacts of climate change. This directs the focus of the scientific research towards a detailed analysis of the state of the LULUCF sector and the need for urgent measures to improve its efficiency.

4. Analysis of emission trends for the period 2014 ÷ 2023

For the purposes of this study, a unit of measurement is used Tonnes per capita (t/capita or tCO_2e/ capita) showing the average amount of greenhouse gases emitted by one person in a given country over a given period (usually annually).[3]

(2) ***Tonnes per capita = Total net emissions (tCO_2e) / Country population***

This unit of measurement gives a more objective view of the state of the problem under study. It allows countries of different sizes to be compared. It shows how "carbon intensive" a country's lifestyle is and can be used to assess sustainability. It helps set targets for reducing emissions per person. Fig. 1 presents the results of the analysis of Domestic net greenhouse gas emissions Total (excluding LULUCF and memo items) for 2014 and 2023 [3] by comparing the values of the average amount of greenhouse gases emitted by one person for Bulgaria and for the other EU Member States, as well as a comparison with the average value of the amount of greenhouse gases emitted by one person for the entire EU. The results show that the values of this indicator for Bulgaria at the beginning and at the end of the research period are below the average for the EU Member States.

Countries such as Belgium, the Czech Republic, Germany, Estonia, Ireland, Cyprus, Luxembourg, the Netherlands, Poland, Finland and Norway significantly exceed the average values, both at the beginning and at the end of the analyzed period. The main reasons why these countries emit more greenhouse gases per person are:

• High industrialization – lots of manufacturing and energy-intensive industries.

• Use of fossil fuels – coal, oil and gas in the energy mix.

• High standard of living – more consumption and transport.

• Climatic conditions – need for more energy for heating.

• Extraction and export of energy resources – especially in countries like Norway.

Countries such as Spain, France, Croatia, Italy, Lithuania, Hungary, Malta, Portugal, Romania and Sweden are below the

average values in all years of the period. These countries have lower emissions because they use more clean energy, have less heavy industry, a milder climate, and lower energy consumption per capita.

Bulgaria is in a transitional stage – it is not among the most polluting countries in the EU, but it is not among the cleanest either. The main challenges are the dependence on coal and the slow pace of introducing renewable sources.

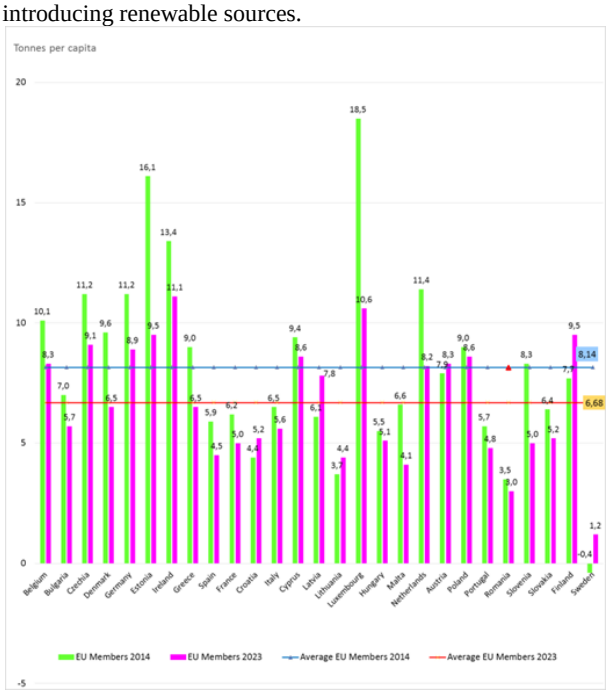

Fig. 2 *Domestic net greenhouse gas emissions Total (excluding LULUCF and memo items) [Tonnes per capita] (Author).*

If the entire period from 2014 to 2023 is analyzed, it can be seen that Bulgaria has less average values for this indicator, with the exception of 2022. (Fig. 2) According to Eurostat data [3], for 2022, Bulgaria and Estonia are the only countries that register significant growth on an annual basis. In 2022, the increase in carbon emissions per capita in Bulgaria is a result of:

• increasing dependence on coal in energy production due to increased natural gas prices and the energy crisis resulting from the military conflict between Russia and Ukraine;

• the economic growth after the pandemic, which activated transport, industry and consumption;

• imported carbon emissions, included from production chains in the EU.

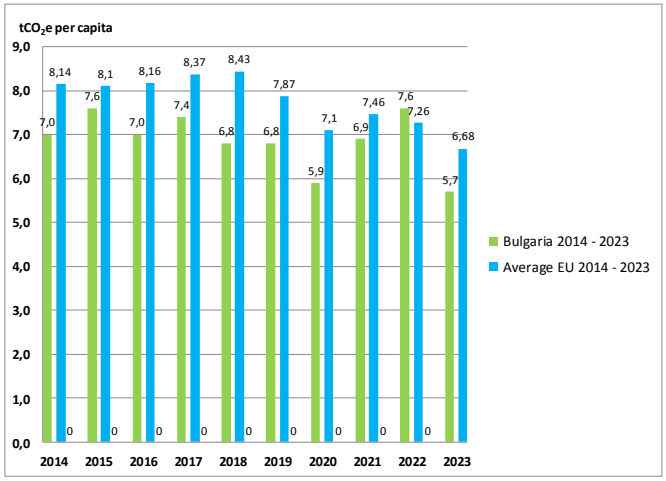

Fig. 2 *Total Domestic net greenhouse gas emissions (excluding LULUCF and memo items) [tCO2e per capita] (Author).*

Overall, during the period 2014 ÷ 2023, the indicator of greenhouse gases per capita [tCO_2e per capita] in Bulgaria has seen fluctuations that are lower than the average values for the EU, which shows that this indicator is sensitive to external events, crises and political decisions.[2]

From the analysis of the data on Domestic net greenhouse gas emissions during the period under review, it can be summarized that Bulgaria is positioned relatively well in the overall ranking of the Member States in terms of the actions taken to reduce greenhouse gas emissions and their impact on the climate. These measures are aimed at decarbonization of the energy sector by gradually replacing conventional fossil fuels with renewable energy sources, increasing energy efficiency in the industrial sector and in households, developing sustainable transport through electric mobility, stimulating recycling and waste recovery. The principles of the circular economy are applied within the framework of Industry 5.0. Various forms of financing are used under national and European programs within the framework of the transition to climate neutrality by 2050.

Along with all these actions, it is worth noting the significant contribution of one important sector to reducing greenhouse gases - LULUCF. This sector focuses on how land is used, how it changes over time and how it affects the carbon cycle.

The categories of land that affect greenhouse gases can be classified [22]:

• Forest land - all land with woody vegetation;

• Cropland - agricultural land, as well as agroforestry systems, outside the category of forest land;

• Grassland - rangelands and pasture land that is not considered as cropland, as well as systems withvegetation that is not in the category of forest land. The category also includes all grasslands, from wild lands to recreational areas, as well as agricultural and forest-pasture systems;

• Wetlands - land that is covered or saturated with water all or part of the year (e.g. peatlands) and that does not fall into the categories of forest land, cropland, pasture or settlements; it includes water bodies as a managed subdivision and natural rivers and lakes as unmanaged subdivisions;

• Settlements - all built-up land, including transport infrastructure and human settlements of any size;

• Other Land - this category includes bare soil, rocks, ice, and all unmanaged land areas that do not fall into any of the other five categories.

Fig. 3 shows the results of the analysis of the contribution of LULUCF in Bulgaria to the reduction of greenhouse gases. It can be seen that this contribution at the beginning of the period shows a tendency to increase (2014 ÷ 2016), then there is a period of maintaining this contribution relatively constant (2017 ÷ 2022) and in 2023 this contribution decreases, which indicates an unfavorable trend and that work must be done to increase it. The decline in greenhouse gas absorption in Bulgaria is a worrying trend that indicates a weakening of natural carbon capture mechanisms. The reasons – aging forests, lack of effective afforestation, fires and urbanization – highlight the need for a more active forest management policy and sustainable land use.

Forests perform an important ecological function – they absorb a significant amount of carbon and help balance emissions. Bulgaria has a stable regulatory framework, consistent with European standards and traditions in afforestation and sustainable forest management. The presence of diverse natural zones and a temperate climate creates conditions for a diversity of species and ecosystems. However, there is a significant gap between the regulatory framework and its practical application. Control over illegal logging and timber harvesting is inconsistent. Forestry is chronically underfunded. There is poor coordination and a low level of implementation of sustainable practices in agriculture.

Bulgaria has the potential to strengthen the role of forests as a carbon sink through active afforestation, restoration of degraded

lands and introduction of agroforestry systems. New technologies such as satellite monitoring, digital maps and soil analysis open up new opportunities for improved management and control.

Climate change increases the risk of droughts, forest fires, pests and diseases that can reduce the carbon capacity of forests. Economic pressure on timber resources, illegal logging and weak institutional controls threaten the sustainability of the sector. If the transition to a greener economy is delayed, Bulgaria risks falling behind in achieving the EU's climate neutrality goals.

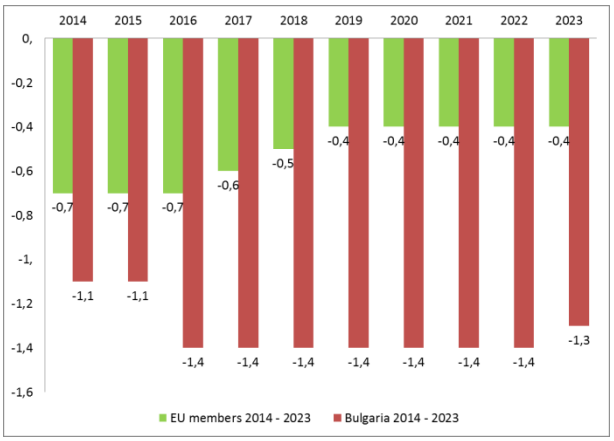

Fig. 3 *Net greenhouse gas emissions LULUCF sector [tCO_2e per capita] (Author).*

The present study also takes into account the fact that Bulgaria has a quantitative target set in the European Regulation 2018/841 [10] for the LULUCF sector: by 2030, net greenhouse gas removals in this sector must reach at least –9718 [$ktCO_2e$], which means that 9,718 [$MtCO_2$] equivalents must be offset annually [4]. This is Bulgaria's contribution to the overall EU target of achieving total net removals from this sector of 310,310 [$MtCO_2e$] by 2030.[12]

Each Member State has committed to increasing net removals from the land use sector by 2030 compared to the average level for the period 2016–2018.

The Fit for 55 package is a set of laws aiming to reduce EU greenhouse gas emissions by at least 55% by 2030 and put the EU to the path to achieve climate neutrality by 2050.

Removals are mainly from forests, while land use change and cropland account for the majority of emissions. From 2026, wetlands will also become a reporting category.

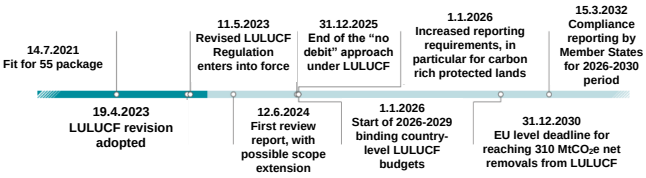

Fig. 4 *LULUCF Regulation: Implementation timeline [9].*

Achieving net removals in the LULUCF sector requires the implementation of sustainable and effective practices in land and forest management. Table 6 provides a summary of some good practices and approaches that can contribute to achieving the set goals in Bulgaria.

Table 6: *Good practices and approaches for reducing greenhouse gas emissions through LULUCF*

Approaches	Description
Afforestation	Planting new forests on unusable, unforested, eroded or degraded land, selecting tree species with high carbon absorption, such as beech, oak, ash, various types of pine
Forest restoration (reforestation)	Afforestation of deforested areas
Sustainable forest management	Reducing deforestation and promoting their natural regeneration and restoration and providing better conditions for biodiversity
Agroforestry	Grasslands with vegetation dominated by perennial grasses, with grazing being the predominant land use [22] Construction of green belts in arable land
Carbon storage in soils	Belowground carbon dominates grasslands, mainly in roots and soil organic matter [22] Controlled rotation of agriculture and pastures and improvement of soil structures
Protection of wet areas	Restoring peatlands, marshes and wetlands as well as key biodiversity habitats. These areas store more water and provide increased resilience during droughts when they can release the stored water
Mapping, modeling and monitoring of fire hazard areas	It enables preventive measures to be taken at the local and regional level to reduce the risk of forest fires, while also allowing real-time simulation of measures to stop a fire if it occurs.
Financial incentives and linking measures to EU funding	Common Agricultural Policy (CAP), LIFE Programme, Emissions Trading System (ETS) и Horizon Europe Motivation of owners and municipalities
Strict technological monitoring and control	Accurate planning, reporting and control

Forests are one of many carbon-rich ecosystems. Forests in the EU absorb around 7% of the EU's greenhouse gas emissions each year.[6],[17] The European Union is promoting the use of this valuable resource in the fight against climate change.[16] Forests can offset greenhouse gas emissions in other sectors such as transport, heating buildings, agriculture, waste management.[18] Intensive work needs to be done to protect and restore existing forests and woodlands, along with peatlands, coastal and marine habitats, to maximize their benefits for climate change mitigation and biodiversity.[15] The growing recognition of these benefits means that interest in nature-based solutions is growing: they can help people adapt to climate change, achieve sustainable development goals, protect biodiversity and mitigate its impacts.[16]

From consultations with forestry experts and based on data from the National Statistical Institute [7], Table 7 summarizes the optimal combination of tree species for afforestation.

Table 7: *Types of tree suitable for afforestation in Bulgaria*

Type	%	Characteristics
Common beech trees	60%	Long-lasting, high absorption capacity CO_2
Black pine	30%	Fast-growing, suitable for afforestation
Field ash/elm trees	10%	Good adaptation, contribute to biodiversity

A forest can consist of either closed forest formations, where trees of different storeys and undergrowth cover a high portion of the ground, or open forest.[22] The quantities of adsorbed CO_2 from the forest massifs can be calculated using the formula:

(3) Removals = Area (ha) × Absorption rate (t/ha/year) × Number of years

According to statistical data, the average rate of carbon absorption can be assumed to be 3,5 [tCO_2/ha/year] The most serious attention in the LULUCF sector should be paid to the regions most affected by deforestation. According to data from Global Forest Watch [19], the largest deforestation during the period 2001 to 2022 was observed in the area of Sofia ~10,3 thousand ha; Lovech ~10,0 thousand ha; Haskovo ~9,3 [thousand ha]; Smolyan ~9,2 [thousand ha]; Blagoevgrad ~9,1 [thousand ha]. [5] These five areas form about 34% of the total deforestation for the country.

In 2020, Bulgaria had 3,43 [Mha] of natural forest, extending over 31% of its land area. In 2024, it lost 3,30 [kha] of natural forest, equivalent to 1,33 [$MtCO_2e$] emissions.[19] In Bulgaria from 2001 to 2024, 3,9% of tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation. (Fig. 5)

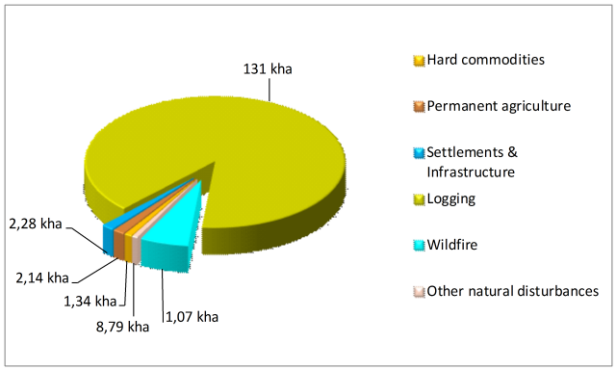

Fig. 5 *Drivers of deforestation In Bulgaria from 2001 to 2024. [19].*

It is visible that the logging and wildfire have largest share of deforestation during the period. This means that in order to achieve the set greenhouse gas removal targets, Bulgaria must take rapid and effective action on the management of LULUCF and in particular forest land.

Forecast data for measures in the LULUCF sector for the period 2025 ÷ 2030 are presented in Table 7.

Table 7: *General forecast for the period 2025÷2030*

Approaches	Scope [ha]	Expected effect [Mt CO_2]
Afforestation of abandoned lands	15 000	~4,5
Restoration of burned forests	10 000	~3,2
Agroforestry	7 000	~1,2
Windbreak forest filds	5 000	~0,9
Rewetting of wetlands	2 000	~0,8
Total	**~39 000**	**~10,6 Mt CO_2e**

If these forecasting is realized, the combination of afforestation, regeneration, agroforestry and wetlands could provide over 10 [$MtCO_2e$] of net removals by 2030, contributing to Bulgaria's LULUCF targets under EU Regulation 2018/841 [10]. Reducing emissions is key to meeting international commitments such as the Paris Agreement [20] and the Sustainable Development Goals (SDGs) [21]

Good management of LULUCF contributes not only to reducing greenhouse gases and achieving climate goals, but also ensures higher profitability and sustainability of agriculture, opens up prospects for the development of a green economy, increases the country's tourism rating and strengthens ecosystems.

5. Conclusion

Achieving net-zero carbon emissions and climate neutrality by 2050 and preventing climate change requires commitment and rapid action. This goal can be achieved not only through traditional methods of sustainable development, circular and green economy in the context of Industry 5.0. Natural solutions can help cool the planet. Analyses show that to limit global temperature rise, we must reduce emissions and invest now to protect, manage and restore ecosystems and the Earth for the future.[14]

Bulgaria has strong natural potential and a regulatory framework for sustainable forest and land management, but better control, financing and technological modernization are needed to become a real tool for reducing emissions and adapting to climate change.

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