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The Brown Economy: Material use, emissions, and the role of agriculture

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Abstract

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This study examines the "brown economy" of Bulgaria, understood as patterns of economic activity associated with intensive resource use, environmental degradation, and greenhouse gas (GHG) emissions. Using economy-wide material flow accounts and emissions data, the analysis assesses the scale, structure, and evolution of material use and environmental pressures, situating Bulgaria in a comparative European Union context. Particular attention is paid to biomass extraction and agricultural activities, given their importance for material flows, land use, and non-CO_2 emissions.

The results show that Bulgaria remains characterised by high reliance on domestic material extraction, limited circularity, and a material footprint above the EU average. Despite notable long-term reductions in GHG emissions, progress has been uneven across sectors, with persistent challenges in energy production, transport, and agriculture. Agricultural activities contribute structurally to emissions through livestock production, agricultural soils, and fertiliser use, while low circularity reflects limited reintegration of organic waste and residues into production cycles.

The findings highlight that further progress in transitioning towards a greener economic model requires not only continued decarbonisation of energy and transport, but also targeted measures addressing material use, waste management, and emissions in agriculture. Strengthening circular practices and improving resource efficiency across sectors are essential for reducing the environmental footprint of the Bulgarian economy.

Keywords: brown economy; material flows; greenhouse gas emissions; agriculture; circular economy; Bulgaria

Introduction

The term "Brown Economy" is generally used to describe economic activities that involve the exploitation of natural resources in environmentally unsustainable ways, often leading to pollution, resource depletion, and long-term ecological damage. In the context of agriculture, the brown economy is manifested in input-intensive farming systems characterised by heavy reliance on synthetic fertilisers and pesticides, fossil-fuel-based mechanisation, monoculture production, and unsustainable land-use practices. These production models contribute to soil degradation, nutrient runoff, biodiversity loss, and greenhouse gas emissions, placing agriculture at the centre of the interaction between economic activity and environmental pressure.

One of the consequences of the brown economy is the emission of vast amounts of climate-changing greenhouse gases (GHGs), resulting in intensification of climate change. Additionally, the brown economy is associated with significant water and air pollution, including the release of particulate matter into the environment. GHGs also pose a macro-significant challenge, as they can have notable adverse effects on the capital stock, agricultural output, productivity, and human mortality over the long term, resulting in substantial economic costs.

This study examines the "brown" aspects of the Bulgarian economy and is organised as follows:

It begins with an analysis of the material flows within the economy, encompassing resource extraction, product movement and waste disposal, which collectively illustrate the economy's "brownness" and its evolution over time. These material flows are shaped by economic activity, institutional structures, and household behaviour, all of which also affect air emissions. Whenever feasible, the indicators analysed are compared with those of the EU-27 countries for a broader context.

The study then shifts focus to greenhouse gas (GHG) emissions, examining recent trends, sectoral contributions, and the challenges policymakers face in achieving reduction targets, with particular emphasis on agriculture as a major source of non-CO_2 emissions linked to livestock production, fertiliser use, and land management practices. It explores strategies for addressing emissions, such as transitioning to renewable energy, improving energy efficiency, promoting sustainable transportation, and adopting greener agricultural practices. In the case of Bulgaria, long-term declines in GHG emissions are noted, but significant hurdles remain in sectors linked to the brown economy, including energy production, transportation, and agriculture. The study underscores the importance of aligning economic and environmental policies, highlighting tools like carbon pricing, clean technology subsidies, and investments in green infrastructure to foster sustainable development.

Material flows and the environmental footprint of the Bulgarian economy

Material resources are vital for sustaining economic activity and food production systems. In agriculture, material flows are dominated by biomass extraction, fertiliser and energy inputs, and water use, while residuals take the form of emissions to air, soil, and water. The scale and intensity of these flows have significant implications for environmental quality, soil fertility, and long-term agricultural sustainability. To analyse and quantify the flow of natural materials and their utilisation in the economy, EU countries have developed economy-wide material flow accounts (MFA), which cover extracted and traded raw materials but exclude water and air as direct material inputs; these appear only as balancing items and as emissions to the environment. MFA is best described as a statistical system that integrates economic and environmental information into a common framework, enabling the measurement of the environment's contribution to the economy and the economy's impact on the environment (Allwood et al., 2011; Statistik Austria, 2024; IRP, 2020). Like the system of national accounts, MFA constitutes a multi-purpose information system. The detailed material flows provide a rich empirical database for numerous analytical purposes, such as the analysis of domestic material consumption, resource productivity and the material footprint of the economy. This section outlines the main components of the material flow accounting system and compares data for Bulgaria with that of other EU nations.

Methodology - Material flow accounting system

Figure 1 displays the main flow accounts and indicators compiled by EU countries (Eurostat, 2024). These accounts capture the total flows of raw materials extracted from nature, goods imported into the society, changes in capital assets, waste and emissions released into the environment, and exports to other national economies. Together, they serve as vital tools for assessing an economy's sustainable development and its environmental footprint. To illustrate the physical exchange processes between society and nature, the entire national economy is represented as an input-output system. In material flow analysis, material inputs are categorised into several main flows – biomass, metal ores, non-metallic minerals, and fossil energy sources – and measured in physical units, typically tonnes. Inputs can be either extracted domestically or imported (directly and indirectly) from abroad.

On the output side, the analysis captures releases to nature via air, soil, and water, along with the dissipative use and loss of goods. The material flow accounting system incorporates also the so-called balancing items, which may be recorded as inputs or outputs. These items, such as the air required for combustion engines or the water demand of the drinks industry, significantly influence the water regime and air quality, even though they are not considered direct or unused withdrawals. When balancing items are included, the material balance of an economy can be expressed using the following equation:

$$\textit{Domestic Extraction (DE)} + \textit{Imports} + \textit{Balancing items} = \textit{DPO (Domestic Processed Output)} + \textit{Exports} + \textit{Balancing Items} \pm \textit{Changes in stocks}$$

Some indicators that are derived from the economy-wide material flow accounts are:

- **Direct material input (DMI)**: Refers to the total amount of materials entering an economy that have economic value and are available for use in production and consumption activities;
- **Domestic Material Consumption (DMC)**: This indicator measures the total amount of materials directly used by an economy. It is calculated as the annual quantity of raw materials extracted domes-

tically, plus all physical imports, minus all physical exports:

Direct material input =
Domestic extraction + Physical imports
Domestic material consumption =
Domestic extraction + Physical imports – Physical exports =
= Direct material input - Physical exports

By comparing direct material input (DMI) and domestic material consumption (DMC), different types of economies can be distinguished: (a) transit economies with high levels of both imports and exports (such as Belgium and the Netherlands), (b) economies, where domestically extracted materials are predominantly used within the country (notably Bulgaria, Cyprus, Finland, Ireland, Hungary, Poland, and Romania), and (c) extraction-based exporting economies, where a large share of extracted materials is exported (especially Norway).

Resource Intensity/Productivity: MFA data enable the measurement of an economy's resource efficiency. This is done by comparing the economic development of a country, i.e. the gross domestic product (GDP), with the domestic material consumption (DMC). The material intensity (DMC/GDP) shows how many material units are needed to produce one unit of the GDP. On the other hand, resource productivity (efficiency), represented by the ratio GDP/DMC, shows how much value-added can be produced with one unit of material input;

The indicators mentioned above are based on the physical weight (in tonnes) of imports and exports. However, the simple weight of traded goods offers an incomplete perspective, as it does not account for the raw materials originally required to produce these goods. A more comprehensive understanding of the "material footprints" can be achieved by converting traded goods into their raw material equivalents (RME) – the total amounts of raw materials needed to produce the respective traded goods.

This is particularly relevant for finished and semi-finished products, where imports and exports in RME are significantly higher than their corresponding physical weight. For example, the production of the battery of an imported electric car likely requires significantly more raw materials in terms of weight (e.g. metal ores) to produce than the weight of the battery itself. Eurostat provides estimates for exports and imports in RME, which result in related indicators for DMI and DMC, referred to as Raw Material Input (RMI) and Raw Material Consumption (RMC), respectively:

- **Raw material input (RMI):** the amount of raw materials required to produce the goods which are

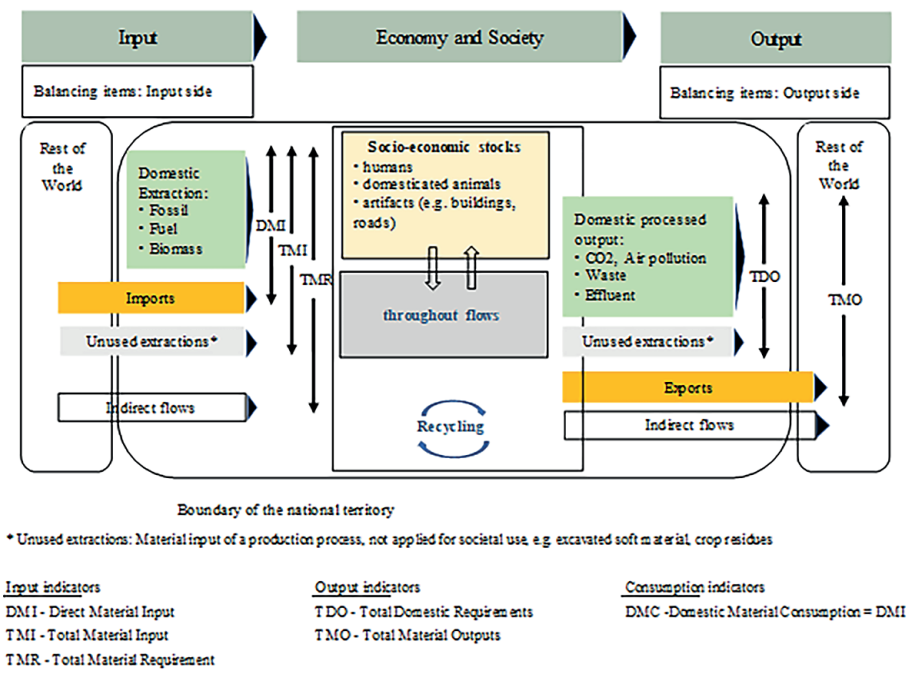


Fig. 1. Economic analysis of material flows
Source: Eurostat (2024), Environment Agency Austria

available for use in production and consumption activities;

- **Raw material consumption (RMC):** measures the total amount of raw materials required to produce the goods used by the economy. RMC is often referred to as the "material footprint" of the economy:

Raw material input =
= Domestic extraction + Imports in RME
Raw material consumption =
Domestic extraction + Imports in RME – Exports in RME =
= Raw material input - Exports in RME

Material flows in Bulgaria

Figure 2 displays a Sankey diagram illustrating material flows within the Bulgarian economy in 2023. The diagram represents the quantities of materials extracted, imported, recycled or disposed of, along with related emissions. Flows are depicted from left to right, with the width of the bands proportional to the quantity of the flow, measured in millions of tonnes. The materials shown include: (1) biomass, which in Bulgaria is primarily associated with agricultural production, including food crops, feed crops for livestock, agricultural residues, and timber, and plays a central role in shaping the environmental footprint of the agricultural sector; (2) metals, vital for construction and manufacturing activities; (3) non-metallic minerals, extensively used in building materials like cement and glass; and (4) fossil energy carriers, such as oil, coal and natural gas, which are used to produce transport fuels, generate electricity or produce materials like plastics and fertilisers. The diagram excludes water and renewable energy sources that do not involve material flows, such as electricity from photovoltaic panels or wind power. Fossil fuel carriers and biomass, such as wood, contribute to air emissions, which are depicted on the right side of the figure as a result of being burned to release energy.

Figure 2 illustrates that of the 184 million tonnes of raw materials processed in Bulgaria, 81% (149 million tonnes) originated from domestic extraction, 16% (29 million tonnes) from imports, and 4% (7 million tonnes) from recycling and backfilling activities. Of the total materials processed, 62% (114 million tonnes) were used to make manufactured products, while the remainder was primarily exported or utilised for energy production. Regarding the manufactured products (represented by the 'material use' node in Figure 2), which are aimed at use within the domestic economy, it is important to note that products vary significantly in terms of their lifecycle. These range from single-use products (e.g. packaging materials) to short-lived products (e.g. clothing, typically used for a few months to a year), long-life products (e.g., vehicles and appliances), and assets like roads and bridges.

A significant portion of construction minerals, in particular, is used to expand or maintain the in-use stocks of buildings and infrastructure. These stocks often remain in use for decades and only become available for recycling at the end of their lifecycle. As the economy grows, these materials accumulate in the form of gross additions to stock each year, while some older materials are removed as buildings are demolished and durable goods are disposed of – referred to as removals. In 2023, Bulgaria's net material

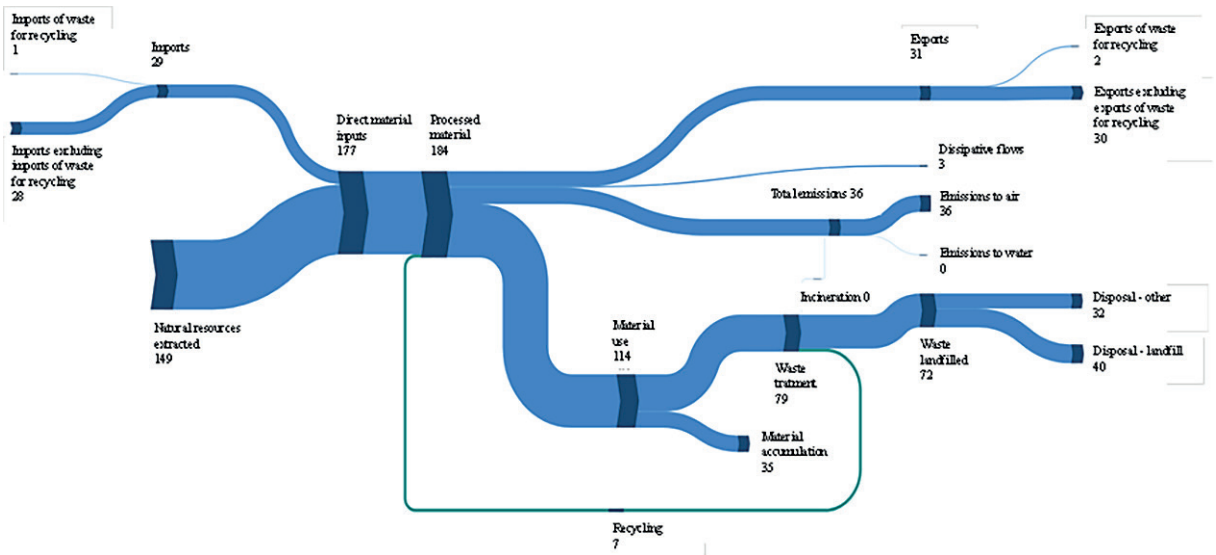


Fig. 2. Sankey diagram of material flows for Bulgaria (million tonnes)

Source: Eurostat (2024)

accumulation reached 35 million tonnes. As long as the demand for raw materials to support long-lived in-use stocks, such as buildings and infrastructure, exceeds the supply of materials from recycling, primary extraction will continue to be necessary.

As a result of economic activity and household behaviour, some of the materials used in the economy lead to waste. The "waste treatment" node produces several types of outputs. Incineration refers to waste burned to generate energy, although this process also results in air emissions. Waste landfilling involves disposing of waste in landfills or through other similar methods. Recovery pertains to reprocessing waste materials into products, materials, or substances for reuse, either for their original purpose or for other applications, encompassing both recycling and backfilling operations. In Figure 2, the share of recycled materials, represented by the green loop in the 'processed materials' node, is often used as a proxy for the economy's circularity. From an agricultural perspective, the low circularity rate reflects the limited reintegration of organic waste, crop residues, and livestock manure into production cycles, indicating untapped potential for nutrient recycling and soil restoration. More broadly, the low circularity rate of the Bulgarian economy points to a structural reliance on primary material extraction and landfilling, combined with insufficient recovery and reuse of waste streams, which limits the transition towards more resource-efficient and sustainable production systems.

A more advanced measure, known as the circularity rate, is discussed further below. In 2023, recycling and backfilling flows involved around 4% of overall material inputs to the Bulgarian economy compared to 12% on average for the EU-27 economy. In Bulgaria, the waste produced by the use of materials, including the material removed from the stocks at end-of-life (demolition and discards), accounted for 79 million tonnes in 2023. Figure 2 reveals that most of the waste in Bulgaria is landfilled.

The upper right side of the Sankey diagram illustrates the outputs from the economy to the rest of the world, which can be grouped into three main types. The first type is the export of products, including materials and goods such as machinery or agricultural products sent to other economies. The second type includes emissions to air and water, representing flows of solid, liquid, and gaseous materials released into water bodies, such as lakes and rivers, or emitted into the atmosphere. The third type consists of dissipative flows, which refer to materials dispersed into the environment either deliberately or as an unavoidable consequence of product use, given current technology. Examples of such flows include road salt used for de-icing and particles released from brake pads during use. According to the data, in 2023, the majority of the outputs from the economy were in the form of emissions into the air (36 tonnes) and exports (31 tonnes).

Eurostat has developed a specifically constructed indicator for measuring the circular economy. It is called the "circular material use rate" – referred to as the *circularity rate* – and it measures the contribution of recycled materials towards the overall use of materials (Ellen MacArthur Foundation, 2019; EEA, 2020). The circularity rate is the share of material resources used in the economy which came from recycled waste materials, thus saving primary raw materials from being extracted. A higher circularity rate means that more secondary materials replace primary raw materials, thus reducing the environmental impacts of extracting primary material. In 2023, the Bulgaria's circularity rate was 4.9%, or 2.8 percentage points up from 2010, the first year for which data are available for Bulgaria. In comparison, the EU's circularity rate was 11.8% in 2023 (compared with 10.7% in 2010 and 8.2% in 2004) (Table 1).

Material footprint of the Bulgarian economy

Raw material consumption (RMC), also known as material footprint, represents the total amount of extracted raw materials required to produce the goods and services consumed by a country's residents. Figure 3 illustrates the development of Bulgaria's material footprint from 2008 to 2023. RMC peaked at around 23 tonnes per capita in 2022, following the COVID-19 pandemic. This peak likely reflects the robust post-pandemic economic recovery and increased domestic and foreign demand for Bulgarian goods and services, including a surge in construction activity.

Over the long term, there is an upward trend in RMC, which partly reflects increased demand for biomass and material inputs associated with agricultural production, food processing, and related rural infrastructure. This trend underscores growing pressure on land, soils, and natural resources. In 2008, RMC stood at 19.7 tonnes per capita, but the global financial crisis triggered a significant decline, reducing it to approximately 15 tonnes per capita during 2009–2013, reflecting subdued economic activity. In the subsequent years, RMC resumed its upward trajectory, surpassing the threshold of 20 tonnes per capita since 2019.

Figure 4 shows that for EU countries, the average RMC decreased slightly from 14.9 tonnes per capita in 2010 to 14.1 tonnes per capita in 2023. Despite this overall decline, there is substantial variability across countries. Compared to 2010, sixteen countries managed to reduce their material footprints over the years, with five of them achieving a reduction of more than 25%. In contrast, thirteen European countries experienced an increase in RMC per capita. In 2023, Bulgaria ranked 9th in terms of RMC, starting from the

Table 1. Circularity rate (2010–2023)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU	10.7	10.2	11.0	11.2	11.1	11.2	11.4	11.5	11.6	11.2	11.2	11.1	11.5	11.8
Belgium	135	14.4	17.3	173	175	18.0	18.0	19.0	20.0	205	225	21.4	13.3	15.7
Bulgaria	2.1	1.8	1.8	2.5	2.7	3.1	4.3	3.4	2.4	4.0	5.8	4.3	3.0	4.9
Czechia	5.3	5.4	6.3	6.7	6.8	6.9	7.5	9.1	105	10.6	11.5	11.0	11.3	12.8
Denmark	8.0	7.0	6.4	7.7	9.0	8.3	9.0	7.9	8.1	7.9	7.8	8.6	9.3	9.1
Germany	11.2	10.6	11.0	11.1	11.2	11.6	11.8	11.6	12.0	12.4	12.8	12.2	12.5	13.9
Estonia	9.0	14.5	19.2	14.7	11.3	11.4	11.9	12.5	13.8	15.3	16.4	20.0	21.4	18.1
Ireland	1.9	2.2	1.9	1.9	2.2	2.1	2.0	1.9	1.9	1.8	1.8	2.1	2.1	2.3
Greece	2.5	2.0	1.8	1.7	1.3	1.8	2.1	2.5	3.0	3.3	4.2	5.3	6.3	5.2
Spain	10.4	9.9	9.8	8.9	7.7	7.6	8.2	8.8	8.9	9.0	9.3	8.8	9.4	8.5
Fiance	17.5	16.9	16.8	17.2	17.8	18.8	19.3	18.7	19.5	17.1	16.2	15.9	17.5	17.6
Croatia	1.6	2.4	3.5	3.9	4.8	4.6	4.1	5.1	5.0	5.4	5.5	6.1	6.8	6.2
Italy	11.6	11.6	13.9	16.0	16.1	17.2	17.8	18.4	18.8	18.8	20.6	19.7	20.6	20.8
Cyprus	2.0	1.9	2.0	2.4	2.2	2.4	2.4	2.4	2.8	3.2	3.8	5.9	8.5	5.4
Latvia	1.2	2.9	1.3	3.9	5.3	5.3	6.6	5.5	4.7	4.8	5.2	5.0	4.5	5.0
Lithuania	3.9	3.6	3.8	3.1	3.7	4.1	4.6	4.4	4.3	3.9	4.0	4.1	4.0	3.9
Luxembourg	23.4	19.8	17.7	15.2	11.1	9.6	7.1	10.6	10.8	9.1	9.4	8.5	12.3	10.2
Hungary	5.2	5.4	6.0	6.1	5.3	5.7	6.3	6.7	6.9	5.5	5.1	5.0	4.9	5.9
Malta	5.3	4.5	3.9	6.3	6.4	4.6	4.2	6.5	8.3	12.8	16.5	19.2	21.5	19.8
Netherlands	25.5	25.0	26.3	26.8	26.5	26.7	29.0	26.7	25.8	25.6	27.1	28.5	27.2	30.6
Austria	6.8	6.9	7.9	9.1	9.9	11.2	11.9	12.0	11.8	11.5	11.4	11.3	12.4	14.3
Poland	11.1	9.4	11.0	12.2	13.0	11.9	10.6	10.4	10.5	9.2	7.4	7.0	6.7	7.5
Portugal	1.8	1.7	2.0	2.5	2.4	2.1	2.1	2.0	2.2	2.3	2.5	2.7	3.3	2.8
Romania	3.5	2.5	2.6	2.5	2.1	1.7	1.7	1.8	1.6	1.4	1.5	1.5	1.5	1.3
Stovenia	5.9	7.6	9.4	9.3	8.5	8.7	9.8	10.1	10.2	9.9	8.9	8.3	8.8	8.8
Slovakia	5.0	4.7	4.0	4.5	4.8	5.0	5.2	4.9	4.7	8.3	10.3	10.4	11.5	10.6
Finland	10.7	11.4	12.2	7.9	5.5	4.9	3.8	4.4	4.4	4.5	4.4	5.1	5.4	2.4
Sweden	7.2	7.6	8.2	7.2	6.4	6.7	6.9	6.7	6.6	6.4	69	9.5	12.1	9.9

Source: Eurostat (2024)

highest value of the indicator, with Finland having the highest material footprint and the Netherlands the lowest.

Although Eurostat does not provide a breakdown of RMC by main material categories, such a breakdown is available for domestic extraction activities, which, as shown in Figure 2, account for the majority of RMC. According to Figure 5, non-metallic minerals represent the largest material category, with their development often closely linked to the activity level of the construction industry. Metal ores extraction is the second-largest category and has been steadily increasing over time. Over the long term, the use of fossil fuels (in tonnes per capita) has declined, while the use of biomass has increased.

An analysis of the components of resource productivity (Figure 6), namely GDP and domestic material consumption (DMC), provides insights into the evolution of resource pro-

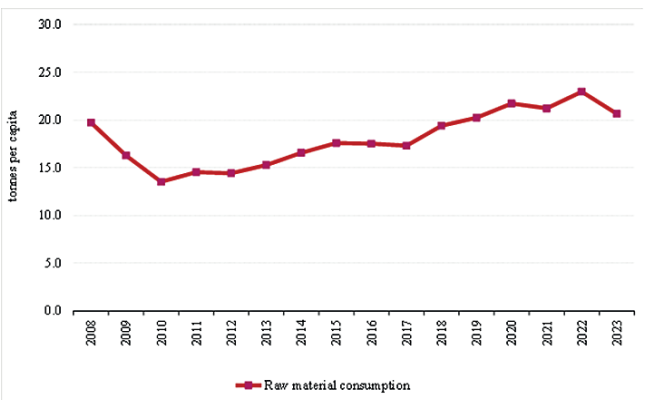


Fig. 3. Material footprint (RMC) of Bulgaria over the period 2008–2023 (tonnes per capita)
Source: Eurostat (2024)

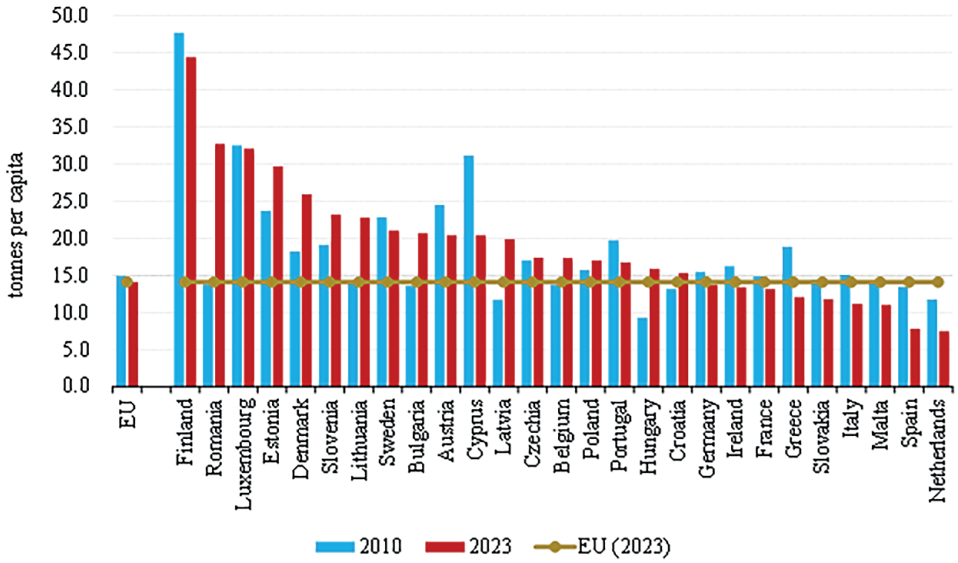


Fig. 4. Material footprint (RMC) by country, 2010 and 2023 (tonnes per capita)
Source: Eurostat (2024)

ductivity over time. Between 2016 and 2020, GDP and DMC grew at nearly the same pace, resulting in relatively stable resource productivity. However, during the recovery from the COVID-19 pandemic in 2021 and 2022, DMC increased more rapidly than GDP, leading to a decline in resource productivity. This trend was reversed in 2023 when DMC decreased while GDP continued to grow strongly.

The recent dynamics of DMC may have been influenced by the significant build-up of inventories in 2021–2022 and their subsequent reduction in 2023, driven by disruptions in global supply chains caused by the pandemic and the war in Ukraine. Over the long term, there is evidence of an improvement in resource productivity in Bulgaria. By 2023, resource productivity was approximately 20% higher than in 2014. This suggests that the increase in DMC and the material footprint of the economy in general is primarily driven by rising economic activity, with only a partial offset from improvements in resource productivity.

GHG emissions in Bulgaria

As shown in Figure 2, emissions to the air are the largest output from the economy. Gas emissions are often regarded as a key characteristic of the brown economy. This section of the study examines data on greenhouse gases (GHGs). Bulgaria has achieved remarkable progress in reducing GHG emissions over the past three decades. Between 1990 and

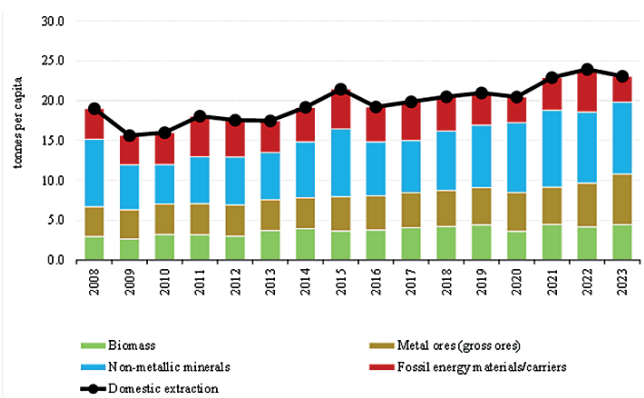


Fig. 5. Domestic extraction by main material categories, Bulgaria, 2008–2023 (tonnes per capita)
Source: Eurostat (2024)

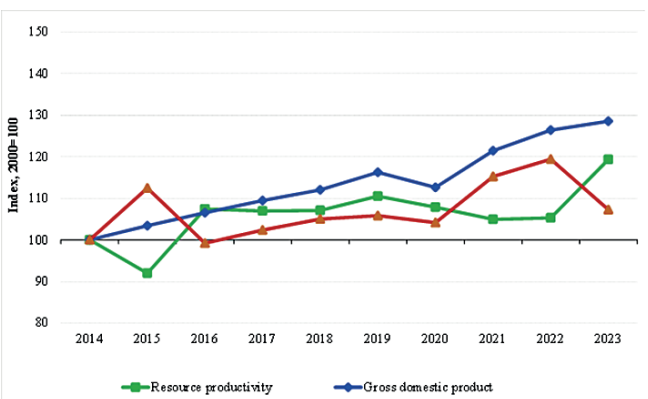


Fig. 6. Development of resource productivity in comparison with GDP and DMC, Bulgaria, 2014–2023
Source: Eurostat (2024)

2021, emissions per capita decreased by 30.1%, a figure closely aligned with the average reduction observed across the EU-27 (32.9% on average, as depicted in Figure 7). Although this progress is noteworthy, the majority of it occurred before 2003, primarily reflecting the decline in real GDP due to the restructuring of the Bulgarian economy amid the transition to a market economy (Figure 8). Nevertheless, between 2005 and 2021, GHG emissions experienced a moderate decrease despite the upward trajectory in economic activity, suggesting an improvement in the efficiency and carbon intensity of the economy. As of 2021, Bulgaria's per capita emissions ranked 17th among EU Member States.

By institutional sectors, firms account for 93% of all GHG emissions, with households contributing just 7% (Figure 9). According to Eurostat data, the electricity and heating sector has the highest GHG emissions, but it also recorded the most substantial improvement between 2008 and 2022,

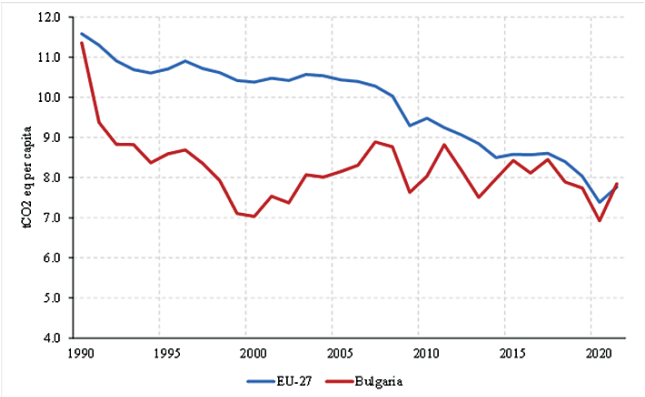


Fig. 7. GHG emissions per capita in Bulgaria and EU 27
Source: European Energy Agency (EAA) (2020)

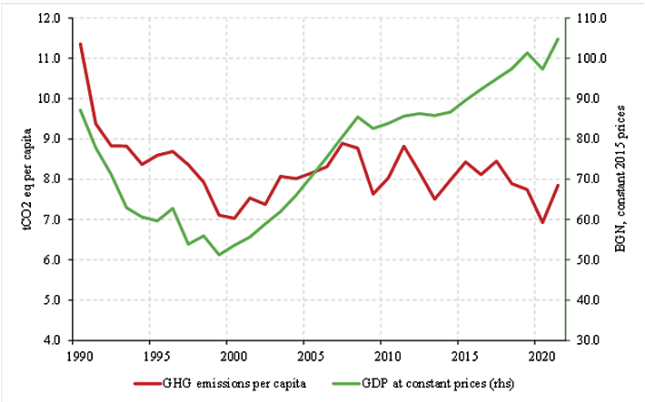


Fig. 8. Gross domestic product and GHG emissions per capita in Bulgaria
Source: European Energy Agency (EAA) (2020)

likely due to its inclusion in the EU Emissions Trading System (ETS). The heightened GHG intensity observed in the electricity and heating sector is, in part, a result of geographical and legacy challenges. Bulgaria continues to contend with inefficient brown assets across its energy sector. Coal, which is readily available domestically, has long been the predominant source for electricity generation in the country. However, in recent years, Bulgaria has succeeded in decreasing the reliance on coal-fired thermal power plants while augmenting the utilisation of renewable energy (Figure 10). This shift may explain the downward trajectory of GHG emissions in the electricity and heating sector over the long-run period.

Activities related to manufacturing, mining, quarrying, and construction constitute the second-largest source of emissions, yet firms in these sectors also achieved a significant decrease in GHG emissions after 2008. The decrease in emissions likely stems from several factors, such as a reduction in the gross value added of the construction sector as a proportion of total value added, along with improved emission efficiency in the manufacturing sectors with the highest GHG intensity, including the production of coke and refined petroleum products, chemicals, rubber, and basic metals. Here, efficiency is measured by GHG emission intensity, i.e. kilograms of GHG emissions per euro of value added, as published by Eurostat; a lower value indicates that less emissions are generated for each unit of economic output.

As for households, their GHG footprint has also decreased since 2008, reflecting a lower CO_2 intensity in household activities beyond heating/cooling and transportation. Despite the implementation of government-supported schemes aimed at energy-saving measures in residential buildings in recent years, GHG emissions from heating/cooling activities by households in 2022 slightly exceeded their level in 2008.

Data from Eurostat reveals that both firm and household transportation activities are significant contributors to GHG emissions in Bulgaria, and their levels have increased significantly since 2008. This could be attributed to the surge in transport activities of courier and freight forwarding firms due to the COVID-19 pandemic. In addition, transport activities fall outside the scope of the ETS, and as of 2022, Bulgaria lacked low-CO_2 emission zones in major cities. Activities related to the agricultural sector also witnessed an increase in GHG emissions between 2008 and 2022, driven mainly by livestock production, agricultural soils, and fertiliser application. Unlike emissions from energy and industry, agricultural emissions are largely non-CO_2 and biologically embedded, making their mitigation more complex and policy-sensitive (Figure 11). From an EU-wide perspective, Bulgaria is among the few countries that have recorded an

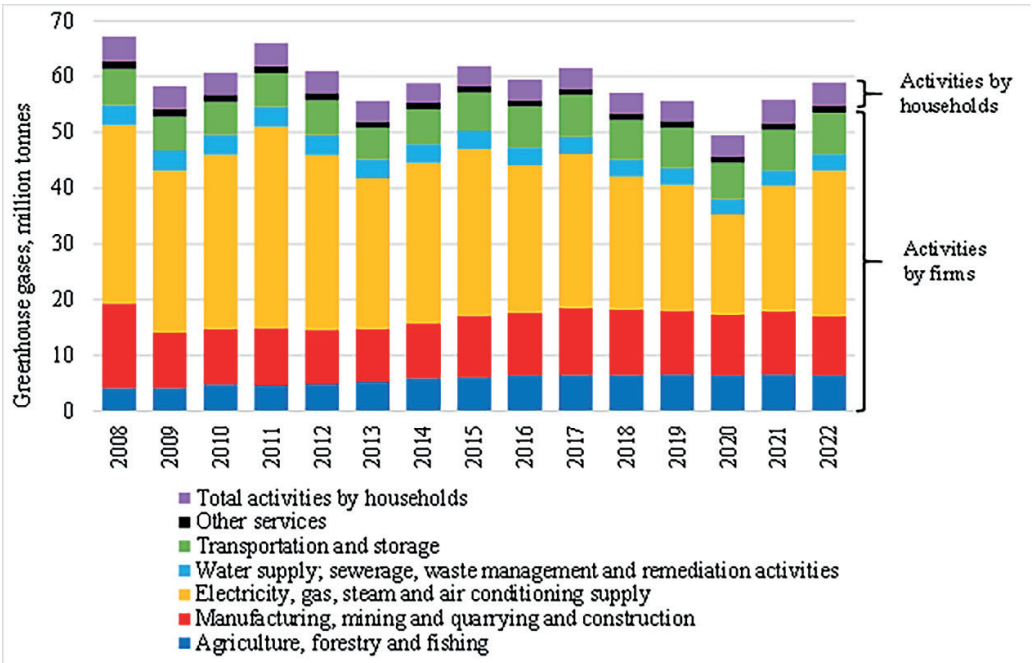


Fig. 9. GHG Emissions by Institutional Sectors (million tonnes in CO_2 equivalent per year)
Source: Eurostat (2024)

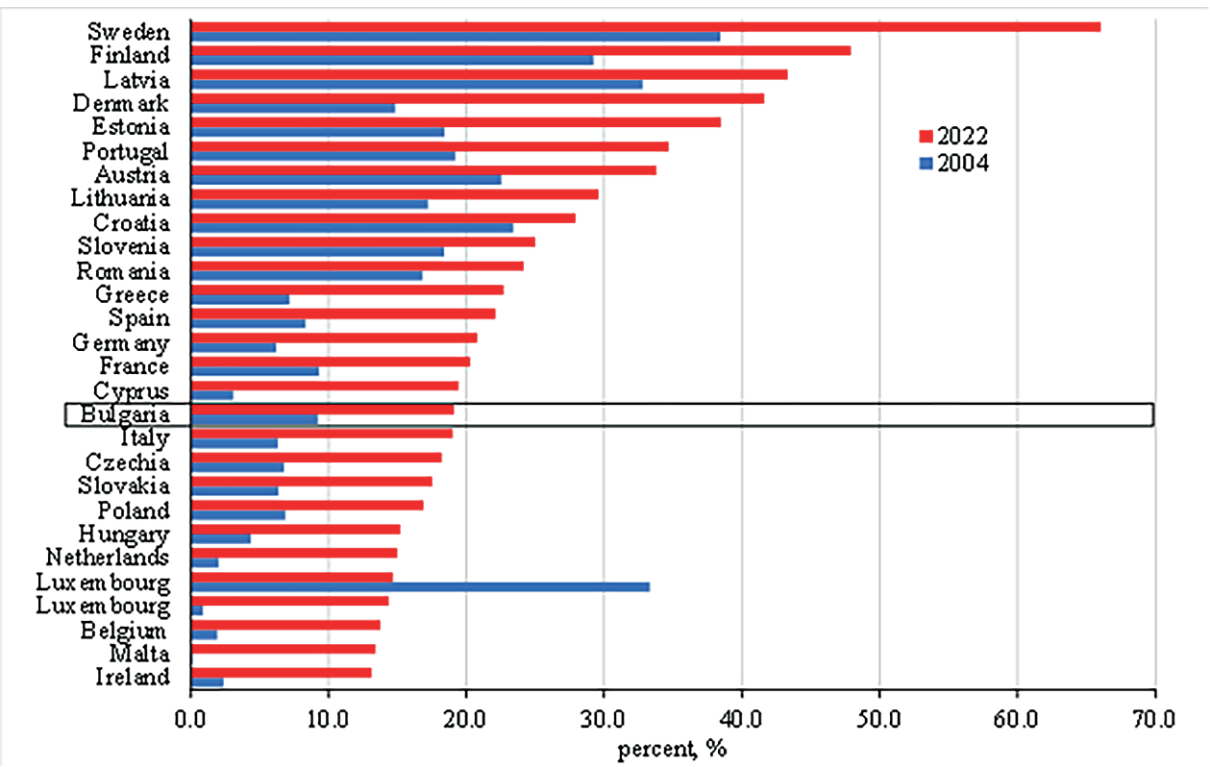


Fig. 10. Share of energy from renewable sources
Source: Eurostat (2024)

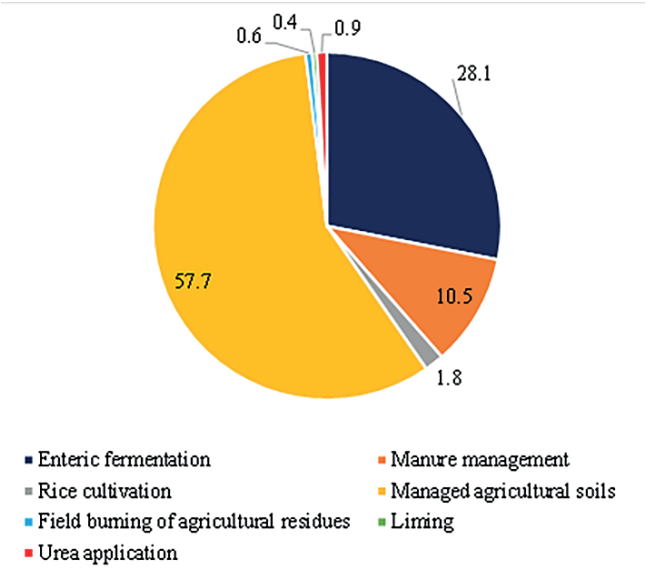


Fig. 11. Structure of GHG Emissions by source in agriculture (%), 2022
Source: Eurostat (2024)

increase of more than 1% in greenhouse gas emissions from agriculture since 2005, alongside Estonia, Latvia, Poland, Ireland, and Luxembourg (Figure 12). In fact, 19 out of the 27 EU Member States have reported a reduction in greenhouse gas emissions from agriculture since 2015, with Croatia recording the largest decline (-30.3%).

Based on the available data, we can conclude that Bulgaria has made significant headway in transitioning from a "brown" to a "green" economy, yet the country still grapples with several major challenges in reducing GHG emissions. Firstly, as of 2022, the economy remains reliant on coal for energy production. Secondly, carbon intensity per value added surpasses the EU average level. Thirdly, the transportation sector contributes significantly to GHG emissions, partly due to the aging motor vehicle stock and slow implementation of low-CO_2 emission zones by city authorities. Lastly, Bulgaria is burdened with low-efficiency housing stock. In addition, the agricultural sector remains a persistent source of greenhouse gas emissions, particularly through livestock production, agricultural soils, and fertiliser use, highlighting the need for targeted mitigation measures beyond energy and transport policies.

Policy measures and implementation challenges for reducing GHGs

The policymakers' strategy for transitioning to a green economy is outlined in the Integrated Energy and Climate Plan of the Republic of Bulgaria 2021–2030 (2020). Bulgaria is set to revise its energy and climate plan in 2024, with certain aspects of the updated strategy already released. According to the revised plan, the government aims to elevate the share of energy from renewable sources in gross final energy consumption to 29.9% by 2030 (Republic of Bulgaria (2024) draft plan). Other targets encompass a decrease in primary energy consumption by 12.1% by 2030 compared to the 2020 reference scenario, as well as a reduction in final energy consumption by 11.1% by 2030 relative to the 2020 reference scenario. These national targets are in line with the EU's targets for reducing GHG emissions by 55 percent by 2030 and achieving net carbon neutrality by 2050. With respect to agriculture, the national plan envisages that by 2030 greenhouse gas emissions will decline to 11.9% above their 2005 level, compared with 19.9% in 2023. Notably, this reduction is projected to occur in the absence of agriculture-specific mitigation measures.

Bulgaria's strategy for decarbonisation revolves around three primary areas: (1) reforming the energy supply mix; (2) improving the energy efficiency of buildings; and (3) reducing the carbon intensity of the transportation sector (Takizawa and Vassileva, 2022). However, achieving a meaningful transition away from brown economic practices also requires agriculture-specific measures, including incentives for sustainable farming, improved nutrient management, precision agriculture, and the integration of circular bioeconomy principles within the agri-food sector. The reform of the energy supply mix is aimed at decreasing the reliance on coal for energy generation; expanding nuclear capacity; and boosting investment in renewable energy sources. The goal of reducing the carbon intensity of transportation activities is expected to be attained by encouraging low- or zero-carbon modes of transportation, such as public transport and electric vehicles. The primary tools for reaching these objectives include the funds allocated through the Recovery and Resilience Plan (RRP), the increasing costs of CO_2 emissions under the existing Emissions Trading System (ETS), which will impact the economic viability of coal-fired thermal power plants (TPPs), and the deregulation of the retail electricity market for households (Republic of Bulgaria, 2020a, 2020b, 2022). The liberalisation of this market will strengthen price signals within the economy, enabling carbon prices embedded in the ETS to be passed on to retail consumers. This, in turn, will bolster incentives for efficiently reducing carbon emissions.

The implementation of government measures aimed at reducing GHG emissions encounters several challenges. First, the government must implement measures to mitigate the impact on vulnerable households after the retail electrici-

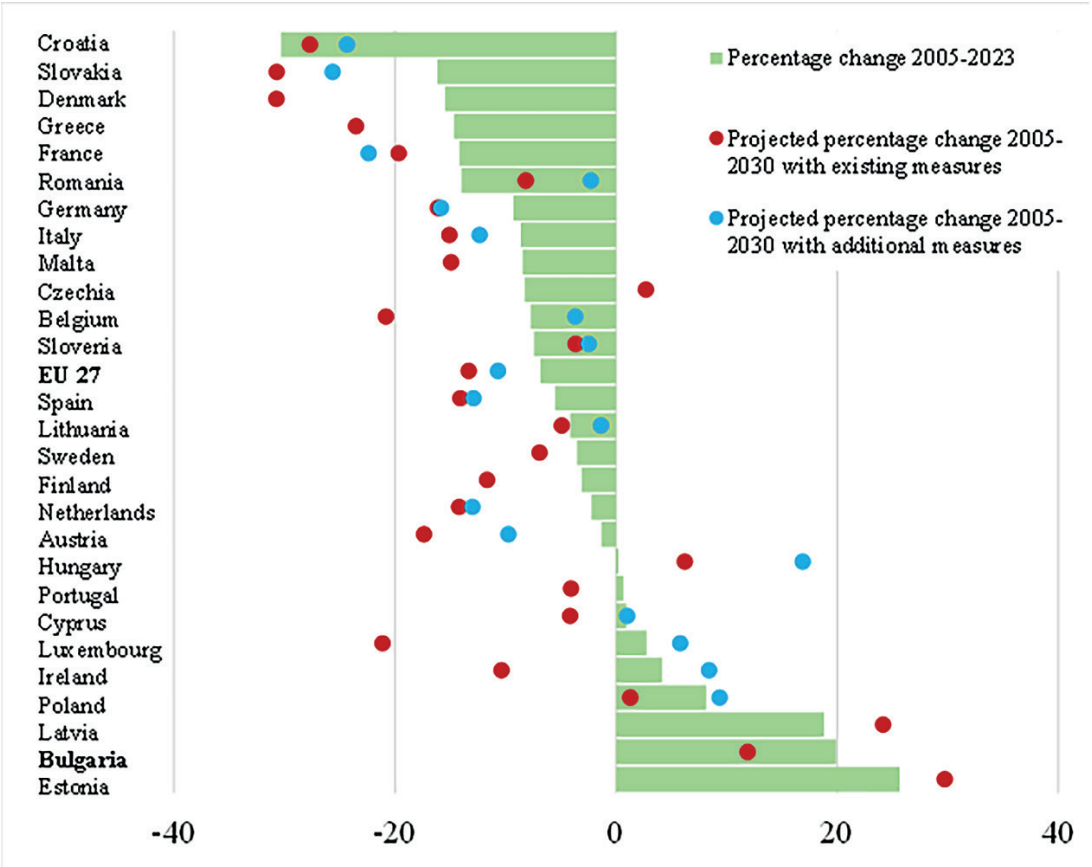


Fig. 12. Agricultural emissions and projected emissions by EU Member State
Source: Greenhouse gas inventory and GHG projections, European Environment Agency (EEA) (2020)

ty market is liberalised. Secondly, the phasing out of coal usage could significantly affect coal-dependent communities, particularly concentrating the impact in a few regions, such as Stara Zagora. Third, higher carbon prices might result in a loss of price competitiveness for energy-intensive firms, potentially leading to their relocation outside of Bulgaria (European Commission, 2020; Vandeplas et al., 2022).

Conclusion

The analysis highlights the pressing need for Bulgaria to transition from a "brown" to a "green" economy, with agriculture playing a central role in this transformation. Given its dominance in biomass extraction, land use, and non-CO_2 greenhouse gas emissions, the agricultural sector represents both a major source of environmental pressure and a key opportunity for advancing sustainability through circular practices and improved resource efficiency. Despite some progress, such as reductions in greenhouse gas (GHG) emissions and incremental improvements in resource productivity, the country's reliance on environmentally detrimental practices continues to pose significant challenges.

The intertwined nature of Bulgaria's economic development and environmental impact underscores the complexity of achieving sustainable growth. Material flows in the economy remain dominated by domestic extraction, with limited reliance on recycling and circular practices. The country's low circularity rate of 4.9% in 2023 starkly contrasts with the EU average of 11.8%, highlighting the untapped potential for integrating secondary materials into production processes. Enhancing the circular economy not only aligns with environmental goals, but also offers economic benefits through resource efficiency and cost savings.

While Bulgaria has achieved notable reductions in GHG emissions over recent decades, much of this progress stems from structural changes during the transition to a market economy. More recent declines in emissions reflect improvements in energy efficiency and the adoption of renewable

energy sources. However, challenges remain, particularly in the energy and transportation sectors. The continued reliance on coal-fired power plants, aging vehicle fleets, and the absence of low-emission zones in major cities contribute significantly to Bulgaria's carbon footprint.

Bulgaria's "Integrated Energy and Climate Plan 2021-2030" outlines ambitious targets, including increasing renewable energy use to nearly 30% and achieving significant reductions in energy consumption by 2030. However, achieving these goals will require addressing structural barriers, such as energy-intensive industries, inefficient housing stock, and the socio-economic impact of coal phase-outs on local communities. Policies promoting energy efficiency, clean transportation, and green infrastructure will be critical to overcoming these hurdles.

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