Losing active substances in plant protection: impacts on Bulgaria's agricultural production, food self-sufficiency and foreign net trade balance

HFFA Research GmbH

(corresponding authors: Steffen Noleppa and Juliane Kaufmann)

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List of abbreviations

BFSA	–	Bulgarian Food Safety Agency
BMEL	–	Bundesministerium für Ernährung und Landwirtschaft
CfS	–	Candidate(s) for Substitution
DLG	–	Deutsche Landwirtschaftsgesellschaft
DLR	–	Dienstleistungszentrum Ländlicher Raum
EC	–	European Commission
EU	–	European Union
FAO	–	Food and Agriculture Organization
OSR	–	Oilseed Rape
PPP	–	Plant Protection Product(s)
TFP	–	Total Factor Productivity

1. Introduction

1.1 Context of the study

Food sovereignty and more particularly food self-sufficiency have become prominent topics of political debate not only at the global level, but also within the European Union (EU) and Bulgaria. After decades of prioritizing the global market, the EU has returned to the question of whether it can secure sufficient supplies of domestically produced agricultural commodities – and above all, food – for its population. In parallel, attention has turned to the foreign agri-food trade balance as a core indicator of resilience, competitiveness, and external vulnerability. Reliable domestic supply is now widely viewed as essential for economic stability, political independence, and sustainable development as recent disruptions have highlighted the fragility of global supply chains. The COVID-19 pandemic (see Arita et al., 2022; Bai et al., 2022) and Russia's war of aggression against Ukraine (see Osendarp, 2022; Alexander et al., 2023; Zhang et al., 2023) demonstrated the risks of overreliance on imports and exposed imbalances in agri-food trade flows and reignited public debate about maximizing food self-sufficiency (see Hutton, 2022; Terpitz, 2025).

Alongside these crises, other factors are contributing to the growing recognition of food sovereignty and a sound agri-food trade balance as a cornerstone of stability, security and risk prevention, including accelerated climate change, new environmental goals, shifting geopolitical and trade dynamics, slow innovation and poorly designed regulatory mechanisms (see Noleppa and Capri, 2022). This recognition is reflected in the European Preparedness Union Strategy (EC, 2025b) and the newly published Vision for Agriculture and Food (EC, 2025c), both of which identify food security and a competitive agri-food sector with a sustainable trade position as a political priority in building a resilient EU agricultural sector.

This raises the question of how well individual EU member states can meet their own food demand and reduce external dependencies. In the case of Bulgaria, domestic agricultural production currently covers well above 100 percent of the national food needs (Brankov et al., 2021). This means that the South-Eastern European country does not depend on net imports to cover its overall demand for agricultural and food products. However, with respect to some starchy roots, sugar, fruits, and vegetables, Bulgaria is already considered not self-sufficient (see, again, Brankov et al., 2021), underscoring both the limits of domestic production capacity and the country's exposure to external market fluctuations.

Maximizing domestic production and productivity is one of the key factors for securing stable supply and reducing external dependencies. For agriculture, and crop production in particular, this translates into securing the highest possible yields. Plant protection products (PPP) are still a cornerstone of stable and high-yield crop production in both Bulgaria and EU. However, they are also among the most tightly regulated inputs in European agriculture. Active substances must undergo multi-year approval and authorization processes before entering the market, and once approved, are subject to repeated and extensive re-evaluations. Decisions on their continued use increasingly reflect a difficult balance between promoting sustainable farming and ensuring adequate protection of crops. Regulatory developments are central to this trend and the EU's portfolio of active substances is undergoing profound change. Efforts to reduce PPP use combined with evolving evaluation criteria and future policy requirements raise questions about which substances will remain available in the medium term.

In the last 15 years, the placing of PPP on the market has been governed primarily by Regulation (EC) No. 1107/2009, which introduced two provisions that particularly have narrowed the spectrum of approved active substances significantly:

- Cut-off criteria: Active substances classified as carcinogenic, mutagenic, or toxic to reproduction must be withdrawn.
- Candidates for Substitution (CfS): Active substances with specific hazard profiles remain approved only until safer alternatives are available, unless substitution would cause disproportionate significant economic or practical disadvantages.

In 2011, around 280 chemical active substances were authorized in the EU; by 2022, this figure had fallen to about 220 – a reduction of more than 20 percent (Marchand, 2023). Looking ahead, projections suggest the portfolio may shrink to roughly 150 active substances by 2030, implying a further decline of over 30 percent (Marchand, 2023). Similarly, Chapelle and Malet (2022) expect up to one quarter of active substances to disappear over this period. This trend is reinforced by additional political strategies aimed at further reducing PPP use, driven by both European institutions (see, e.g., EC, 2022) and national governments (see, e.g., BMEL, 2024).

Against this backdrop, emergency authorizations under Article 53 of Regulation (EC) No. 1107/2009 have drastically increased (EC, 2020). They now cover not only fruit and other specialty crops but also staples like potatoes, sugar beet, and winter oilseed rape (OSR). Because many cases involve PPP with already approved active substances, the European Commission (EC) suspects EU member states are using Article 53 to bridge procedural delays and to address the insufficient availability of PPP for minor uses. This runs against the Regulation's intent of such approvals being strictly temporary; the EC therefore urges a return to standard authorization pathways. Public debate reinforces that emergency approvals should not become a permanent instrument.

Public debate also questions how CfS are handled. Some argue their approvals should end quickly because of their hazard profiles (PAN Europe, 2020), although, by rule, CfS stay approved only until clearly safer alternatives exist and substitution would not cause unacceptable production losses. In practice, public pressure and the time, cost, and complexity of renewals reduce planning certainty, so some CfS are not even re-applied for.

Combined with fewer emergency authorizations, these developments point to a steady erosion of the chemical toolbox available to farmers. Assessing the potential consequences of a loss of active substances due to these regulatory restrictions is therefore essential.

1.2 Objective and structure of the study

Against this backdrop, this study assesses how a substantial reduction in available plant-protection options would affect domestic agricultural production, food self-sufficiency and the agri-food trade balance in Bulgaria. We model a scenario in which, by 2030, all active substances classified as CfS and applicable emergency authorizations are not reapproved, resulting in the non-availability of these active substances. By quantifying the magnitude of these effects, the study results are intended to inform policymakers on safeguarding agricultural sustainability and national food sovereignty.

The study builds on the latest data from official statistics and applies advanced models in agricultural economics to test the following working hypothesis: The loss of numerous active substances would significantly reduce production of key crops and increase the reliance on imports (and reducing exports).

The report is structured as follows:

- Chapter 2 presents the analysis of current self-sufficiency ratios and net trade balances.
- Chapter 3 examines the potential impacts of losing active substances under regulatory restrictions.
- Chapter 4 summarizes the findings and offers recommendations.

2. Status quo of food self-sufficiency and the foreign trade balance for selected crops (reference situation)

2.1 Methodological considerations

In close cooperation with the initiator of this study, the analysis was narrowed to seven exemplary agricultural commodities. Table 2.1 presents the selected crops, comprising three arable crops and four specialty crops, which serve as the basis for assessing potential changes in production and trade balances as well as food self-sufficiency in Bulgaria.

Table 2.1: Selected arable and specialty crops for analysis

Arable crops	Specialty crops
Wheat	Raspberry
Sunflower	Peach
Oilseed rape (OSR)	Cherry
	Onion

Source: Own table.

Self-sufficiency rates and foreign trade balances are key indicators for assessing a country's agricultural and food sovereignty at the level of these primary agricultural products.

The self-sufficiency rate measures the extent to which domestic agricultural production can meet the population's consumption needs. Beyond simply comparing production with consumption, the ratio also reflects structural factors such as import and export dynamics, stock changes, shifts in cultivation strategies, and other external influences over time. Accordingly, the self-sufficiency rate may fall below, equal, or rise above 100 percent:

- Below 100 percent indicates that national demand exceeds domestic production, resulting in a partial dependence on net imports.
- Exactly 100 percent signals full self-sufficiency or a neutral trade balance (exports equal imports).
- Above 100 percent shows that domestic production exceeds national demand, resulting in net exports.

To evaluate the current self-sufficiency rate for selected crops in Bulgaria, food supply balances were obtained from FAO (2025) and EC (2025d). Available data from the three most recent years were used to determine the reference situation, with multi-year averages providing a more robust basis by smoothing out the effects of, e.g., weather variability, market fluctuations and trade-related shocks.

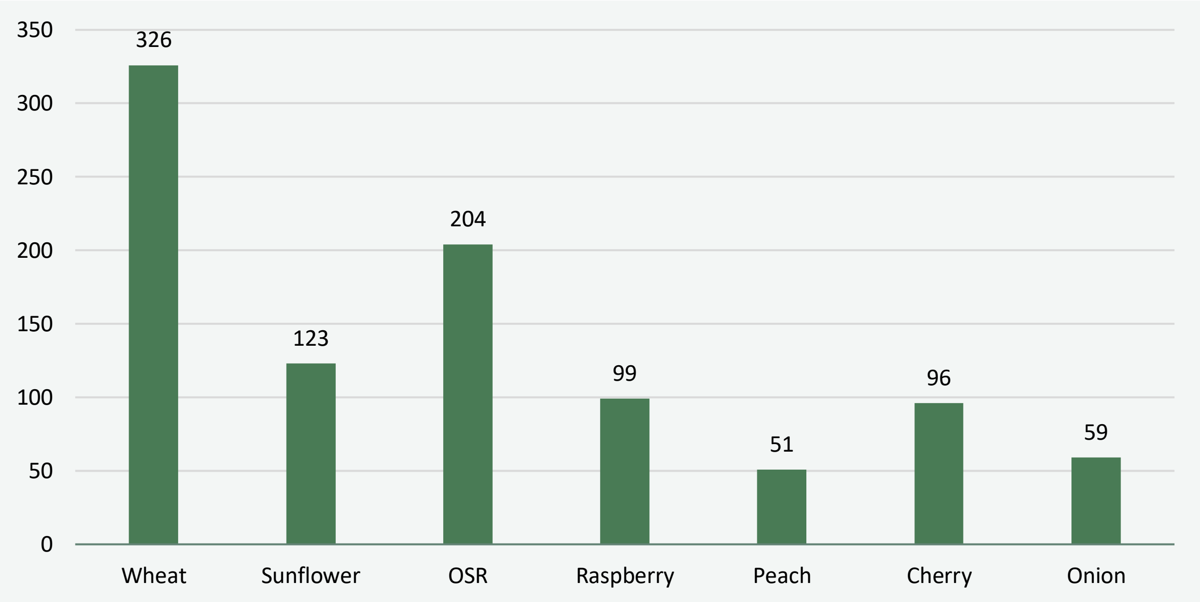
The foreign trade balance complements the self-sufficiency rate by showing whether, in value terms, a country earns more from exporting a product than it spends on importing it. While the self-sufficiency rate compares domestic production with consumption in physical terms, the trade balance translates the resulting surplus or shortfall into net imports or exports. Again, available data from the three most recent years in accordance with FAO (2025) and EC (2025d) were used.

When the self-sufficiency rate declines for a product, the foreign net trade balance tends to move toward a deficit as imports rise or exports fall; when the self-sufficiency rate increases, the balance tends to improve toward a surplus.

2.2 Calculation of current self-sufficiency rates and foreign net trade balances

Using this approach leads to the self-sufficiency rates displayed in Figure 2.1 for the selected crops. It turns out that Bulgaria is currently (more than) self-sufficient in the three arable crops. The current self-sufficiency rate is 326 percent in wheat, 123 percent in sunflower, and 204 percent in OSR. In the cases of the four specialty crops, Bulgaria is not self-sufficient. It has a self-sufficiency rate of 99 percent in raspberry, 51 percent in peach, 96 percent in cherry, and 59 percent in onion.

Figure 2.1: Average self-sufficiency rate of the selected arable and specialty crops in the reference situation (in percent)



Source: Own figure based on FAO (2025) and EC (2025d).

This results in positive or negative trade balances for the selected crops. Table 2.2 reports the average export and import tonnages for the years considered; positive figures at the end indicate a net export position, while negative figures indicate a net import position. The results show that Bulgaria enjoys not only a rather high crop-specific self-sufficiency but also positive net trade balances in wheat, sunflower, and OSR. Accordingly, the net trade balance is negative in the cases of raspberry, peach, cherry, and onion mirroring comparably low self-sufficiency.

Table 2.2: Average foreign trade and trade balance of selected arable and specialty crops in the reference situation (in k tons)

Arable or specialty crop	Export	Import	Net balance
Wheat	4,360	50	4,310
Sunflower	1,410	922	488
OSR	240	64	176
Raspberry	0.0	0.1	-0.1
Peach	3	21	-18
Cherry	0.7	2.8	-2.1
Onion	0	22	-22

Source: Own table based on FAO (2025) and EC (2025d).

3. Changes in food self-sufficiency and the foreign net trade balance under a "regulatory scenario"

3.1 Methodological considerations

In the introduction of this report, it was noted that different regulatory restrictions will presumably lead to the ban and non-approval of several active substances in the coming years. Against this backdrop, the "regulatory scenario" assumes that by 2030 significantly fewer active substances – and thus PPP – will be available for crop production in Bulgaria.

To operationalize this assumption, two aspects must be addressed: first, identifying which active substances would be affected; and second, estimating the yield and production effects of their potential loss. The methodological approach applied here is outlined below.

a) Active substances currently authorized for each crop as fungicides, herbicides and insecticides were identified using resources such as the PS Info database from DLR Rheinpfalz (2025) and the register of the Bulgarian Food Safety Agency (BFSA, 2025).
b) These active substances were then cross-checked against the EU Pesticides Database (EC, 2025a) to determine which ones are classified as CfS.
c) The identified active substances were then reviewed by BASF Bulgaria to account for possible national specificities, e.g. emergency authorizations, which are not captured by the below approach.

As a result of this process, a specific number of fungicidal, herbicidal, and insecticidal active substances were identified for each crop that are under threat to be withdrawn from the market in Bulgaria by 2030. The specific findings can be obtained from Table 3.1.

Table 3.1: Number of potentially lost active substances by 2030 that are subject to regulatory restrictions per crop

Arable or specialty crop	Fungicidal active substances	Herbicidal active substances	Insecticidal active substances	Total number of active substances
Wheat	7	8	5	20
Sunflower	7	4	3	14
OSR	6	3	5	14
Raspberry	6	2	1	9
Peach	5	2	1	8
Cherry	6	2	1	9
Onion	7	3	1	11

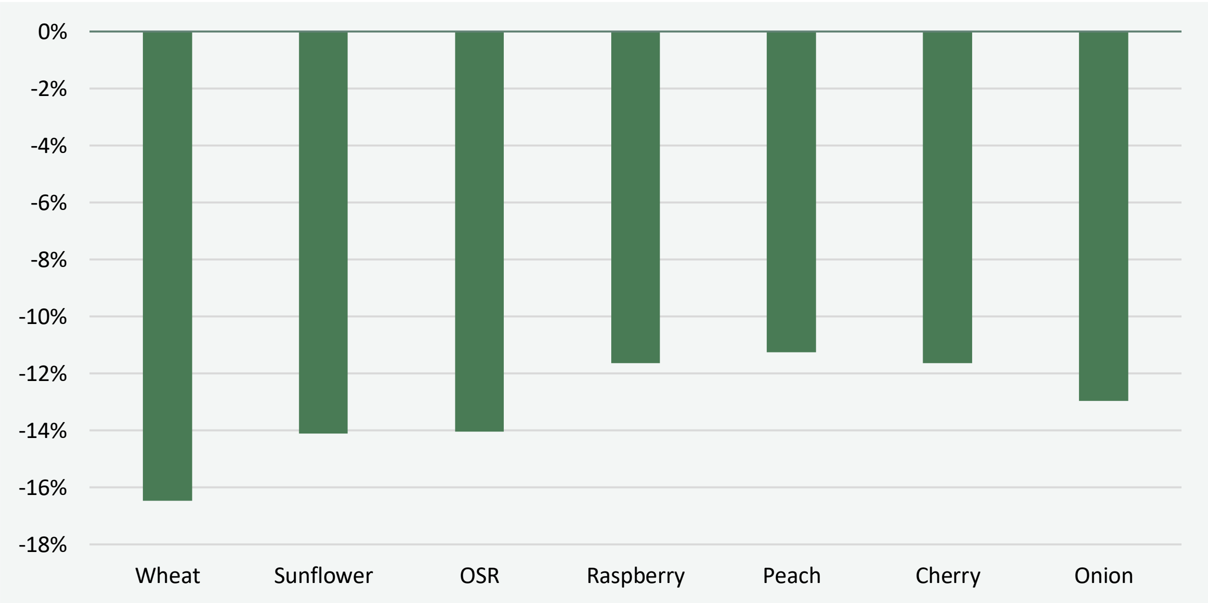
Source: Own table.

Ideally, assessing the yield and production impacts resulting from the potential loss of individual active substances would involve analyzing the yield effect of each specific active substance by crop and multiplying it by the share of the crop area treated with that active substance. In this case, the individual results could be aggregated to estimate the nationwide production effect. However, due to data limitations on yield effects for individual active substances and the extensive effort required to find this data, such an approach is not feasible within the scope of this study.

Therefore, this analysis relies on meta-analyses and modeling studies as proxies instead, which examine the effects of a hypothetical further loss of active substances used in crop protection without alternatives being available, drawing on expert assessments and, in some cases, experimental data. Key sources include Kim et al. (2016; 2020), Noleppa and Hahn (2013), Noleppa (2017), and Noleppa (2025). From the studies, around 1,000 data pairs could be retrieved, linking the number of (potentially) withdrawn active substances to corresponding production losses. On this basis production impacts were estimated and then used to analyze changes in the self-sufficiency rate and net trade balances, as described in Annex A.

Figure 3.1 illustrates the initial relative production effects of a potential loss of the active substances in Table 3.1 by 2030. Production losses in this "regulatory scenario" would range from 11.3 percent for peach to 16.5 percent for wheat. Between these extremes are sunflower (14.1 percent), OSR (14.1 percent), raspberry (11.6 percent), cherry (11.6 percent), and onion (13.0 percent). Although these reductions are substantial, they remain below the long-established estimate of over 30 percent losses in crop production in the complete absence of plant protection (Oerke, 2006).

Figure 3.1: Potential production loss in the "regulatory scenario" per crop



Source: Own figure based on own calculations.

3.2 Calculation of changed self-sufficiency rates and foreign net trade balances

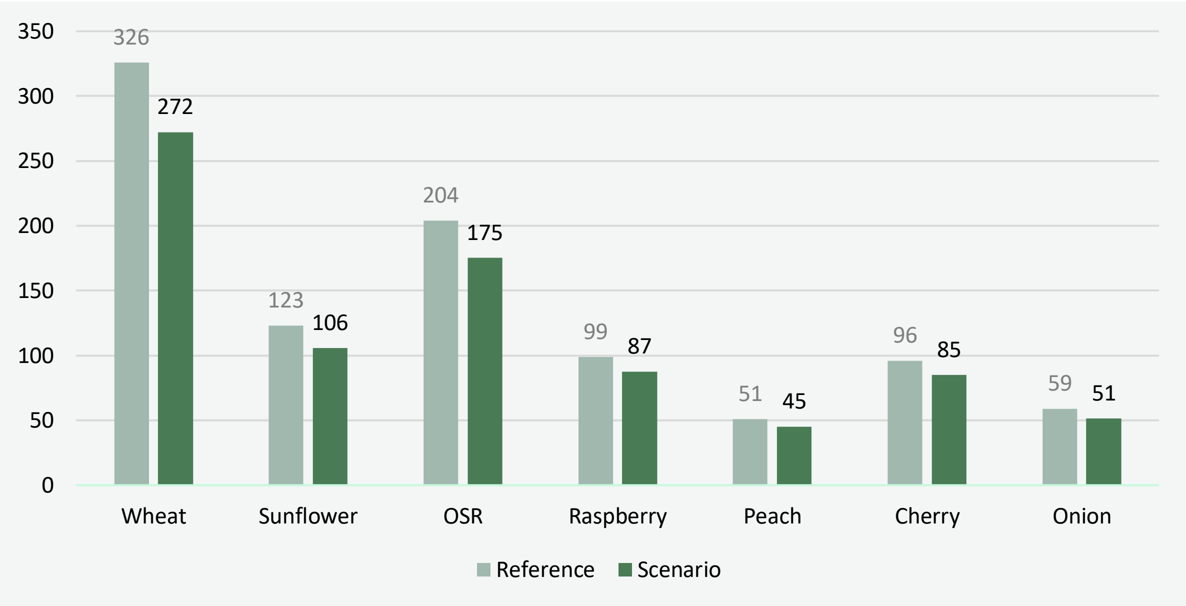
The above calculated potential production losses are now applied to the self-sufficiency rates in the reference scenario (see Figure 2.1) to estimate their changes under the "regulatory scenario" by 2030. Figure 3.2 presents the results for the seven selected arable and specialty crops, clearly showing a decline in self-sufficiency across all of them.

It turns out that, under the specific scenario, the country will remain self-sufficient in three of the seven selected crops. However, the self-sufficiency rate remarkably declines from 326 percent to 272 percent in wheat, 123 percent to 106 percent in sunflower, and 204 percent to 175 percent in OSR. In the other cases, the self-sufficiency rates will fall further below 100 percent in the "regulatory scenario" to:

- 87 percent (from 99 percent) in the case of raspberry,
- 45 percent (from 51 percent) in the case of peach,
- 85 percent (from 96 percent) in the case of cherry, and
- 51 percent (from 59 percent) in the case of onion,

indicating an increasing dependence on imports of Bulgaria for the specific fruit and vegetable crops.

Figure 3.2: Potential changes in the self-sufficiency rate in the "regulatory scenario" per crop (in percent)



Source: Own figure based on own calculations.

In the "regulatory scenario", the foreign net trade balance is consistently negatively affected across crops, as shown in Table 3.2. In other words, without the potentially withdrawn active substances in this scenario, Bulgaria would face significant losses not only in domestic production but also in international market and trade competitiveness.

Table 3.2: Net trade balance and changes thereof per crop in the reference and in the "regulatory scenario" (in 1,000 tons)

Arable or specialty crop	Net trade balance in the reference	Net trade balance in the scenario	Change of the net trade balance
Wheat	4,310	3,286	-1,024
Sunflower	488	120	-368
OSR	176	127	-49
Raspberry	-0.1	-0,6	-0.5
Peach	-18	-20	-2.0
Cherry	-2.1	-7.8	-5.8
Onion	-22	-26	-4.0

Source: Own table based on own calculations.

Although the results still suggest an export surplus for some crops, this should not be taken to mean that the potential loss of the considered active substances have no serious implications for food availability and trade balances in Bulgaria. A closer look reveals at least two important considerations:

1. Limited scope of analysis: The crops examined in this study are selected examples and therefore do not provide a full picture of national food availability and sovereignty. If losses in certain active substances due to regulatory changes also affect other crops – and given that self-sufficiency with respect to, e.g., starchy roots and sugar in Bulgaria is already below 100 percent (see, again, Brankov et al., 2021) – the present situation could deteriorate further, leading to a considerable net import position for many essential food items.
2. Role of competitiveness: Even where Bulgaria remains partially competitive in food production (e.g., wheat and some other commodities), a decline in competitiveness can have serious indirect effects on national food availability and sovereignty. A competitive agricultural sector can generate export revenues, strengthen foreign exchange reserves and better enable reinvestment in domestic food production. This not only reduces import dependence but cushions price volatility and supports overall rural development. Ultimately, it lowers vulnerability to external market shocks and ad-hoc political pressure while safeguarding long-term sovereignty through regional production capacity. By contrast, a non-competitive agricultural sector risks greater reliance on food imports and diminished control over food choices. In this sense, international competitiveness through comparably high domestic production and productivity is the foundation of national food sovereignty.

In Bulgaria, production capacity could potentially decline if the active substances used in plant protection — as defined by the “regulatory scenario” — were no longer available. Given that Bulgaria is a relatively small country well integrated into European and international agricultural markets, the change in trade volume shown in the last column of Table 3.2 can also serve as a reasonable proxy for the corresponding loss in agricultural production volume. This can also be interpreted, ceteris paribus, as the direct (absolute) production effect of a shrinking set of plant protection tools available to farmers in the country.

Farms would need to adapt to these potential changes. However, facing other restrictions and limitations such as climate change and other structural problems of the agricultural sector, this adaptation process might become a challenge. In this respect, changes in the availability of PPP could well be the catalyst for greater structural upheavals and (negative) changes in production and trade than this partial analysis only referring to the potential loss of some, but important, active substances can suggest for Bulgaria. Modern plant protection based on a sufficient spectrum of available tools therefore also has systemic significance.

4. Conclusions and recommendations

This study aimed at assessing the risk exposure of food self-sufficiency and foreign trade balance in Bulgaria, since – given the current geopolitical and agricultural-policy constellation – the impression is growing that dependencies in food supply should be reduced. Based on a scenario referring to regulatory restrictions in crop protection, including the non-availability of CfS, it could be shown that there are risks to the current food availability situation and foreign net trade balance in Bulgaria as all self-sufficiency rates would decline.

This requires decisive political action. The Draghi Report (Draghi, 2024a; b) has recently pointed out that the current legal landscape in general but also specifically in regulating plant protection in the EU is too complex and inconsistent. Lack of harmonization and lengthy approval procedures are concrete competitive disadvantages. As a result, the EU – and thus also Bulgaria – risks losing essential tools of good agricultural practice. In the scenario calculated above, it was shown what could potentially happen if regulatory restrictions were tightened and active substances were lost. If more active substances disappear, economic feasibility of arable and specialty crop cultivation will become more difficult and, in some regions, maybe impossible. In addition, the remaining active substances would be used more intensively, accelerating resistance development and causing further productivity losses. Ultimately, this would noticeably and further weaken the competitive position of Bulgarian (and European) agriculture in international markets. Some farms might be forced to decrease production, and cultivation would increasingly concentrate on crops that require less crop protection. This in turn would contradict society's expressed desire for greater agrobiodiversity and bring further uncertainty.

The current approval system in the EU is not capable of responding to these and other uncertainties (e.g. climate change) and trade-offs, for example in the context of balancing the economy and ecology. Many active substances have already been lost for regulatory reasons and others could be withdrawn. For dealing with crises, however, more – not fewer – potential options, e.g. PPP are needed to maintain plant health, protect yields, and increase production. A legal framework is therefore needed to promote rapid action on the authorization of active substances, the preservation of existing PPP and the authorization of new products. Innovation bottlenecks – not only in approval and authorization procedures for crop protection, but also, for example, in the use of new breeding technologies or fertilizer legislation – must be removed. It is not enough, however, to loosen these brakes. Given the lengthy investment and innovation cycles, private sector investment and innovation in crop production will only increase in the future if this is accompanied by reliable (agricultural) policy frameworks.

The importance of removing regulatory and other barriers in plant protection and of innovation can be illustrated by the following argument. Total Factor Productivity (TFP) measures productivity progress through innovation. In the first decade of the 21st century, TFP in Bulgarian agriculture was still above one percent. However, it has weakened since then and it is currently already negative at approximately minus 0.8 percent (Agnew et al., 2024). In other words, innovative capacity has been lost in Bulgarian agriculture in recent years, and productivity progress is currently tending toward zero. Yet it would need to increase significantly to meet the various geopolitical and other challenges that agriculture in Bulgaria and the entire EU is facing and will continue to face.

As mentioned at the beginning, food security of Bulgaria and in the entire EU is not only affected by the (non-)availability of active substances in PPP, but many other factors. The supply of food and other agricultural raw materials must be regarded as a crucial component for safeguarding national security and stability. Particularly in an increasingly globalized world, where trade routes and thus foreign trade dependencies, as well as domestic supply chains and political alliances, are subject to constant and sometimes ad-hoc change, the production of food using domestic resources is gaining growing importance as a factor for stability. Geopolitical tensions, natural phenomena and disasters, as well as economic crises, can disrupt supply chains at almost any time and turn dependence on imported food into a particular challenge, if not even a (temporary) threat.

A key geopolitical risk, for example, is a country's dependence on imports from unstable regions. For certain agricultural products, a considerable share of Bulgarian domestic demand is already met by imports from countries experiencing (geo)political or economic turbulences. Trade conflicts, sanctions, or even military confrontations can significantly disrupt these supply chains, especially when not only Bulgaria but also other EU member states – from which compensation of own losses may come – are affected. An example is the global grain crisis triggered by Russia's war against Ukraine. Ukraine and Russia are among the world's largest grain exporters, and restrictions there have led to rising prices worldwide and regional food shortages. Strong domestic production can, in such situations, at least increase resilience and help mitigate supply shortages in other countries, thereby assuming greater responsibility for not only regional but also global food security.

Another source of risk lies in broader economic uncertainties. Global crises, rising transport and energy costs, and currency fluctuations can significantly raise the cost of both domestic food production and agricultural imports. During periods of recession or high inflation – such as those recently experienced – large parts of the population may no longer be able to afford a healthy and balanced diet, simply because of rising prices. Strengthening domestic agricultural production and expanding the national supply base can help mitigate these risks.

In addition to geopolitical and economic challenges, environmental factors and the risks arising from them are also of great significance. Climate change is increasingly leading to extreme weather events such as droughts, floods, late frosts, and storms, which do more frequently have negative impacts on agricultural yields at the regional level. A strong and productive domestic agriculture sector, adapted to climate change, can help better cope with climate-induced volatility and ensure food security on a larger scale.

In addition to safeguarding food availability, domestic production also generates some important macroeconomic, social, and health benefits. Regional production fosters the further use of agricultural raw materials along national value chains, strengthening local economies well beyond the farm sector and creating employment. Moreover, producing food domestically often promotes more sustainable practices, particularly when national standards are higher than those in countries from which imports would otherwise originate.

In summary, it can thus be argued that domestic production and the supply of food play a decisive role in societal security and resilience. It should therefore be considered to further promote and strengthen domestic agricultural production. This requires, on the one hand, corresponding private-sector investments. On the other hand, this also requires appropriate policy frameworks and regulations.

Modern crop protection is one of the central drivers of innovation to meet these challenges. However, the goal is not simply to use more crop protection, but to achieve better protection – qualitative rather than quantitative growth. This calls for supportive, rather than restrictive, approval and authorization procedures that secure a sufficiently broad toolbox, including PPP alongside innovations in plant breeding and nutrition. Without this diversity, farms cannot adequately respond to societal expectations and external pressures. The loss of active substances, particularly in chemical-synthetic crop protection, would therefore be counterproductive and should be avoided as far as possible or at least minimized.

At the same time, political and societal demands for reducing the use of PPP are increasing rather than declining (DLG, 2025). This confirms that the scenarios of stricter regulatory restrictions leading to the loss of numerous active substances is realistic. In such a context, it is not enough to emphasize the importance of PPP and modern plant protection in general. It is essential to recognize the increasing restrictions and call for political measures and regulatory frameworks that protect the tools that farmers in Bulgaria (and beyond) absolutely need to maintain productivity, self-sufficiency and maximum sustainability.

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Annex: Method for quantifying production effects due to loss of active substances

This study builds on several meta-analyses (based on expert assessments and experimental results) that examine the effects of hypthetical losing active substances used in crop protection without alternatives being availabe. From these studies, around 1,000 data pairs were extracted for various arable and specialty crops. Each pair links the number of active substances withdrawn – whether fungicides, herbicides, insecticides, or all three combined – with the corresponding production loss. These losses account for both yield reductions per hectare and the share of farmland affected.

Now, this dataset makes it possible to estimate the production impacts of losing multiple active substances. Figure A.1 illustrates this for the combined category "all three modes of action", which includes about 120 data pairs. The figure shows that the relationship between the number of substances lost and the resulting production losses is widely dispersed. This variability reflects a considerable degree of uncertainty, which must be taken into account when analyzing and interpreting the results.

Figure A.1: Expert assessments and experimental data on the production effect of the withdrawal of a specific number of active substances across all application areas, and the corresponding linear and logarithmic trend

Source: Own figure and own calculations based on expert assessments and experimental data obtained from Kim et al. (2016; 2020) as well as Noleppa and Hahn (2013), Noleppa and Lüttringhaus (2016), Noleppa (2017), and Noleppa (2025).

In addition, it is possible to estimate trend values for production losses caused by the hypothetical loss of active substances. These values – hereinafter referred to as condensed expected values – are shown in Figure A.1 in both linear and logarithmic forms. The comparison reveals two important insights:

- The linear trend tends to overestimate production losses when only a few active substances are withdrawn (up to ~15) or when very many are withdrawn (above ~60).
- The logarithmic trend produces smaller estimates at the extremes, while in the intermediate range (15-60 active substances) it deviates only slightly (one to two percentage points) from the linear trend.

To avoid systematic overestimation, this study adopts the logarithmic trend as the basis for national-level calculations of production effects.

While more realistic overall, the logarithmic trend may underestimate losses in specific situations. If enough effective alternatives remain available, the loss of individual active substances has only a limited impact. However, once the number of options becomes too small, the risks rise sharply:

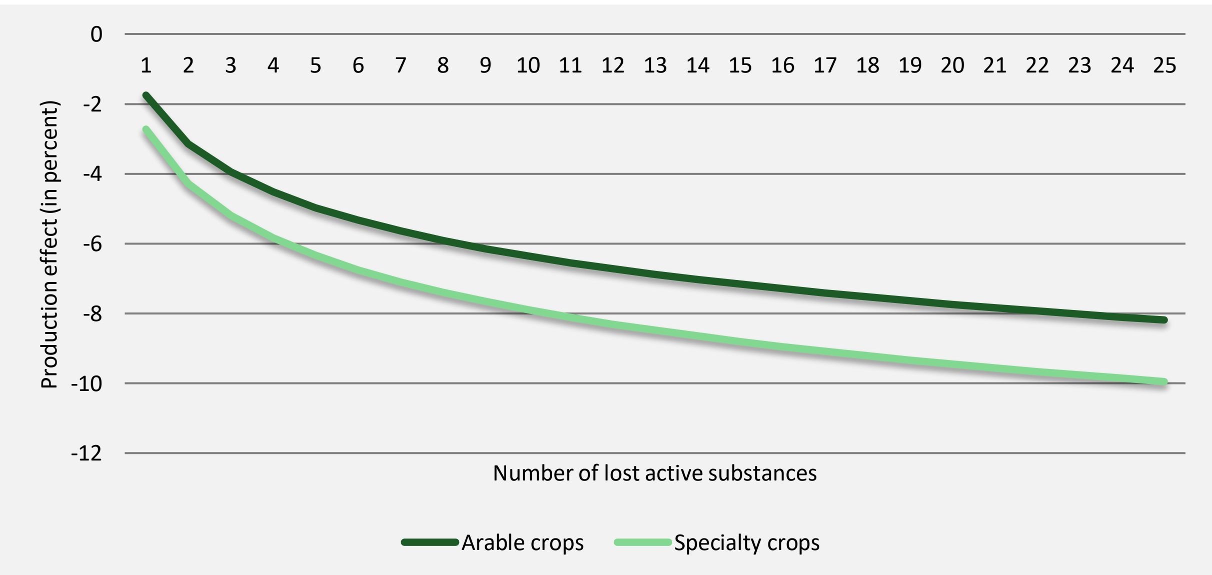
- Medium-term resistance may develop from overusing the few remaining substances.
- Short-term severe yield losses may occur if alternatives are much less effective or no longer effective at all.

This logic explains why CfS are still permitted despite risks, and why emergency authorizations exist. Without them, the loss of certain critical active substances would make the cultivation of specific crops uneconomical, and the real production effect would far exceed the estimate based on a logarithmic trend.

Nevertheless, the use of the logarithmic metric is in favor, as it offers an additional advantage. The logarithmic specification provides a more realistic representation than the linear trend because, with an increasing number of lost active substances, diminishing marginal costs – in the sense of additional marginal production losses associated with each further withdrawal of an active substance – arise, and these diminishing marginal costs are explicitly reflected. This mirrors a production loss function that approaches an upper limit. Figure A.1 suggests that this limit is roughly one third of total production across fungicides, herbicides, and insecticides – consistent with Oerke (2006), who reported average potential losses of 32 percent, i.e. roughly one third across crops in the absence of plant protection.

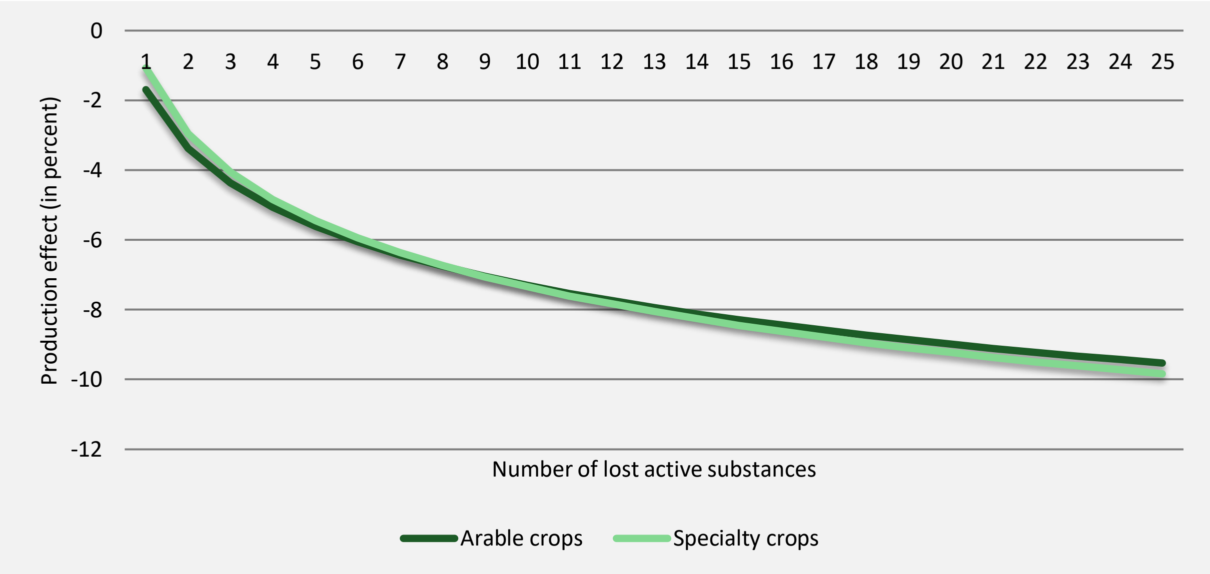
While Figure A.1 shows aggregated results (for all three active substance categories combined, based on ~120 data pairs), the dataset also allows disaggregation for fungicides (based on 377 data pairs), herbicides (based on 212 data pairs), and insecticides (based on 244 data pairs). The resulting production loss functions are presented separately in Figures A.2 to A.4. These functions make it possible to assign crop-specific losses to the withdrawal of fungicides, herbicides, or insecticides, as reported in Table 3.1 of the main text.

Figure A.2: Estimated production loss functions for the further analysis of fungicide withdrawals in arable and specialty crops



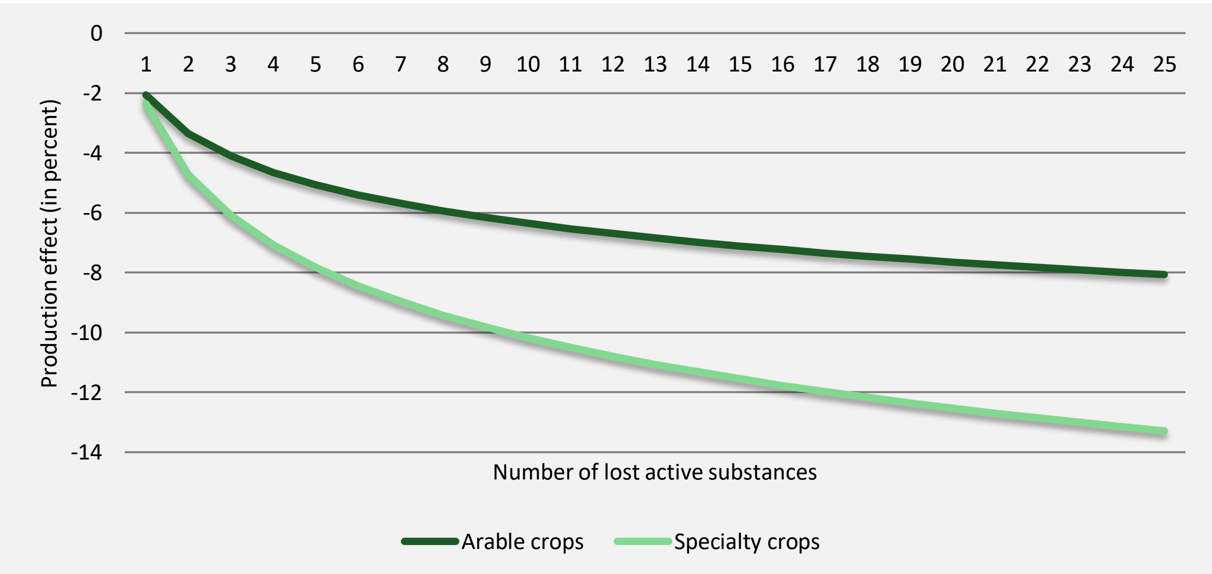
Source: Own figure and own calculations based on expert assessments and experimental data obtained from Kim et al. (2016; 2020) as well as Noleppa and Hahn (2013), Noleppa and Lüttringhaus (2016), Noleppa (2017), and Noleppa (2025).

Figure A.3: Estimated production loss functions for the further analysis of herbicide withdrawals in arable and specialty crops



Source: Own figure and own calculations based on expert assessments and experimental data obtained from Kim et al. (2016; 2020) as well as Noleppa and Hahn (2013), Noleppa and Lüttringhaus (2016), Noleppa (2017), and Noleppa (2025).

Figure A.4: Estimated production loss functions for the further analysis of insecticide withdrawals in arable and specialty crops



Source: Own figure and own calculations based on expert assessments and experimental data obtained from Kim et al. (2016; 2020) as well as Noleppa and Hahn (2013), Noleppa and Lüttringhaus (2016), Noleppa (2017), and Noleppa (2025).

The threshold values of these functions are of particular interest in this context, as they provide additional insights into the maximum production loss that would occur if all relevant active substances were withdrawn. In this sense, they serve as a stress test for the plausibility and acceptance of these production loss functions for subsequent analyses. As noted above, across all three categories (fungicides, herbicides, and insecticides), the maximum average production loss across all crop types in the event of the withdrawal of all active substances would amount to roughly one third. This estimate is consistent with other scientific findings. Specifically, Oerke (2006), who has not been revisited extensively in the academic literature since, reported an average loss of 32 percent across multiple crop types, which aligns with the value derived here.

Oerke (2006) also differentiates between yield losses that would occur if fungicides, herbicides, or insecticides were unavailable and, consequently, weeds, insects (including viruses transmitted by them), or pathogens were able to spread and reduce yields across entire production areas. According to his estimates, again averaged across multiple crops, production losses would amount to approximately ten percent in the absence of all fungicides, nine percent in the absence of all herbicides, and 13 percent in the absence of all insecticides.

The threshold values of the production loss functions derived in this study, assuming a sufficiently large number of withdrawn active substances (e.g., n = 50), are as follows (see, again Figures A.2 to A.4):

- Fungicides: approximately nine percent for arable crops and twelve percent for specialty crops,
- Herbicides: approximately eleven percent for both field and specialty crops,
- Insecticides: approximately nine percent for field crops and 16 percent for specialty crops.

Thus, even under this disaggregated perspective, the magnitudes obtained here are broadly consistent with the prevailing scientific consensus.

Taken together, this provides a solid basis for employing the production loss functions presented in Figure A.2 for fungicides, Figure A.3 for herbicides, and Figure A.4 for insecticides in the context of scenarios to be applied in the framework of this study approach.

Title: Losing active substances in plant protection: impacts on Bulgaria's agricultural production, food self-sufficiency and foreign net trade balance

Corresponding authors: Steffen Noleppa and Juliane Kaufmann

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HFFA Research GmbH
Bülowstraße 66/D2,
10783 Berlin, Germany

E-Mail: office@hffa-research.com

Web: www.hffa-research.com