foodwatch

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LOCKED-IN PESTICIDES

The European Union's dependency on harmful pesticides and how to overcome it

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The path that leads to the lock-in of a technology often starts with a small historical event or a sequence of such events. The historical event is often an accident, a haphazard marketing gadget, or a political problem demanding immediate action. In standard models of path dependence, an initial advantage gained by one technology can create a snowballing effect, based on learning by doing, learning by using, and learning about pay-offs, which quickly makes the technology preferred to others.

From Cowan & Hulten (1996): Escaping lock-in: The case of the electric vehicle. Technological Forecasting and Social Change 53 page 61.

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LOCKED-IN PESTICIDES

The agricultural system of the European Union is dependent on the use of pesticides to a degree that is commonly described as "lock-in". This term is derived from the neurological disorder "locked-in syndrome", describing a paralysis of the body. Although the patient is conscious and their cognitive function is usually unaffected, they have no control over their body.

The analogy to "modern" agriculture is striking. Most of the agricultural produce is sold to a "handful" of corporations and large retailers who determine the price, varieties and quality (O'Kane 2011). Many farmers do not even know the price their product(s) will bring until the harvest begins.[1] "Locked-in" farmers can only make a profit by reducing costs per produced unit or producing more units at the same costs. This strategy is pursued by most farmers, leading to a permanent race to the bottom, along with the associated adverse external effects: rural exodus (migration and elimination of infrastructure especially related to processing), environmental destruction, overproduction and large subsidies. The external costs of the global food system are staggering.

Pesticides are at the centre of this strategy. Initially, pesticides seemed to be a useful tool for controlling pests and diseases, but that is a narrow-minded view. Soon after their introduction, pesticides became the key technology for generating and maintaining very simplified, and thus – in all aspects – fragile agricultural production systems. This fragility creates a self-reinforced dependency on pesticides, which has led to a "lock-in" where no escape seems possible.

1

THE FIRST SECTION of this report briefly describes how agriculture became dependent on pesticide use. The focus is on three main socio-economic drivers: international trade, land grabbing and rural exodus (migration). These three drivers are closely interrelated and, over time, have made the large-scale use of pesticides unavoidable. The availability of certain pesticides (or use types) also presented a "first-mover advantage", enabling farmers to either grow their crops more cost-effectively or produce crops that are more visually pleasing – forcing all competing farmers to follow suit (snowballing effect [Cowan & Hulten 1996]). Herbicides and plant growth regulators (PGRs) are two examples: Once introduced, their

[1] For some large crops and livestock products, it is common that large farmers can negotiate a future price much earlier (contracting). Small farms that market directly to the consumer can also determine their price.

large-scale adoption was inevitable. The rapid acceptance of herbicides and PGRs was also a reaction to global overproduction in the 1960s. Many governments restricted production, usually via area contingencies (Traulsen 1967). Low producer prices forced farmers to reduce labour costs, which led to herbicide use, while the use of PGRs allowed for higher nitrogen use and thus more production per permitted hectare. Since risk assessment prior to authorisation did not exist, pesticide dependencies were created without awareness or discussion.

Pesticide use has been criticised strongly at least since the 1960s, and the debate has been ongoing for about six decades. The European Union harmonised pesticide authorisation, and EU legislation was adopted to reduce pesticide use and/or risks.

2

THE SECOND SECTION of this report looks at pesticide use in the European Union over the past few decades. Overall, no reduction in pesticide use can be observed. Herbicide use has increased since the 1990s, and it is very likely that pesticide-use intensity (the number of doses per area) has also risen, because more low-dose pesticides are being used, while the total amounts sold have either remained stable or increased.

France, Germany and the Netherlands are the largest pesticide users in the European Union. Three sub-sections look at the various parameters for evaluating pesticide use in these countries. In France the Ecophyto plan to reduce pesticide use by 50% between 2008 and 2018 failed despite excellent research by governmental institutions (e.g. INRAE) and the existence of alternatives. In Germany and the Netherlands pesticide use has not declined in either quantity or toxicity, and intensity has increased (number of hectares treated).

Since the very beginning, various negative side effects of pesticide use have been observed. Pests quickly became resistant even against arsenic pesticides and hydrocyanic acid (Haseman & Meffert 1933). The fact that pesticides eliminate beneficial organisms and may cause even higher pest pressure (resurgence) has been known since the 1950s. Both resistance and resurgence are leading to higher pesticide use (self-reinforced dependency).

Residues in food began worrying consumers as early as around 1900 (Omeis 1903), and the first serious negative health effects were observed in the 1920s, when German winegrowers became seriously ill following heavy applications of calcium arsenate to combat the codling moth. Today, the same or similar negative effects of pesticide use can still be observed. In addition, pesticides (mostly herbicides) in groundwater are causing considerable economic harm.

3

THE THIRD SECTION of this report gives insight into the claimed benefits of pesticide use and its adverse economic effects. The true price of pesticide use is high. Although little data is available, the annual external costs in the EU are estimated to be in the billions of euros rather than in the millions. At the same time very little is being spent on the avoidance and/or reduction of pesticide use.

Although pesticides cause considerable harm and can be seen as the catalysts of a damaging and costly agricultural system, almost every attempt to reduce pesticide use on a large scale has failed. There are several reasons for this situation. Pesticides are often viewed as farming tools that simply need to be substituted by less harmful tools. This narrow-minded approach is destined to fail. Although non-chemical control, especially the biological control of arthropod pests, is usually more efficient than the use of insecticides/acaricides, there are social and some economic constraints. Substitution fails when it comes to herbicide and fungicide use. The current agricultural system has been centred around their use for decades. It is of utmost importance to understand the socio-economic drivers that are "imprisoning" growers and forcing them to use pesticides.

4

In **SECTION 4**, the old and new drivers of pesticide lock-in are described in more detail.

The socio-economic drivers of pesticide lock-in can be grouped into two categories: One reduces diversity (genetic diversity, crop diversity), and the other forces rationalisation (cost reduction) and reduces biodiversity. These drivers are intertwined and interrelated. The global competition among (still) millions of farmers and the strong consolidation on both the supply side (farm inputs) and the demand side (buyers of produce) are the two key drivers, leading to a race to the bottom. It seems this race to the bottom has created an eternal lose-lose-lose situation for farmers, the environment and the rest of society – except for the consolidated businesses on the supply (pesticides, fertiliser, seed, feed stock) and demand side.
The human food production system currently faces several serious threats:

climate change, loss of (bio)diversity and rural exodus (migration plus elimination of rural infrastructure). "Modern" agriculture is a main cause of these threats. Any initiative aiming at a large-scale phase out of pesticide use needs to look at agriculture, human nutrition and the current global threats in a holistic manner. The "good news" is that the European Union (and all industrialised countries) have an overproduction problem rather than a food shortage. In addition, a large amount of funding is available, which can be reallocated. This situation should be viewed as a comfortable starting position, in which a win-win-win situation can be created as soon as society can come to an agreement in a transparent, democratic and open dialogue.

To analyse the possibilities for escaping the pesticide lock-in, it is necessary to evaluate the "toolbox" available for "freeing" the farming systems from the lock-in.

5

In **SECTION 5**, the most important agronomic measures for **preventing** pesticide use are described. Almost all of these measures increase diversity (above and below ground), which is the key to successful plant protection (and agriculture). A sub-section discusses some non-chemical technological approaches to controlling pests and diseases: e.g. robots and genetic engineering. The advantages of the preventative measures are obvious: They are effective, they are feasible[2], and most of them eliminate or mitigate adverse side effects such as $CO2_{eq}$ emissions, loss of (bio)diversity, pollution/eutrophication and rural exodus. Some non-chemical, technological approaches are more controversial and may even exacerbate the current threats to the food system.

Sub-section 5.3 describes the numerous policy changes that are needed to encourage the implementation of agronomic measures to **prevent** pesticide use. Because the farming system is in an economic pesticide lock-in, policy changes need to primarily address economics. The changes must serve several objectives:

1. **increase the costs of current, unsustainable and externally costly agricultural practices,**
2. **increase farm income from diversified, pesticide-free production and**
3. **protect sustainable production from competition by unsustainable production.**

[2] They are feasible, but not necessarily economically viable for "locked-in" farmers. For example: A cereal farmer can diversify crop rotation without great additional costs, but it won't be economically viable if he/she has no market for the additional/different crops.

Most political, economic “tools” for transforming agriculture and eliminating pesticide use already exist. They just need to be implemented and/or strongly improved. Furthermore, there are already substantial public funds (CAP[3] subsidies) for financing a transformation, and more funds will be made available when the pesticide levy/tax is implemented and a sufficiently high carbon price (via taxation or emission trade) is set for all external farm inputs, including imported feed stock and fertiliser. However, a reallocation of the CAP subsidies is urgently needed. CAP needs to support farm labour (not land possession), direct marketing and regional value chains.

The EU **pesticide policy** has major flaws and is – like much of the agricultural/environmental policy in the EU – not coherent and not aligned with overarching political objectives. Above all, national authorisation must be strictly aligned with the objectives of the “Sustainable Pesticide Use Directive/Regulation”.[4] Registrations for all uses[5] that are not compliant with integrated pest management or biological control, or are solely for cosmetic purposes, have to be withdrawn. A cumulative maximum residue level of 0.01 mg/kg must be gradually introduced to support the transition to pesticide-free farming. Furthermore, consideration should be given to the banning of advertisements for pesticides.

To avoid “leakage” effects, border adjustment agreements like the recently proposed ***“Carbon Border Adjustment”*** must be implemented for agricultural trade. Very recently, all OECD members agreed on a minimum tax for companies, and the UN Human Rights Council recognised access to a clean environment as a fundamental right. These major achievements show that worldwide action is possible. A global dialogue on agricultural production and trade is also urgently needed. The current food production system has a negative economic balance in most countries when all external costs are accounted for. Most countries are facing the same costly challenges. Considering the unavoidable acceleration of climate change and the continued loss of biodiversity, the current political stagnation in agricultural policy is irresponsible. Global co-operation is imperative. However, there are certain belief systems that hinder progress.

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[3] European Common Agricultural Policy (CAP).
[4] There are plans to transform the directive into a regulation.
[5] In most Member States, pesticide products are authorised for very specific purposes, such as the control of certain target organisms in a certain crop.

6

SECTION 6 takes a closer look at the existing belief systems regarding agriculture and pesticides.

Industrial agriculture, including pesticides, is often perceived as the "necessary evil" for producing large amounts of affordable food ***"for a growing population"***. However, when looking at input versus output, African and Asian farmers produce food much more efficiently than European farmers; smaller farms need not generally be less profitable than larger farms. Diverse farms outperform monocultures when it comes to yield and profitability. Large farms depend more on subsidies than smaller farms. Only a fraction of the European agricultural land is currently used for producing the types of food that people should eat to maintain a healthy (and climate-friendly) diet. Large amounts of land and other resources are used for producing animal feed for meat and dairy production. EU agriculture feeds 7 billion farm animals a year and about 0.45 billion people. Millions of tonnes of food are wasted. The total external costs of the food system are soaring. The claim that industrial agriculture produces affordable food seems to be in stark contrast to reality. Essentially, the proponents of "modern" agriculture have a contrafactual understanding of achievement.

Often, politicians do not address challenges until grave issues have become urgent. Over the past few decades, industrial agriculture has created many environmental and social issues, resulting in a large patchwork of ad-hoc legislation and policies. Since each problem is addressed separately, there is no coherence, and some policies are even contradictory. However, many agricultural issues, such as pesticide use, are closely related to other issues, and future agriculture must be envisioned and planned comprehensively.

The mitigation of anthropogenic climate change is a chance to transform a "locked-in" system and create positive synergies. As already stated, many agronomic measures for preventing pesticide use also solve or reduce other pressing challenges, and a reallocation of funds towards the increased economic independence of farmers will solve social issues.

An innovative approach to problem-solving is necessary.

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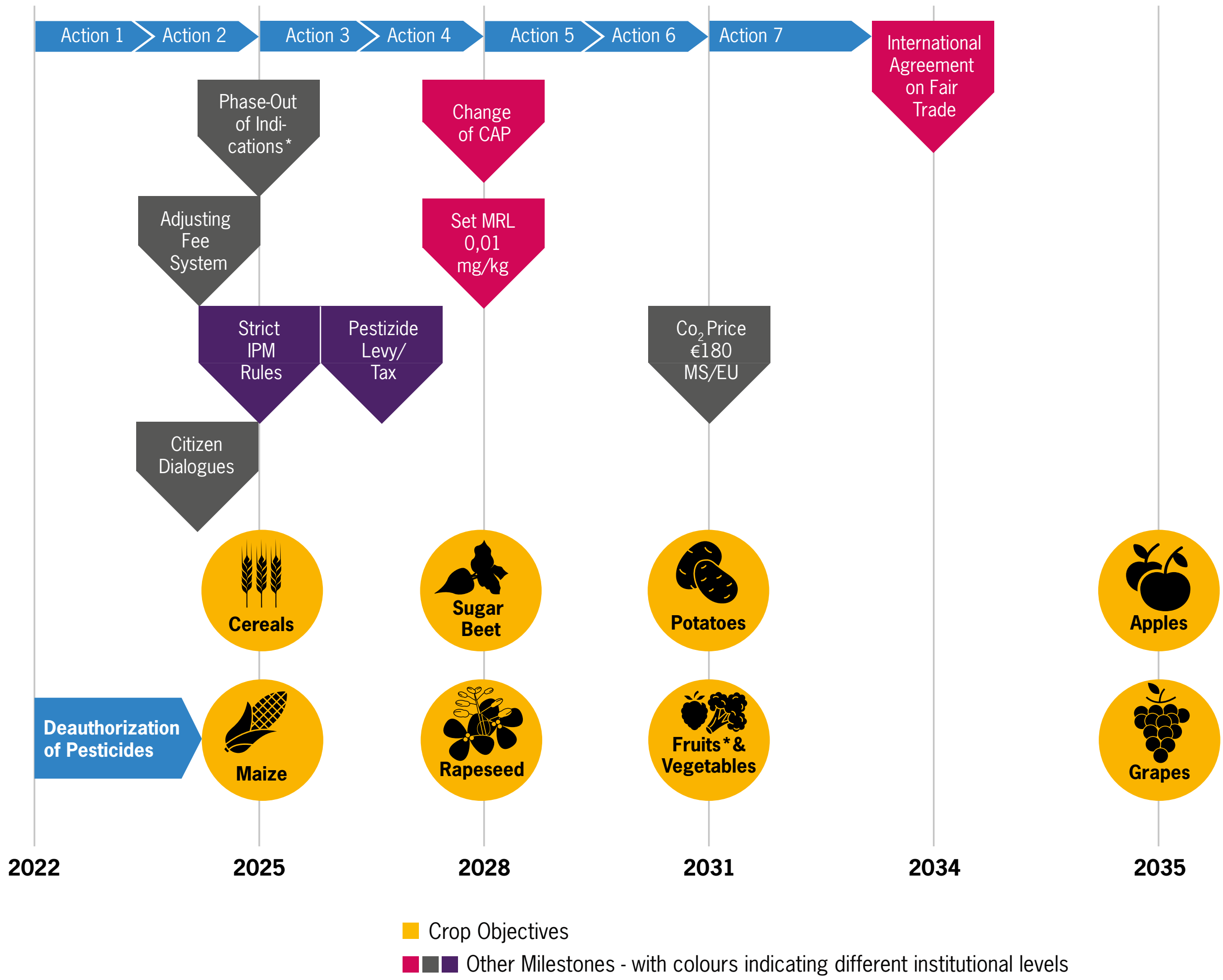
[6] In groups.

7

THE LAST SECTION illustrates such an innovative approach: Crop by crop,[6] the potential future is outlined, key agronomic measures towards pesticide-free farming are listed, and the supporting policy is described. When broken down in this way, the path towards freeing the EU from pesticides appears very manageable. All instruments are available, and a production decline is not to be feared.

It should be clear that agricultural production will change tremendously in the coming decades: All farm inputs based on fossil fuels must be strongly reduced or replaced, and water shortages will require a rethinking of water use in agriculture. Some of the best soils in Europe are currently being utilized for growing non-food silage maize, feed cereals and sugar beet – a discussion on resource allocation and energy efficiency is urgently needed. In general, society needs to decide if a continuation of ***"policy design by chaos"*** is preferable to a ***"design by choice".***

Figure 1:
MODEL OF A PESTICIDE-REDUCTION PLAN WITH CROP OBJECTIVES



1 THE PATH TO PESTICIDE DEPENDENCY

In Europe, agriculture based on external inputs started around the mid-19th century with the import of fertiliser from South America and the regular use of specific pesticides. Before that, agriculture was mostly a local or regional business with very limited access to external inputs, such as fertilisers. Europe's small-scale, low-input agriculture was also a driver of biodiversity (Meyer et al. 2013; Burrichter et al. 1993). Back then, pests, weeds and diseases were mostly controlled by preventative measures and manually.[7] Many relevant plant pathogens, diseases and pests did not occur in Europe before 1840.

The industrial revolution in the mid-19th century, especially the faster transportation systems, completely changed society and agriculture. Specific **economic drivers**, along with a lack of governmental regulation, facilitated the use of pesticides. Not only are these economic drivers (see below) interrelated; they also created specific self-reinforcing mechanisms:

1 INTERNATIONAL TRADE AND TRAVEL

International trade in agricultural commodities has been one of the main drivers of pesticide use. It has both ecological and economic consequences. Regular pesticide use in Europe started after harmful pathogens, pests and weeds had been introduced from North America and other regions by trade and travel: the mildews (grapes), the potato blight and later[8] the potato beetle (Colorado beetle). By 1900, **fungicides** based on sulphur and copper[9] were regularly used against these pathogens, mostly in vineyards and on potatoes and fruits.

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[7] It is not clear to what extent tobacco extract was used in earlier times.

[8] There were several introductions of the potato beetle in the late 19th and early 20th century (Riehm & Schwarz 1927).

[9] The "Bordeaux mix" containing copper sulphate and slaked lime was the first and most famous copper pesticide.

The economic consequences are even more important. As international commodity trade started on a large scale, farmers became global competitors (Gras 1925; Lipsey 1994; Fornari 1976). Stock-market prices began to define to what extent and how crops are grown. This has a direct effect on crop selection (and accordingly crop rotation), along with crop area and the use of external inputs. Today's dominance of cereal crops in Europe and the considerable increase in **herbicide** use in the 1960s are direct results of this international competition. Cereals can be grown with a small workforce, and herbicides reduce the need for human labour even further – the potential[10] margin of profit is higher than in other arable crops. This fact has also led to an expanded use of certain crops beyond their suitable geographic areas, which in turn leads to increased pesticide use.

2 LAND GRABBING

Over the centuries, Europe's land heritage system created (in most regions) a countless number of small farms with small fields and many field edges. The diverse, arable cropping system was probably quite resistant to pests and diseases (see "Crop diversification" in Section 5.1). When European settlers started farming in North America, the land taken from the indigenous population appeared unlimited, was often[11] free of charge and often extremely fertile (e.g. the Great Plains). Low-cost, large-scale farming started very early, with individual farms that were larger than 20,000 ha (Gras 1925 p. 398; Krausmann & Langthaler 2016), boosting international trade (Ruhland 1901; Gras 1925; Fornari 1976). The lack of diversity, as well as the introduced pests, resulted in insect plagues. In the beginning, biological control was seen as the only solution, but several circumstances (see McWilliams 2008; Escherich 1913) eventually led to the use of arsenical **insecticides**.[12] These highly toxic insecticides were used on a large scale in the US as early as the 1890s and became popular in Europe soon after (Hughes 2011; Hiltner 1909; Trappman 1948).

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[10] The problem, of course, is that all farmers rationalise production, which leads to a race to the bottom, overproduction and, in turn, rural exodus.

[11] A large part of the continent was given for free to railway companies, which later sold land to settlers (Ruhland 1901).

[12] "Paris Green" (copper acetoarsenite) was one of the first formulations.

3 RURAL EXODUS (MIGRATION)

When the industrial revolution in the mid-19th century began, many farmworkers – and even farmers –left the rural areas.[13] This trend has continued until today and has affected pesticide use: (1) a shortage of farmworkers forces farmers to further rationalise, resulting, for example, in increased herbicide use, and (2) farms are consolidated and become larger, making large-scale mono-cropping[14] more likely. Rural exodus in Europe was also triggered by the cereal crops that were grown in the Great Plains and exported to Europe (Lipsey 1994; Ruhland 1901).

1.1 ENTERING THE "LOCK-IN"

After entering the ***"pesticide path"*** in the late 19th and early 20th century, European agriculture found itself on a slippery slope towards permanent pesticide dependence. A technology had been unleashed without any assessment of the potential consequences. Pesticides became a premise for the production of certain crops (mostly wine grapes, potatoes and apples), and the search for other solutions was abandoned. By the mid-1920s large multinational companies like I.G. Farben were already dominating the pesticide market and influencing politics. Each year, these companies pushed new fungicides and insecticides for an increasing number of uses onto the unregulated market. Chemicals were generally viewed as a global solution to numerous problems that humans had been facing for centuries. Governmental institutions promoted pesticide use (McWilliams 2008; see Riehm & Schwarz 1927). Eventually, with the introduction of selective herbicides (2,4-D, MCPA, 2,4,5-T) in the 1940s (Troyer 2001), the production of cereals also became pesticide dependent.

Public pressure, along with evidence of severe problems, led to some early pesticide restrictions, usually bans. However, it took many decades for risk assessment to be established as a requirement for pesticide authorisation. In West Germany, for example, it was not until 1968 that potential health risks were assessed prior to pesticide authorisation – by this time, industrial farming had already become the standard (Neumeister 2020b).

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[13] There is a dispute as to whether an earlier "agricultural revolution" triggered the industrial revolution in England.

[14] Defined as the growing of genetically uniform species/cultivars on a large scale in a homogenous landscape with little spatial diversity.

2 PESTICIDE USE IN THE EUROPEAN UNION

Throughout the last decades, public pressure and the increasing evidence of damage caused by pesticides has led to private and public initiatives (legislation) for reducing pesticide use and/or specific risks associated with pesticide use. In 1993 the 5th EU Environmental Action Programme called for ***"a substantial reduction of pesticide use per unit of land under production"***. The 6th EU Environmental Action Programme (2001-2010) sought to ***"reduce the impact of pesticides on human health and the environment"***. More recently, the Farm to Fork Strategy and Biodiversity Strategy have laid out a plan ***"to reduce by 50% the use and risk of chemical pesticides by 2030 and to reduce by 50% the use of more hazardous pesticides by 2030"***.

This section evaluates how pesticide use in the European Union has developed in recent decades.

In the past two decades, several hundred active ingredients have been substituted due to harmonised EU-authorisation, and there has been a global trend towards low-dose, highly effective pesticides.
Therefore, the interpretation of time trends based on accumulated data must be done with caution. A reduction of total pesticide use by amounts at national level is not necessarily associated with a reduced toxicity or reduced pesticide intensity.

At national or international level, pesticide use is often measured in total amounts active ingredients (a.i.) by use type. Such highly aggregated data is not a suitable indicator for assessing pesticide use, because pesticides can vary considerably in toxicity and application rates. Some highly toxic pesticides are applied at rates of 100 grams or less per hectare, while others are applied at much higher rates of 1 kg or more per hectare.

The analysis of sales data, or – even better – usage data per individual active ingredient or per product, is much more significant and would be needed for conducting more profound and realistic evaluations (see examples in Möckel et al. 2021, Neumeister 2020a). The necessary indicators are described in the box ***"How to measure pesticide reduction"***.

In the EU, Member States were not required to report on aggregated pesticide sales data until the introduction of Regulation (EC) No 1185/2009 at the end of 2009. The same regulation also requires regular field surveys for main crops. Eurostat[15] collects the respective sales data aggregated by chemical groups, but this data is still not complete,[16] and some EU accession countries did not report data before 2012. Individual chemical groups are too aggregated and do not allow for scientific evaluation. The European Court of Auditors (ECA) has also criticised the data collection and interpretation (ECA 2020), and a revision of Regulation (EC) No 1185/2009 is in process.

In 2020 about 322 million kilograms of pesticide active ingredients[17] were sold in the EU-27 countries (EC 2022). The slight reduction 2019 and 2020 in comparison to previous years was caused by droughts[18] and perhaps by delivery issues due to COVID-19 (see Lamichhane & Reay-Jones 2021). However, the volumes are still in a similar range as the years before. Figure 2 shows the pesticide sales data for 2013 through 2019. For 2011 and 2012 Eurostat data are not complete for the EU-27.

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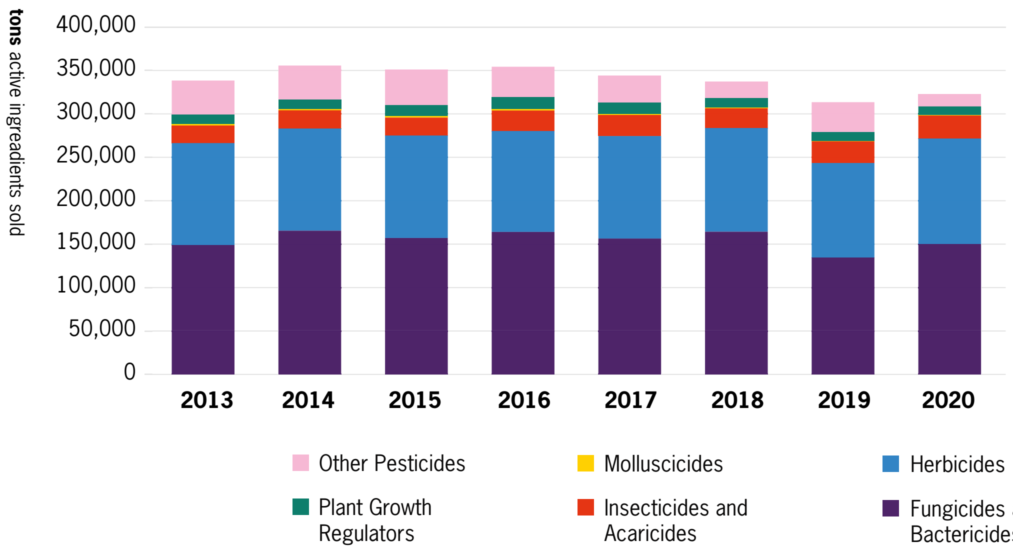
15 Eurostat is the statistical office of the European Union.

16 For some large countries, like Bulgaria and Poland, the data on chemical groups is not complete for any reporting year. Data on a lower aggregation level is missing for most countries before 2018.

17 Without CO2 sales (used for storage treatment) in Austria (see Grüne Berichte) and Germany, and without inorganic (garden) herbicides.

18 See https://ihsmarkit.com/research-analysis/global-crop-protection-market-down-1-in-2019.html

Figure 2:
PESTICIDE SALES (KG ACTIVE INGREDIENTS) IN THE EU-27 2013-2020



In addition, sales of illegal pesticides – 13.8% according to OECD 2021 – must be added to the official EU numbers for authorised sales.

When considering the long-term trends of pesticide use in the European Union, it is important to distinguish between the early EU (EU-15 Member States until May 2004) and the newer EU Member States, because there has been no harmonised data collection in recent decades.

In the **EU-15 countries,**[19] the amounts of pesticides sold annually, especially herbicides and insecticides, have increased substantially in the past few decades. Apparently, the pesticide reduction demanded by the 5th and 6th EU Environmental Action Programme has not resulted in any change. Figure 3 shows pesticide sales data for the main use types[20] in the EU-15 countries from a 1992-2003[21] sales analysis (EC 2007) and amounts reported to Eurostat from 2011 to 2019 (EC 2022; BVL 2012-2020). Data for the years 2003 to 2011 is not available at EU level, because there were no reporting requirements at that time.

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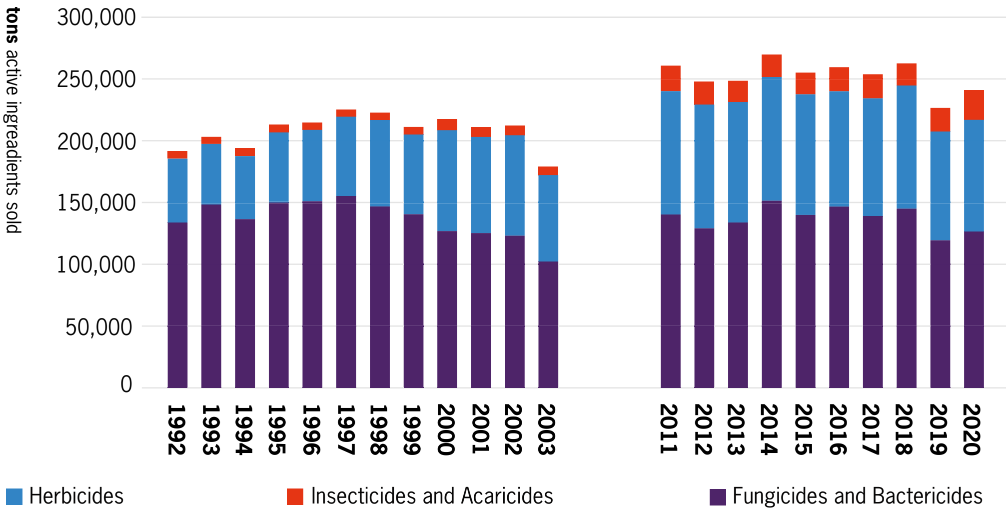
[19] AT = Austria, BE = Belgium, DE = Germany, DK = Denmark, EL = Greece, ES = Spain, FI = Finland, FR = France, IE = Ireland, IT = Italy, LU = Luxembourg, NL = Netherlands, PT = Portugal, SE = Sweden, UK = United Kingdom

[20] There was no consistent reporting of plant growth regulators (PGRs) before 1997. Therefore, PGRs were excluded from the newer data. Carbon-dioxide use, reported from Germany (BVL 2011-2019) and Austria, was excluded. Inorganic herbicides (garden pesticides) were excluded from 2011-2020 data)

[21] There is no complete historical data available for the countries that joined the European Union in 2004.

Figure 3:
PESTICIDE SALES (KG ACTIVE INGREDIENTS) IN THE EU-15 1992-2003 and 2011-2020



For the Eastern and Southern European countries that joined the EU in 2004[22] and 2007,[23] no reliable pesticide-use data from prior to 2005 (EC 2007) exists; therefore, valid trends can only be observed for the years following EU accession.

In the first years after the accession, pesticide sales remained stable in most new EU Member States, except in Poland where sales increased. Since 2013/2014 pesticide sales have been increasing in most of the twelve countries, with particularly strong increases in Bulgaria and Cyprus (FAO 2020; EC 2020a; Cyprus Statistical Service 2020).

In Croatia (HR), which joined the EU in July 2013, pesticide sales increased until 2015 and have been decreasing since then.

Figure 4 shows pesticide use (active ingredients, a.i.) per hectare in the year 2018 in the current 27 EU Member States. Shown are the amounts per hectare[24] by share of use type (EC 2022, EC 2020b). The graph shows that pesticide use per hectare varies greatly between the individual EU Member States.

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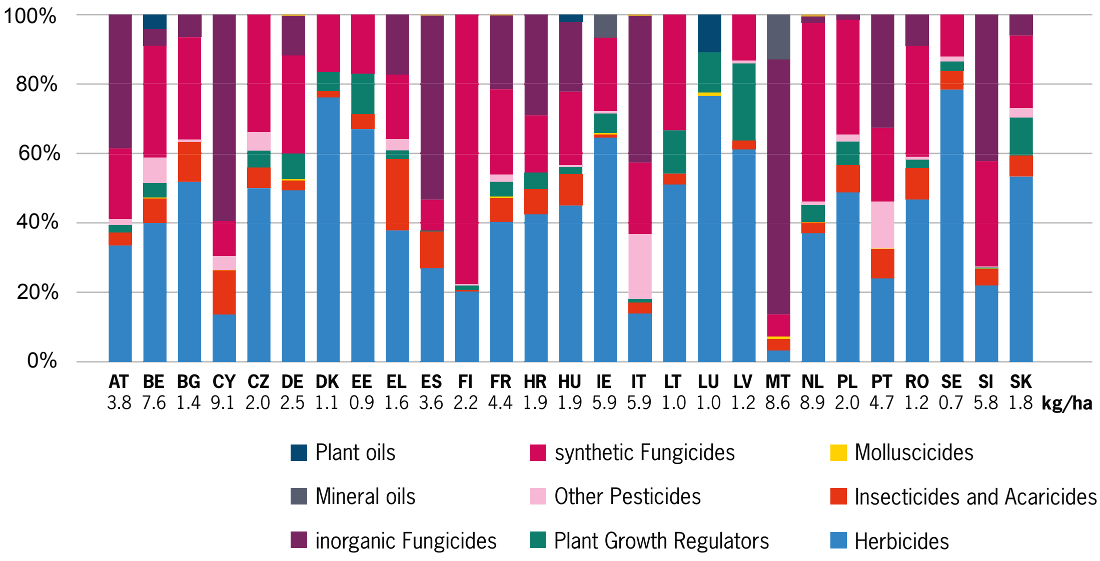
22 CY = Cyprus, CZ = Czech Republic, EE = Estonia, HU = Hungary, LT = Lithuania, LV = Latvia, MT = Malta, PL = Poland, SI = Slovenia, SK = Slovakia.

23 BG = Bulgaria, RO = Romania.

24 Amounts sold (CO2 excluded) divided by area of arable land plus land under permanent crops.

Figure 4:

PESTICIDE USE (A.I.) IN THE YEAR 2018 IN THE EU-27 COUNTRIES –
Proportional use in kg per ha by use type



On a country level, the main determinants of pesticide use are the climate and the percentage of land used for growing specialty or permanent crops. A larger percentage of land use for permanent and specialty crops is usually associated with higher amounts per hectare. Higher humidity is generally associated with a greater use of fungicides and herbicides.

The Netherlands, a humid country with a high density of specialty crops, has the highest use of synthetic pesticides per hectare of agricultural land. Malta and Cyprus have the highest use per hectare among the more arid Member States, but the inorganic fungicide sulphur,[25] which is of much lower toxicity than synthetic fungicides, accounts for a high percentage of the pesticides used. In general, Northern European countries show a much higher share of herbicides, while Southern European countries show a higher share of inorganic fungicides like sulphur and insecticides.

France, Germany and the Netherlands are the countries with the highest consumption of synthetic pesticides in the EU. Section 2.1 will discuss whether or not pesticide use in these three countries has increased in recent years and how the intensity varies between different crops.

[25] See also details in Malta's National Action Plan for Sustainable Use of Pesticides 2013-2018 https://mccaa.org.mt/media/1154/nap-mt.pdf

INFLUENCE OF ORGANIC AGRICULTURE ON NATIONAL PESTICIDE USE

About 8% of all agricultural land in the EU-27 countries is farmed organically (data from 2018). So far, the increase in organic agriculture has not resulted in any visible reduction in overall pesticide amounts. The time span 2011-2018 may be too short to detect an effect. In addition, some high-use pesticides (inorganic fungicides [sulphur and copper compounds], mineral/plant oils) are allowed in most organic permanent crops (12% organic share) and potatoes. A high proportion of organically farmed land is permanent grassland (meadows) for livestock (11%). As conventional permanent grassland is rarely sprayed with pesticides, a conversion to organic production does not substantially reduce pesticide use. Arable organic cultivation is most likely completely pesticide-free to a large extent (except potatoes), but currently accounts for only 6% of the total arable land in the EU-27 (EC 2020b & EC 2020c). Herbicide use is not allowed in organic agriculture, but the EU data for 2011 to 2019 does not show any reduction in herbicide use at EU level.

In Austria, organic agriculture has already reached the Farm to Fork target of 25% (EC 2020c). Nevertheless, the increase in organic cultivation has not automatically led to a reduction of sales of chemical-synthetic pesticides on national level for different reasons. While in the timeframe 1999 to 2003 around 2,100 to 2,400 tonnes of chemical-synthetic pesticides were sold per year, sales of such pesticides were about 2,400 to 2,800 tonnes (active ingredient) per year between 2014 to 2018 (Lebensministerium 2004; Lebensministerium 2020). Without other measures, the target of 25 per cent organic farming alone will not achieve the desired pesticide reduction.

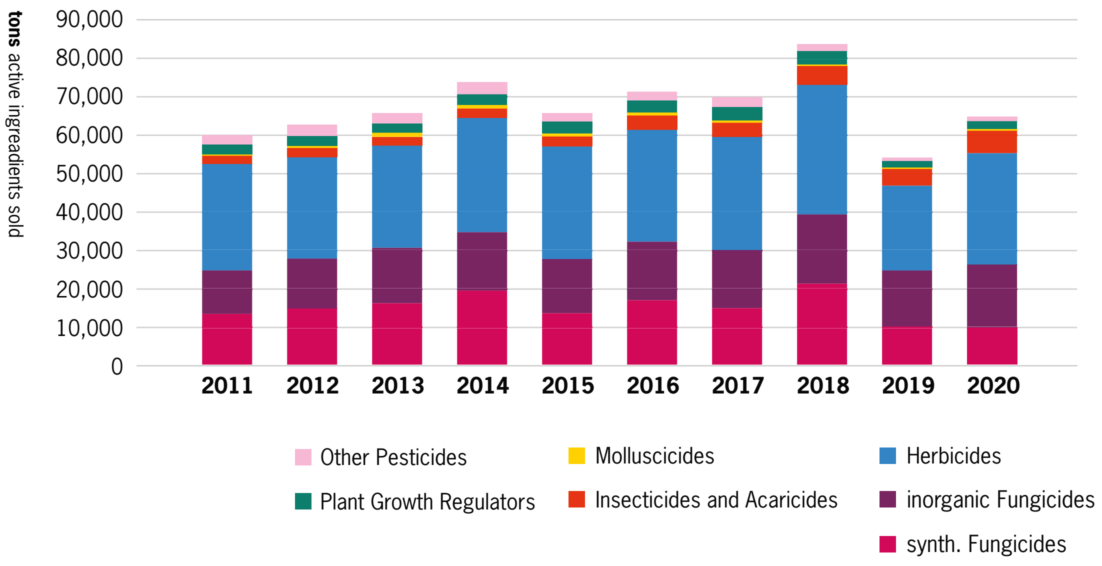
2.1 PESTICIDE USE IN FRANCE, GERMANY AND THE NETHERLANDS

In Germany and France, access to pesticide sales and usage data has strongly improved since 2019. Information on sales by active ingredient (Germany) or by pesticide product (France), as well as a higher survey frequency for major crops (annually in Germany since 2011), allows for a detailed analysis of pesticide use. Surveys are conducted in all three countries and give insights into pesticide-use intensity for various crops. The intention of this section is not to compare the three countries, but to describe the situation and illustrate the trends.

FRANCE

Due to its large agricultural area and extensive viticulture, France is the country with the highest consumption of synthetic pesticides in the European Union. On average, about 67,000 tonnes of active ingredients were sold annually between 2011-2020. Herbicide sales represent the largest share, followed by synthetic fungicides (see Figure 5).

Figure 5:
PESTICIDE USE (KG ACTIVE INGREDIENTS SOLD[26]) IN FRANCE 2011-2020



It is particularly noteworthy that France installed a national pesticide reduction plan called “Ecophyto” in 2008, with the objective of achieving a 50% reduction in pesticide use by 2018 (MAA 2020).

However, the plan did not yield the desired outcome. On the contrary: Pesticide sales went up in most French departments and in important crops, such as wine grapes, soft wheat, barley and rapeseed (SSP 2019; agreste 2020). The failure of “Ecophyto” was predictable because it focused on the practices of farmers and advisors while ignoring the broader effects of the socio-technical lock-in (Guichard et al. 2017).

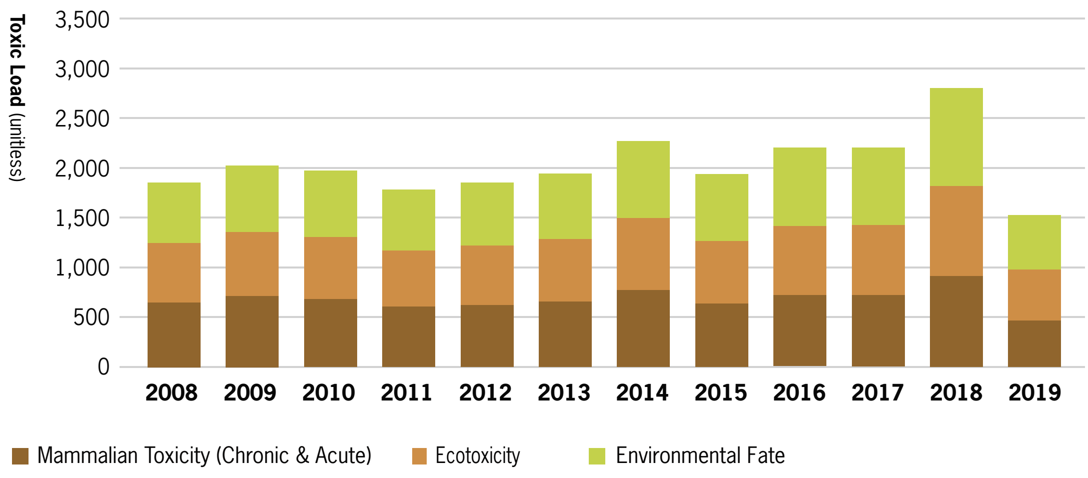
The increase is also reflected in national sales data (see Figure 5). In 2020, the French government published sales data for over 5,000 pesticide products and over 500 active ingredients for the period 2008 through 2019. This data

[26] Without inorganic (garden) herbicides.

is available by department and on a national level (MTE 2020). **It was the first time that a European government published sales data by product.** This data provides in-depth insight into pesticide use in France. When sales data by product and/or active ingredient is made available, more profound evaluations are possible, because toxicological and chemical properties can be assigned to each product/active ingredient. The Toxic Load Indicator (TLI) is one instrument for evaluating the use of active ingredients (Neumeister 2017). The TLI is based on 15 criteria in three groups for a given pesticide active ingredient, and pesticide use can be evaluated for each criterion or accumulated for each parameter group.

For this report an evaluation[27] by risk group was conducted. Pesticides whose EU approval expired or was withdrawn between 2008 and 2019 and which were not sold throughout the entire period are excluded from the evaluation. This excludes reduction effects caused by the expiration or withdrawal of approval. Figure 6 shows the Toxic Load in France for sales of agricultural pesticide active ingredients (n=311). Pesticides with lower toxicity, like sulphur, oils and other inorganic substances,[28] were excluded in order to focus more strongly on chemicals with higher toxicity.

Figure 6:
TOXIC LOAD IN FRANCE 2008-2019



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[27] For each amount of product sales, the amount of active ingredient was calculated using France's authorisation database, which contains the exact composition. Then each amount was multiplied with the TLI (author's database) for each risk group.

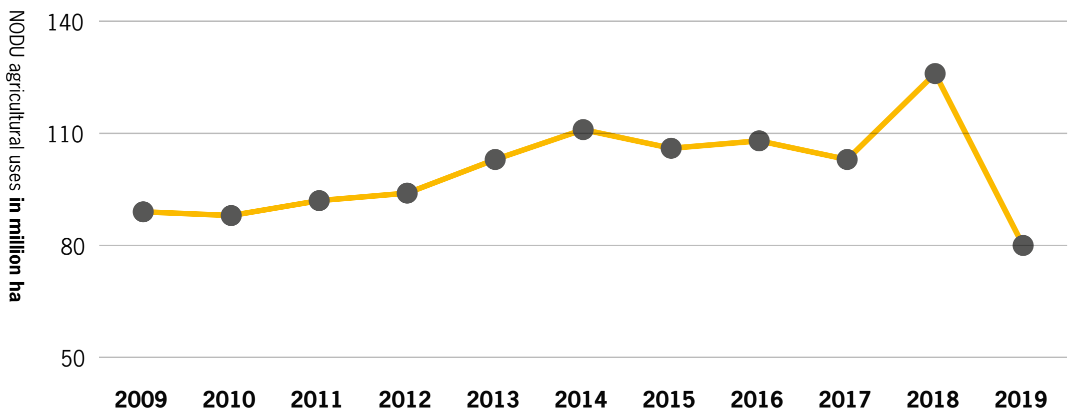
[28] All copper-based compounds are included in the evaluation.

The Toxic Load in France remained at a similar level throughout the period 2008-2017 but peaking in 2018. In 2019, a reduction of the Toxic Load can be observed. However, according to MAA (2021) the decline in 2019 sales can be explained by the consumption of existing stocks, which had resulted from the massive volumes purchased in 2018 in anticipation of an increase in the non-point source pollution charge (ibid.), as well as the generally good growing conditions in 2019, which limited the development of diseases and pest populations.

Each year, the French government calculates the "number of dose units" (NODU) sold. This calculation is based on the product-specific sales data and approved application rates (dose). The NODU for agriculture reflects the number of potentially treated hectares.

Figure 7 shows that the NODU for agriculture increased significantly during the implementation period of the "Ecophyto" programme – instead of declining by 50%. With the amounts sold in 2018, each hectare of agricultural land could receive 6.5 treatments (MAA 2020).

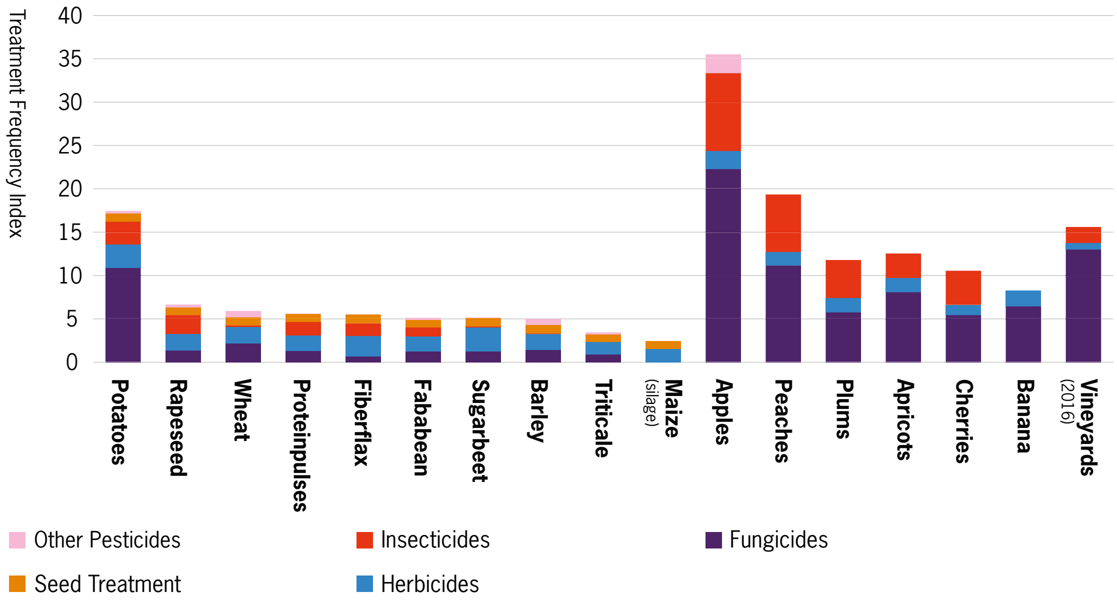
Figure 7:
"NUMBER OF DOSE UNITS" (NODU) SOLD IN FRANCE 2009-2018



In 2019, the NODU declined for the first time, parallel to the sales data.

In France, apples, peaches, potatoes and vineyards are associated with the highest pesticide treatment frequency. The diagram below shows the Treatment Frequency Index (TFI) – i.e. the number of applications on 100% of the crop area with the full recommended dose – for the most important arable crops (season 2016/2017), fruits (season 2015) and vineyards (2016).

Figure 8:
TREATMENT FREQUENCY INDEX BY CROP IN FRANCE 2016/2017



The large-scale crops wheat, rapeseed and barley have a Treatment Frequency Index (TFI) of over five (2016/17).

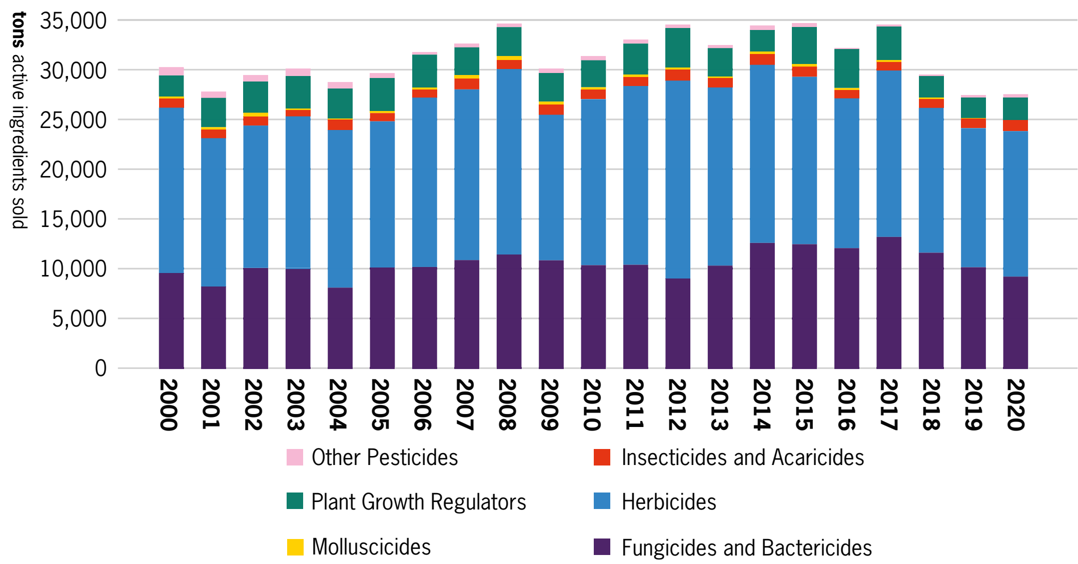
Almost every crop receives two herbicide applications. In general, arable crops are treated with fungicides before being sown (seed treatment). However, the combination of fungicides and insecticides is also common. Foliar fungicide and insecticide applications vary among the crops. The use of plant growth regulators is not included in the French TFI, although they are commonly used (one treatment) in cereals and fruit production.

GERMANY

In Germany, pesticide production and use have a long history. Companies like Bayer (now Bayer CropScience) and BASF started to develop and sell pesticides over 100 years ago.

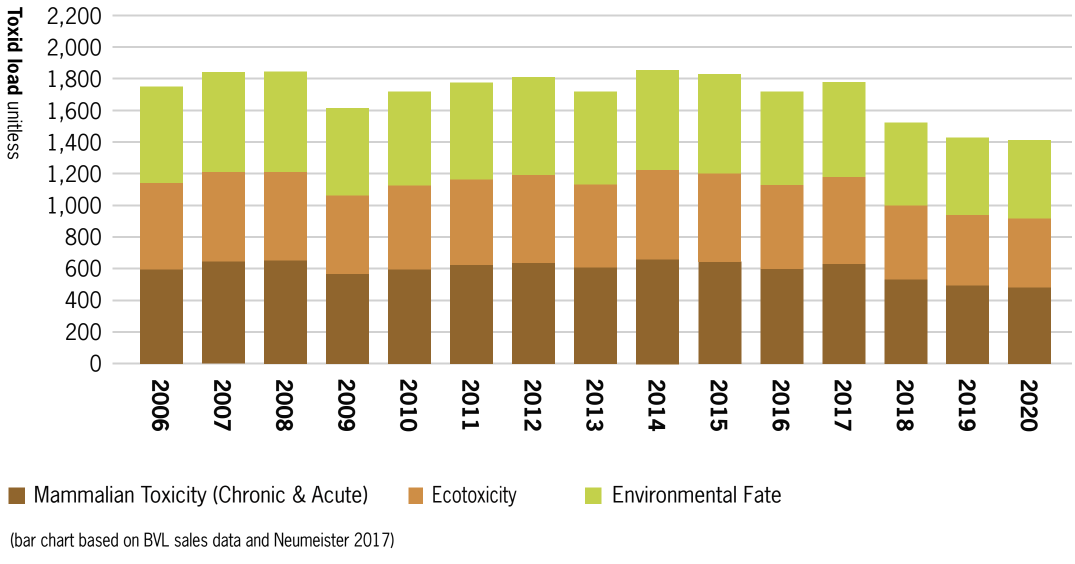
Since 1995 between 28,000 and 35,000 tonnes of active ingredients have been sold annually in Germany (BVL 2021). Herbicides have the highest share, followed by fungicides and plant growth regulators (see Figure 9).

Figure 9:
PESTICIDE SALES (A.I.) IN GERMANY 2000-2020



Since February 2019, German pesticide sales data has been available by active ingredient. Figure 10 shows the Toxic Load in Germany for sales of agricultural pesticide active ingredients. Sulphur, oils and fatty acids were excluded in order to focus more strongly on chemicals with higher toxicity.
The evaluation of the sales data for 2005 to 2020 shows that the national Toxic Load remained at a similar level throughout the sixteen years (see Figure 10). The lower toxic load in 2018-2020 is an effect of the drought, which caused a decline in pesticide sales.

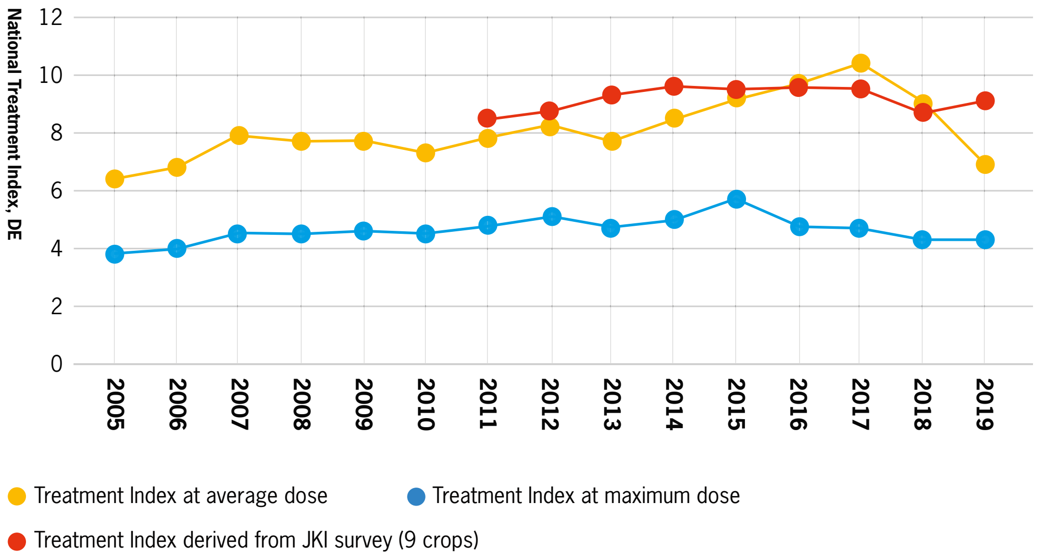
Figure 10:
TOXID LOAD IN GERMANY 2005-2020



(bar chart based on BVL sales data and Neumeister 2017)

The sales volumes divided by the common application rates indicate a clear increase in number of treatments per hectare over the years 2005-2015.[29] After 2015 the index develops differently depending on doses used. Data from representative surveys on the main crops shows a similar trend (see Figure 11) - Neumeister 2020a, data 2018 and 2018 added.

Figure 11:
NATIONAL TREATMENT INDEX IN GERMANY BASED ON PESTICIDE ACTIVE INGREDIENTS
(Diagram Neumeister 2022)

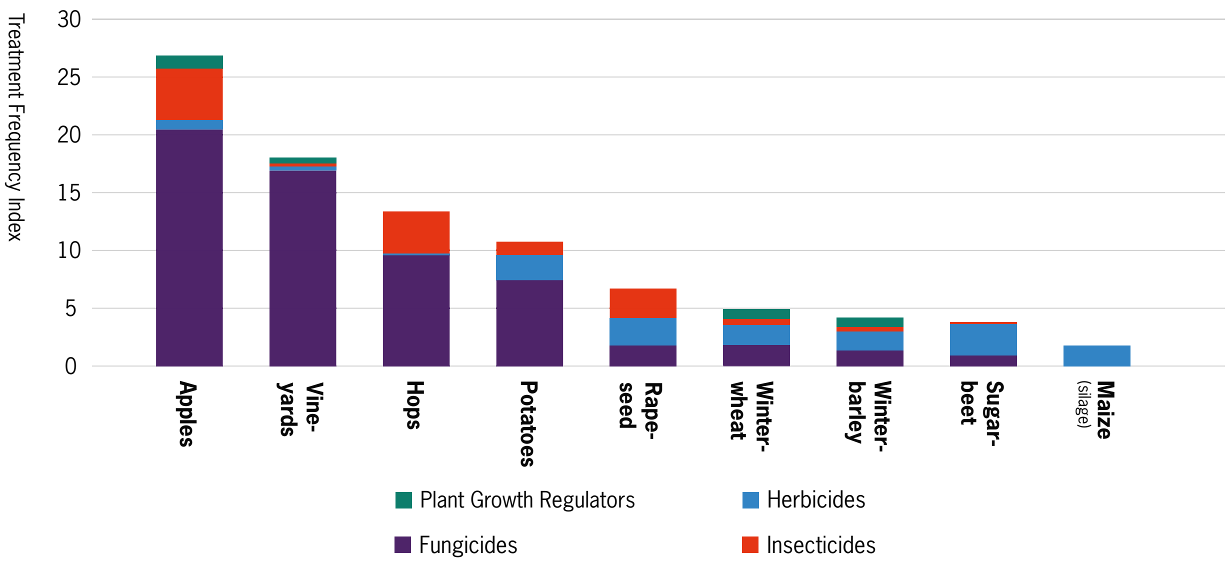


Index without seed treatment and without Imidacloprid, Thiamethoxam and Clothianidin

[29] Similar to the French NODU, sales data by active ingredient was divided by the specifically approved application rates (max. and average dose/ha). The result is the number of potentially treated hectares. Divided by the agricultural area (sum of arable land and land under permanent crops for each year), a national treatment index was derived.

In 2000, regular surveys of pesticide use in specific crops started in Germany. Since 2011 nine crops have been surveyed each year. The Treatment Frequency Index (TFI) is one of the key results of the surveys and reflects the pesticide-use intensity. Figure 12 shows that permanent crops like apples, vineyards and hops are treated most often with pesticides. Among the arable crops, potatoes and rapeseed show the highest frequency.

Figure 12:
TREATMENT FREQUENCY INDEX 2018 BY CROP



The large-scale crops winter wheat and winter barley have a Treatment Frequency Index (TFI) of 4-5.

Each arable crop receives at least two full herbicide applications. In general, all seeding material is treated with pesticides before being sown (seed treatment) – this treatment is not reported in the survey.

THE NETHERLANDS

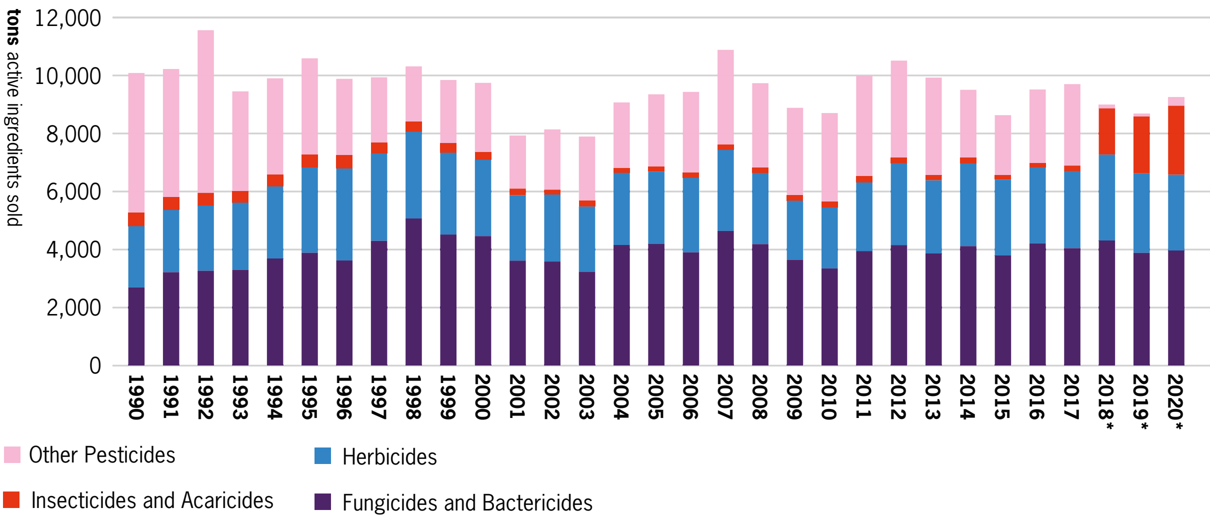
The Netherlands has a small agricultural area but is a leading nation when it comes to agricultural exports. Nearly 100% of the arable land is treated with pesticides. Specialty crops, like flowers, are treated with over 100 kg active ingredients per ha (CBS 2022a).

Several organisations collect pesticides sales and usage data. Nefyto, the association of pesticides sellers, has been publishing data since 1990 (Nefyto

2019). This data is not comprehensive because only the sales of its members are counted. The data reported to Eurostat (available for 2011-2019) is about 10-12% higher than the Nefyto sales data.

Since 1990 between 8,000 and nearly 12,000 tonnes of active ingredients have been sold annually in the Netherlands (see Figure 13).

Figure 13:
PESTICIDE SALES IN THE NETHERLANDS 1990-2020



*Data from Eurostat. Note: Eurostat classifies some pesticides (e.g. mineral oils, PGRs) different from Nefyto (1990-2017)

Figure 13 graphs the Nefyto data from 1990 to 2017 to show the historical trend. The data for 2018-2020 is not available from Nefyto. Therefore, data from Eurostat (EC 2022) was added to the graph. The classification of pesticides differs between Nefyto and Eurostat: For example, mineral oils are classified as “other pesticides” by Nefyto but as “insecticides/acaricides” by Eurostat.
The Netherlands Food and Consumer Product Safety Authority (NVWA) and the Central Bureau of Statistics (CBS) also collect sales data.

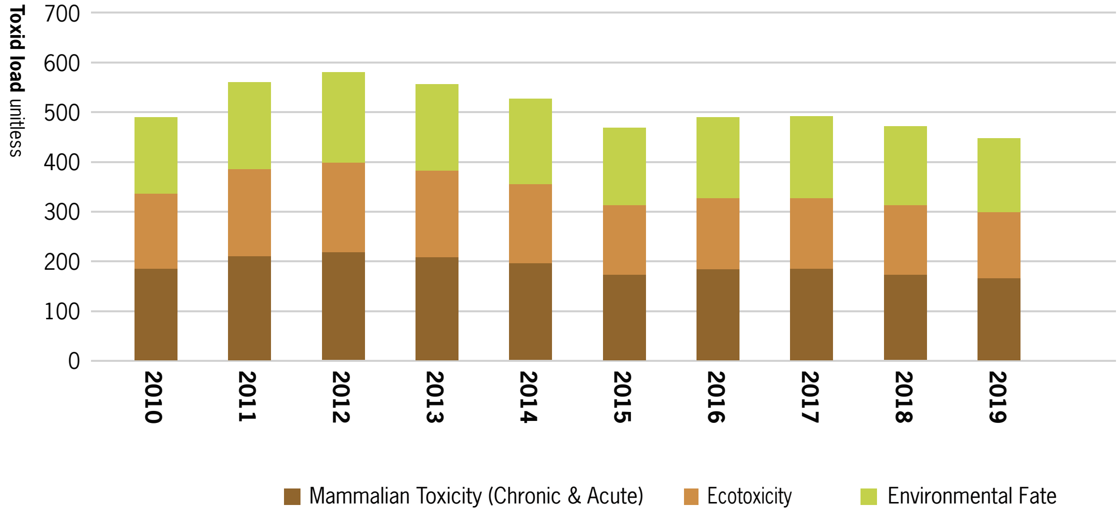
The Netherlands Food and Consumer Product Safety Authority (NVWA 2022) publishes sales data by active ingredient (available for 2010-2019). The total volumes[30] per year differ from those published by Eurostat and Nefyto. The NVWA lists contain sales of some co-formulants and synergists, as well as typical garden pesticides, such as iron sulphate/ferric sulphate.

[30] Neumeister´s calculation and comparison (2022).

The NVWA data allows for a profound analysis of the years 2010-2019.

For all synthetic pesticides the Toxic Load was calculated (Figure 14). The Toxic Load peaked in 2012 and decreased slightly thereafter.

Figure 14:
TOXIC LOAD IN THE NETHERLANDS (2010-2019) FOR SYNTHETIC PESTICIDES



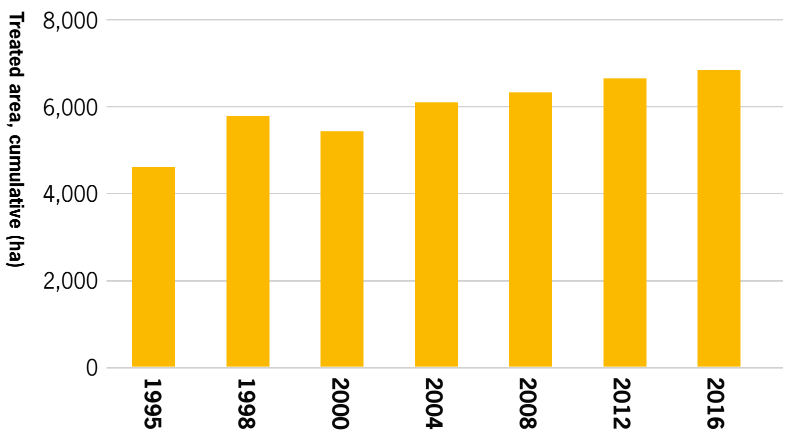
(author's bar chart based on BVL sales data and Neumeister 2017)

Of all synthetic pesticides, the highly toxic mancozeb contributes the most to the Dutch Toxic Load (34% in 2019), followed by glyphosate (7%) and captan (5%). Over 2 million kg of mancozeb were sold in 2019. Since January 2022, its use has been prohibited in the EU, meaning that a reduction of Toxic Load and volume sold can be expected.

Since 1995, the Central Bureau of Statistics (CBS) has been collecting detailed data by crop and active ingredient in a four-year[31] cycle. The most recent data available is from 2016.[32] The data represents about 60% of all pesticide sales. The evaluation of the data collected by the CBS (CBS 2016 & CBS 2022b) shows that intensity of pesticide use, measured by the cumulative area[33] treated, has increased, while the utilised agricultural area (UAA) remained stable (EC 2020b). This means that the frequency of treatments, and thus the exposure, has increased.

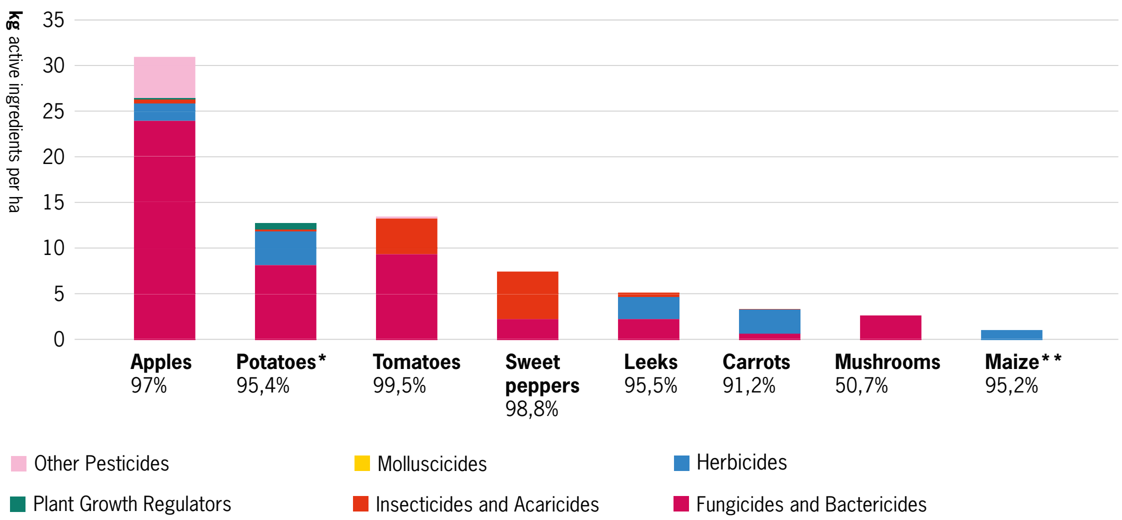
[31] The sequence changed in the year 2000.
[32] Last check February 2022.
[33] Sum of hectare treated for each active ingredient.

Figure 15:
CUMULATIVE TREATED AREA 1995-2016 IN THE NETHERLANDS



The Dutch flower industry uses very high amounts of over 100 kg of pesticides per hectare, and crops grown for human consumption are also intensively treated. Apples receive about 30 kg of active ingredients/ha, and potatoes and tomatoes about 12-13 kg of active ingredients/ha. The following diagram shows the amounts of pesticide used per hectare for important crops. The percentage of the crop area treated is shown in the parentheses below the crop name.

Figure 16:
PESTICIDE USE IN KG (A.I.) /HA (2016) BY CROP AND PERCENTAGE OF CROP



(Neumeister's bar chart (2022) based on CBS 2020) *human consumption **incl. maize for silage

REASONS FOR DIFFERENT PESTICIDE-USE INTENSITIES

The previous two sections described how agriculture became dependent on pesticide use and showed that pesticide use in Europe is on the rise considering the trend towards low-dose pesticides. However, there are no indicators that are applicable throughout the EU based on toxicity **and** hectares treated or doses applied (see box: ***"How to measure pesticide use"***). Data availability is insufficient.

Pesticide use varies greatly between countries. Climate, cropping systems and farming systems are the main determinants. However, high pesticide use in kg per hectare does not necessarily indicate a high risk or a high pesticide intensity (or vice versa). In Spain, Malta and Cyprus the relatively harmless substance sulphur – a high-dose fungicide[34] – constitutes a large share of the annual use, whereas in Northern countries low-dose, synthetic pesticides are applied on 100% of the conventional arable cropland and permanent crops. Sales and usage data suggests that the entire area of conventional cropland (arable land and permanent crops) receives two full herbicide applications annually. **Herbicides are designed to eliminate on-field biodiversity and drive species loss, and many herbicides are prone to groundwater contamination.**

It is important to note that there is little variation in pesticide intensity among the same crop or group as long as the climatic situation is (more or less) similar. Independent of crop type and region, the use of insecticides and acaricides is driven by a combination of factors which often occur together: nitrogen (over)use and a lack of spatial and/or genetic and/or functional diversity. In general, crops which are continuously propagated by cloning (most fruit trees, grapes, fruit shrubs and potatoes) have the highest pesticide-use intensity, because cloning causes genetic uniformity, resulting in vulnerable immune systems (Bannier 2010; Myles et al. 2011; Migicovsky et al. 2017; Pelsi 2010; Zhang et al 2019). When these clones are grown on a large scale, the ***"genetic connectivity"*** allows for the easy spread of pests and diseases (see e.g. Bousset et al. 2018). **Genetic uniformity (and inbreeding[35]), along with humidity, are the main drivers of fungicide use in permanent crops and potatoes.**

Conventional vegetable production is also very pesticide intense. Individual crops may receive 7-8 pesticide treatments. In market gardens, a high sequence of crops is usually grown over one season. When, for example, three crops are grown on one site (consecutively), and each crop receives 7 applications, the

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[34] Sulphur is also an effective acaricide, but it is more commonly used as a fungicide.

[35] Inbreeding is, for example, very commonly used for creating new apple cultivars (see Bannier 2010).

site is exposed to a total of 21 applications. Therefore, an individual vegetable field and the pesticide users may be exposed to a large "cocktail" of pesticides over the course of an entire season.

Arable crops (excluding potatoes) are usually treated 2-7 times per season. Arable crops are grown on a large scale, meaning that any pesticide use affects extensive agroecosystems.

The table below provides general information on the pesticide use and risks for main crops/crop groups. Pesticide use and the associated risks depend on many factors. The risks increase with higher frequency of use and when highly damaging[36] pesticides are used. The application method and the number of exposed people are also risk factors.

CROP GROUP	PESTICIDE USE AND AREA AFFECTED	POTENTIAL RISKS
Permanent crops (fruit trees, shrubs, grapes etc.)	High pesticide-use intensity, but small percentage of EU agricultural land.	Higher risk for the pesticide users and bystanders. Regional environmental risks. Potential risks for consumers via residues.
Vegetables	Very high pesticide-use intensity, but very small percentage of EU agricultural land.	High risk for pesticide users and bystanders. Potentially large number of exposed people. Regional environmental risks. Potential risks for consumers via residues.
Wheat, barley, triticale, maize	Lower pesticide-use intensity, but large total area. Consecutive mono-cropping is common.	High ecological risk through direct and indirect effects (e.g. reduction of trophic food web) and for groundwater.
Sugar beet, potatoes, rapeseed	High pesticide-use intensity. Regionally large areas. Pauses of 3-4 years in the rotation reduces some ecological risks.	High risk for neighbouring ecosystems and for pesticide users. Potential groundwater risks.
Permanent grassland, meadows	Very low pesticide-use intensity.	

[36] The potential damage is not necessarily determined by the toxicity to non-target organisms incl. humans. Any use may damage trophic interdependencies or cause contamination off-site.

3 POSITIVE AND NEGATIVE EFFECTS OF PESTICIDE USE

3.1 CLAIMED BENEFITS OF PESTICIDE USE

The manufacturers of pesticides and other representatives of industrial farming argue that pesticide use is essential for providing sufficient and affordable food for a growing human population. Without pesticides, they assert, pests and diseases would severely affect plant growth, and weeds would outcompete crops (CropLife International 2021). The argument is that pesticides allow for a high productivity per area of land (high yields), i.e. less agricultural land is needed, and that, by the same token, a reduction in pesticide use would promote the conversion of natural land to arable land, producing CO2 emissions (HFFA 2013; ECPA 2020).

A study financed by Syngenta and Bayer CropScience estimated that an EU-wide ban of only three seed-treatment insecticides (insecticides for which these two companies had a quasi-monopoly) would reduce yields on a large scale and cause

1. **a decline of EU economic welfare by €17-23 billion,**
2. **an additional loss of 40,000 jobs in agriculture and**
3. **the conversion of an additional 3.3 to 5.7 million hectares of unused land into arable land, causing more than 1 billion tonnes of additional CO2 emissions (HFFA 2013).**

Another publication (Cooper & Dobson 2007), based on research by CropLife International, a trade association of pesticide producers, lists 26 primary benefits and 31 secondary benefits of agricultural and non-agricultural pesticide use. These benefits include increased crop and livestock yields, improved food safety, human health, quality of life and longevity, and reduced labour, energy use and environmental degradation.

Fruit and vegetable growers claim that they are forced to apply more pesticides to satisfy the aesthetic standards of retailers. Retailers demand perfect-looking, unblemished fruits of standardised appearance at low prices. "Ugly fruits" with damaged peels or unusual shapes are, in their view, not marketable. Sometimes, it is also argued that pesticide use protects consumers from toxins created by fungal pathogens (mycotoxins), because fungicides control the fungal infections.

Herbicide use is often promoted as a soil-friendly technology which also prevents erosion, because it can take the place of mechanical soil disturbances like ploughing.

Figure 17: **CLAIMED BENEFITS OF PESTICIDE USE: ADVERTISEMENT 1905 FOR LEAD ARSENATA** (PbHAsO4), an inorganic insecticide composed from lead (Pb) and arsenate (As), both highly toxic substances

3.2 ADVERSE ECONOMIC EFFECTS OF PESTICIDE USE

Pesticides are designed to interfere with the basic biological processes of living organisms, and pesticide use is associated with numerous adverse effects on human health and the environment. The literature on this subject encompasses a countless number of scientific articles, books and reports. A search for the term "pesticide" in the United States National Library of Medicine within the National Institutes of Health (NIH) produces more than 200,000 results, of which over 700 articles are "systematic reviews".

This report will highlight several aspects that have not been the focus of attention in the past: e.g. the economics of pesticide use. The number of studies analysing pesticide lock-in, path dependencies and the associated external costs is relatively small compared to the number of toxicological studies.

The role of pesticides as the **catalysts** of an extremely costly (UN Food System Summit 2021; G20 Insights 2020; Niewkup 2020) "modern" global food system receives very little if any attention: Pesticides made it possible to eliminate genetic, biological and agronomical diversity, as well as human labour, from the agricultural system and to maintain unstable, vulnerable cropping systems. Once these systems were created, pesticide use became a (self-reinforcing) prerequisite, creating a pesticide "lock-in".

None of the problems created and/or driven by industrial farming, such as pesticide use, biodiversity loss, climate change or rural exodus, will ever be solved while ignoring the fact that most agricultural holdings are economically and socially "locked-in" (e.g. Frison 2021).

THE TRUE PRICE OF PESTICIDES

In 2019 a commercial, organic beekeeper near Berlin detected a high concentration of glyphosate in his honey. As a result, four tonnes of his honey were rendered unmarketable, and the beekeeper lost approximately €70,000 of his turnover (Seusing 2022) forcing him to temporarily close his business. In 2018, 70 field workers in France were poisoned after a highly toxic pesticide was applied to the soil and evaporated. Seventeen of them were hospitalised (EP 2018). In the Netherlands, about two thirds of the drinking-water sources are contaminated with pesticides (Sjerps et al. 2019); one drinking-water company alone spends €15 million per year to clean the contaminated water (NL Times 2018). In the 1980s fishermen on Lake Shinji (Japan) used to catch 30 to 60 tonnes of eels and 120 to 300 tonnes of smelt per year. After 1993, both fish populations collapsed because rice farmers in the estuary of the lake had started to use imidacloprid – a newly introduced insecticide.[37] The pesticide run-off from the fields affected the fish food web so severely that smelt fishing yields dropped to zero and eel fishing yields to about 10 tonnes per year. Neither population has recovered (Yamamuro et al. 2019). In 2000 and 2003, 1,500 tonnes of unused, highly toxic pesticides were shipped from Ethiopia to Finland. They were incinerated at a cost of US$4.4 million (Haylamicheal & Dalvie 2009).

The five aforementioned examples illustrate three important facts:

1. **Pesticides do not remain in the place where they were applied.**
2. **Pesticides can cause considerable harm to people and the environment.**
3. **Pesticides can have a devastating impact on the economy.**

Economic damages caused by pesticide use are also called "external costs", but the definition of this term is much broader. Basically, external costs are all costs borne by society (public and private sectors) that are related to a service or product but not reflected in the price of the service or product. The true price of pesticides includes the pesticide price and the hidden, external costs borne by society. External costs are not always unwanted costs. For example, the respective legislation needs to be created and amended, but the costs of this work need to be internalised into the pesticide price (via fees, taxes).

THE EXTERNAL COSTS OF PESTICIDES ARISE FROM THE

- creation and updating of pesticide-related **legislation**,
- **authorisation** of pesticide active ingredients and pesticide products, if not covered by fees,
- **monitoring and reporting** of pesticides in food and the environment incl. groundwater,
- **surveillance and reporting** of pesticide trade (incl. targeting the trade in counterfeit and illegal pesticides – e.g. "Silver Axe" by Europol),
- **controls** and reporting of legal compliance by pesticide users and pesticide sellers,
- **avoidance** of undesirable side effects,
- **resistance** of pests,
- **impacts on health and the environment,**
- **economic damages to organic producers** caused by pesticide drift,
- **decontamination** of soils and drinking-water sources, disposal of contaminated food,
- **disposal** of stockpiles of unused pesticides, regular containers and expired/unused leftovers (if not taken back by the pesticide seller) and
- **loss of land value** and/or fertility due to contamination.

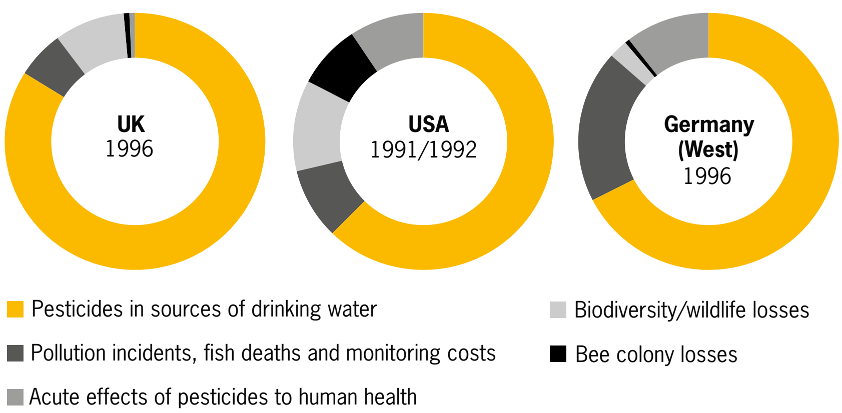
[37] Imidacloprid was the first insecticide of a group called the "neonicotinoids".
[38] According to the EC (2020), the EU approval system costs about €44 million per year for all EU MS, and these costs are NOT fully recovered by the fees paid by the pesticide industry.

Much of these costs are borne by taxpayers and people who pay health insurance contributions. Consumers indirectly cover the costs for pesticide testing, reduction programmes and the water purification conducted by food and water suppliers. Higher food prices are likely when pesticides reduce the efficacy of pollinators, resulting in fruit and vegetable yield losses. For farmers, the development of weed resistance may double the costs for weed control (Hicks et al. 2018). In England, herbicide-resistant black-grass (***Alopecurus myosuroides***, a very common weed in Northern European cereal crops) results in annual costs of £0.4 billion (Varah et al. 2020). The widespread use of triazole fungicides, a group of substances also used in human medicine, and the resulting resistance could even lead to a global health problem (Fisher et al. 2018). In the US, billions of dollars are spent each year on the control of resistant arthropods and weeds (Gould et al. 2018).

In the 1990s several researchers in the US, the UK and Germany made the first attempts to estimate these external costs of pesticide use for entire[39] countries. These (under[40])estimates ranged from **annual** external cost of €129 million for West Germany to US$12 billion for the US. Recalculations for the US showed annual costs of US$39.5 billion per year at the end of the 1980s or start of the 1990s (Bourguet and Guillemaud 2016).

Major external costs in all three countries were caused by pesticides in drinking water sources. Acute health effects played a larger role in the US and West Germany. Costs for environmental damage varied greatly. The loss of bee colonies played a larger role in the US, where many beekeepers provide pollination as a service, especially for almond production.

Figure 18:
DISTRIBUTION OF EXTERNAL COSTS BY EFFECT IN THREE COUNTRIES



(Neumeisters's diagram (2022) based on Leach & Mumford 2008)

[39] The German study only covered data from West Germany.

[40] All authors stated that their results were a gross underestimate because some significant cost factors (biodiversity loss, healthcare costs for chronic illness, resistance/resurgence) could not be calculated.

Although the research conducted in the 1990s on the external costs of pesticides laid a foundation for further research, no further attempts were made to calculate all[41] external costs on a national level. The very high complexity of the topic would require very large interdisciplinary teams, new methodologies and comprehensive data collection on various levels.

For the European Union, it would be impossible to estimate the total external cost of pesticides. There are simply too many organisations and individuals involved. Seven major directives/regulations on the EU level require national action and EU enforcement related to pesticides. There are six official institutions involved on the EU level alone: the EFSA, the ECHA, Eurostat, the Council of the EU, the EU Parliament, and the European Commission. Across the EU, tens of thousands of people are involved in academic research, local authorities, retail chains, water suppliers and NGOs, and there are millions of farmers using pesticides. However, there are some indications of the magnitude of some costs:

PESTICIDES IN DRINKING WATER SOURCES

Pesticides in drinking water sources are still a major external cost factor. There is no reason to assume that contamination levels have decreased since the mid-1990s. Pesticide use has increased or stagnated in all EU countries except Denmark. Pesticides like atrazine, which contaminated groundwater in the 1990s, are still detectable today (Mohaupt et al. 2020). Once a well has been contaminated, the contamination will persist for decades, because there is almost no chemical degradation in groundwater. Nearly 80% of groundwater bodies (by area) in Luxembourg, some 50% in the Czech Republic, approx. 24% in Belgium and 17% in France are affected by pesticides (ibid).

Other pesticides and their metabolites may appear in relevant amounts. The German Environment Agency (UBA) recently increased the thresholds for a metabolite of flufenacet and flurtamone (very popular herbicides in Germany and France) from 3μg/l to 60μg/l. The standard level of 3μg/l would endanger the drinking water security, because the metabolite (TFA) cannot be filtered out, and contaminated sources would need to be closed (UBA 2020a). The metabolite of flufenacet is just the tip of the iceberg. Kiefer et al. (2019) reported very frequent detections of 13 pesticide metabolites previously never analysed in groundwater. The highly toxic metabolite 1,2,4-triazole[42] is another example of underestimated exposure.

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[41] Leach & Mumford (2008) developed a Pesticide Environmental Accounting (PEA) tool, which was applied on a national level (e.g. Praneetvatakul et al. 2013). The PEA is based on the UK data collected by Pretty et al. (2000) in the 1990s and grossly underestimates external costs, because costs for legislation, control, monitoring and existing chronic effects (healthcare, drinking water) are not taken into consideration.

[42] 1,2,4-triazole is a reproductive toxin (Repr. 1B), a metabolite of the commonly used triazole fungicides and an ingredient of nitrification inhibitors. It is not included in the standard monitoring of groundwater or drinking water but was detected by private water suppliers above the legal limits.

It could cost several hundred million euros throughout Europe each year to test (extrapolated from Neumeister 2010; see also NLWKN 2019) and clean water from pesticides in order to achieve concentrations below the maximum residue levels (MRLs). In spite of this fact, very little data is available on the amounts spent – it is not even transparent how many samples are analysed each year in the EU by government authorities and private companies. According to Mohaupt et al. 2020, about 64,000 groundwater samples a year are analysed for atrazine, the most tested pesticide. Assuming costs of €400 per sample, this testing alone would cost over €25 million.

In Lower Saxony (**Germany**), one large private water supplier alone spends about €0.8 million[43] a year on analysing water for pesticide residues (calculated from NLWKN 2019). And there are tens of thousands of water suppliers in the European Union.

In the **Netherlands**, much of the drinking water is sourced from surface water. Pesticides and/or metabolites have been detected in two thirds of the Dutch water abstraction areas (Sjerps et al. 2019). For the time period 1991-2000, the total costs caused by pesticides in drinking water sources were calculated at €244 million (KIWA 2001). In **France**, a total of €360 million[44] is spent every year on the removal of pesticides from drinking water, and consumers spend €137 million per year on bottled water to avoid drinking tap water with pesticide residues (Marcus and Simon 2015; GCDD 2017).

PESTICIDE RESIDUES IN FOOD

Across the EU, it is estimated that the monitoring of pesticide residues in food alone costs more than €100 million each year. The residue regulation (Reg. No. 369/2005 EU) costs about €5 million a year (EC 2020c), and each year authorities take and analyse 88,000 to over 90,000 samples for the monitoring of pesticide residues (EFSA 2020). For Germany, the author calculated full public monitoring costs of €500-€550 for one food sample tested for pesticides (Neumeister 2010).
The private sector (food industry) spends a **multitude** of this amount on sampling and analyses, because food producers, importers and retailers bear the main responsibility for food safety in the EU, and they are under constant scrutiny by civil society. However, no comprehensive data is available on this testing. The German quality assurance system (QS) for fruit and vegetables, for example, analysed over 25,000 samples for pesticides in the period 9/2018 - 10/2019 (QS 2020). Aldi-Süd tests between 5,000 and 9,000 samples annually (Mempel 2018). Lidl has about 21,000 analyses performed each year (Lidl 2019).

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[43] Over the period 2000-2016, €13.6 million in laboratory costs were spent on the analysis of approx. 34,000 water samples.

[44] A small share of the costs for purifying water is covered by the French pesticide tax – that share would not be counted as “external costs”.

When residues are detected above the legal limits before a product enters the market, the whole batch is declared unmarketable and must be disposed of. This can result in very high costs, but no data on this subject has been published.

BIODIVERSITY AND POLLINATOR DECLINE

The use of pesticides affects biodiversity in three ways:

1. Pesticides are the primary instrument for establishing and maintaining cropping systems with genetically (more or less) uniform crops in large-scale (monocropping) and consecutive monocropping – these growing systems are one of the main drivers of biodiversity loss in Europe.

2. They adversely affect on-field biodiversity by killing[45] target organisms (pests, weeds, diseases) and non-target organisms (natural enemies, pollinators).

3. Owing to run-off, drift and evaporation, pesticides have adverse effects on nearby and remote habitats.

According to a recent, global assessment of pollinator decline, ***"Pesticides were scored as 'important' or 'very important' drivers of pollinator decline in all regions, with the greatest confidence in Europe (...)"*** (Dicks et al. 2021). However, the monetary evaluation of biodiversity, pollination and their decline is very complex. Most economic evaluations focus on specific "ecosystem services" useful for humans: pollination and natural pest control (see, for example, Losey & Vaughan 2006; Naranjo et al. 2019).
The estimated value of these services is impressively high. The monetary value of pollination in Europe amounts to 14.6 billion (Leonhardt et al. 2013). In the US, the production of pollinator-dependent crops has an annual value of US$50 billion, with wild pollinators contributing at least[46] US$1.5 billion of this value (Reilly et al. 2020). Natural pest control through beneficial organisms has an annual value of US$4.5 billion in the US (Losey & Vaughan 2006) and US$100 billion globally (EASAC 2015).

These numbers may only be estimates, but they show that even small percentages of decline in pollination or natural pest control by pesticides result in high external costs.

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[45] There are also numerous sublethal effects interfering with the function of target and especially non-target organisms.
[46] Only some pollinator-dependent crops were included in the investigation.

A SHORT HISTORY OF MAXIMUM RESIDUE LEVELS (MRLS)

Much of the history of pesticide regulation dates back to the massive use of DDT and other highly hazardous pesticides between 1945 and 1965. These uses had negative impacts on the environment, human health and other areas. Residues in food became a major focus.[47] Residues of DDT in milk led to regulatory measures in the US as early as 1949 (Krieger 2005). In 1954 residues of DDT and other pesticides were legalised in the US by so-called "tolerances" (maximum residue levels) in the 1954 Pesticide Chemicals Amendment (Kirk 1964). This piece of legislation prevented lawsuits against high residues. Other countries followed suit. The differences in national maximum residue levels were recognised early on as a trade barrier. Therefore, the international Codex Alimentarius Commission (CAC) was formed in 1963 with the intention of creating internationally uniform standards for global trade in contaminated agricultural products. The basic procedure for deriving maximum residue levels has therefore been internationally standardised (see IPCS 2009). However, there are major differences in many details, which is why the global "harmonisation" of individual maximum residue levels only works to a certain extent.

HEALTH COSTS FOR CHRONIC ILLNESSES

Despite risk assessment and authorisation programmes, numerous pesticides identified as probable carcinogens and/or associated with other severe diseases have been approved and marketed. There is also evidence that many pesticide users have been exposed to pesticide concentrations above the acceptable levels, with and without protective clothing.[48] The number of available highly hazardous pesticides in the EU has been declining very recently. Most highly neurotoxic insecticides/nematicides (chemical classes organophosphates and n-methyl carbamates) have been delisted, and most commonly used reproductive toxins and probable carcinogens have lost their authorisation.[49]

However, de-authorisation does not immediately reduce the health costs related to chronic diseases. If a pesticide user develops a chronic illness, this illness may continue to reduce quality of life and result in healthcare costs long after the actual use.

[47] In 1958, Zeumer (1958) already compiled a 124-page reference list for literature on pesticide residues.

[48] The EFSA calculates the anticipated exposure levels for pesticides and compares them with acceptable levels. For some major-use pesticides, the exposure levels have exceeded those levels with and without protective clothing.

[49] Some stored amounts can still be used – there is a certain period of grace after a pesticide is withdrawn from the market.

Mancozeb is one of the oldest (introduced around 1960) and most popular synthetic fungicides in the world. Because of its high toxicity, it lost its EU authorisation in 2020. Since 1999, it has been classified as a probable carcinogen (US EPA 2018). Research in France on people with brain tumours showed that the use of mancozeb increases the tumour risk. In general, long-term pesticide use is the leading hypothesis for a higher risk of brain cancers in farmers (Piel et al. 2019; Baldi et al. 2021).

It is extremely difficult to obtain evidence linking a chronic disease to occupational pesticide exposure. There is laboratory evidence that pesticides have certain health effects on the tested animals. There is also evidence of human (over)exposure, usually concerning pesticide users. And there are also specific statistical associations between certain illnesses and pesticide exposure (epidemiological research). Despite this evidence, it is very difficult to determine a causal link between a chronic illness and a specific pesticide or pesticide use. There are three major reasons for this:

1. Experiments are carried out on laboratory animals, not humans.

2. Conventional farmers and other users will use a countless number of pesticides and other chemicals throughout their lifetime, and they are also exposed to other agents that could potentially cause chronic illnesses.

3. There are many other factors,[50] like genetic disposition, that can contribute to the development of a chronic illness.

Because of these challenges, it is nearly impossible to estimate the costs of chronic illnesses caused by pesticides. However, some researchers have identified the high costs to society. For the year 2005, Bourget & Guillemaud (2016) estimated societal costs of €10.3 billion in the US just for cancer caused by pesticides. And there are many more illnesses associated with pesticide use: e.g. Parkinson’s Disease (Pochieu et al. 2018) and specific types of lymphomas (Schinasi & Leon 2014; Orsi et al. 2008). A recent review of over 5,000 publications by the French National Institute of Health and Medical Research (INSERM) confirms a ***“strong presumption of a link between pesticide exposure and six pathologies: non-Hodgkin's lymphoma (NHL), multiple myeloma, prostate cancer, Parkinson's disease, cognitive disorders, as well as certain respiratory system disorders (chronic obstructive pulmonary disease and chronic bronchitis).”*** (INSERM 2021 engl. summary p. 1).

[50] In epidemiologic studies, the multiple causes of an illness are usually filtered by statistical methods, which have more power with a large number of participants.

AVOIDANCE – COST OF PREVENTION AND PESTICIDE REDUCTION

All governments of EU Member States, many water companies and some supermarkets maintain pesticide-reduction programmes aimed at the reduction of risks and contamination caused by the use of pesticides. Although some of these programmes are aimed at the elimination of pesticide use, the costs of these programs should also be counted as external costs of pesticide use. Taxpayers and consumers of food and water indirectly pay for these programmes.

No data is available on the total costs of such programmes throughout Europe. However, compared to other external costs, it seems that only limited resources are made available for avoiding or reducing pesticide use.[51] The aim of the French Ecophyto plan was to reduce pesticide use by 50% between 2008 and 2018. However, only about €32[52] million to 36 million[53] were spent on the Ecophyto programmes annually. In Germany, the Ministry of Food and Agriculture (BMEL) spends about €5.4 million per year (timeframe 2017-2023) on pesticide alternatives and reduction (BMEL 2020).

The costs for research on pesticide alternatives, risk reduction and integrated pest management have been funded by the EU (e.g. LIFE Programme; Horizon 2020) and national governments. A partly EU-funded zero-residue programme (LIFE Zero Residues), for example, had a budget of €3.4 million for four years.[54] Within the EU research landscape (Horizon 2020, FP7 etc.), numerous research projects related to alternatives to synthetic pesticides and integrated management have been funded.

The following table shows a selection of EU-funded research projects for the period 2010-2024 with a total budget of about €80 million. All projects aimed directly or indirectly at pesticide reduction and starting after 2010 were selected.

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[51] An older table with expenses per country can be found here: http://www.endure-network.eu/content/download/7035/49907/file/SCAR%20IPM%20Executive%20Summary.pdf

[52] 194 in the period 2009-2014 (Guichard et al. 2017)

[53] A total of €400 million was spent, but €71 million were revenues from the pesticide tax, which can be counted as internalisation.

[54] LIFE Public Database of the European Commission. LIFE12 Project reference ENV/ES/000902 Acronym: LIFE Zero Residues

Table 2:

EU-FUNDED RESEARCH PROJECTS AIMED AT PESTICIDE REDUCTION SINCE 2010

RESEARCH TITLE	BEGIN	END	DURATION IN YEARS	TOTAL BUDGET	ANNUAL BUDGET
PURE (Pesticide Use-and-Risk Reduction in European Farming Systems with Integrated Pest Management)	01/03/2011	28/02/2015	4.0	€12,354,824	€3,095,154
Integrated Weed Management: Practical Implementation and Solutions for Europe	01/06/2017	31/05/2022	5.0	€7,237,213	€1,447,443
Warsaw Plant Health Initiative	01/11/2011	31/10/2015	4.0	€4,453,094	€1,113,274
Coordinated Integrated Pest Management in Europe	01/01/2012	31/12/2016	5.0	€2,644,343	€528,869
Novel biocontrol agents for insect pests from neuroendocrinology	01/06/2015	31/05/2019	4.0	€6,995,054	€1,748,763
Early detection and bio-control of mushroom pests and diseases in an Integrated Pest Management approach to comply with the European Directive 2009/128/EU	01/11/2012	31/10/2015	3.0	€1,876,227	€625,409
Innovative biological products for soil pest control	01/07/2012	31/12/2015	3.5	€6,387,362	€1,824,960
Optimised Pest Integrated Management to precisely detect and control plant diseases in perennial crops and open-field vegetables	01/09/2018	31/12/2021	3.3	€3,425,600	€1,027,680
Pheromones for Row Crop Applications	01/03/2020	28/02/2023	3.0	€8,510,358	€2,844,688
BIO-Based pESTicides production for sustainable agriculture management plan (BIOBESTicide)	01/05/2020	30/04/2023	3.0	€4,402,773	€1,468,951
Biocontrol of Xylella and its vector in olive trees for integrated pest management	01/05/2020	30/04/2023	3.0	€8,025,112	€2,677,517
SMART agriculture for innovative vegetable crop PROTECTion: harnessing advanced methodologies and technologies	01/01/2020	31/12/2022	3.0	€1,996,188	€665,396
Stepping-up IPM decision support for crop protection	01/06/2019	31/05/2024	5.0	€4,998,096	€999,619
Innovative tools for rational control of the most difficult-to-manage pests (super pests) and the diseases they transmit	01/09/2018	31/08/2022	4.0	€3,095,900	€773,975
Virome NGS analysis of pests and pathogens for plant protection (VIROPLANT)	01/05/2018	30/04/2022	4.0	€3,331,580	€833,474

ON AVERAGE, THE EU SPENDS LESS THAN €6 MILLION PER YEAR ON RESEARCH INTO PESTICIDE REDUCTION.

Bourguet & Guillemaud (2016) categorise expenditures on organic food as “defensive expenditure” and as external costs in a strict sense. In 2019 organic retail sales in the European Union were valued at €41.4 billion (FIBL 2021). However, this figure does not take into account the diverse motives for purchang organic foods (ibid; Eyinade et al. 2021). Organic farming is not simply conventional farming minus pesticides. Pesticides based on copper and mineral oils, as well as sulphur, pyrethrins and Spinosad, are allowed[55] in many organic growing systems and crops. Therefore, organic agriculture or organic food consumption is not per se the avoidance of pesticide use. The main differences between conventional farming and organic farming are the types of fertilisers allowed, the origin of the animal feed and the number of animals allowed per area. Many organic farmers also do direct marketing, and therefore, organic food is often associated with regionality and freshness. Bourguet & Guillemaud (2016) assumed that about a half of organic consumers purchase organic food to avoid pesticide residues. Furthermore, they were willing to pay an organic premium price of 20% above the conventional food price – this additional spending would reflect the external costs of pesticides. Following their methodology, the “defensive expenditure” on organic food in 2019 would be at €3.45 billion in the European Union.

Each year, pesticide use results in high external costs throughout the European Union. Although little data is available, it is safe to assume that the annual costs are in the billions of euros rather than the millions. The smallest amounts seem to be spent on the avoidance and/reduction of pesticide use.

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[55] Individual organic standards may permit/prohibit different compounds individually. In Denmark, all copper based pesticides have been prohibited since 1995.

4 THE LOCK-IN SYNDROME

Section 1, on the history of pesticide use, showed how agriculture became dependent on pesticides. These early drivers of pesticide use still exist: **Rural exodus (migration)** continues and causes a lack of rural labour force, driving rationalisation, incl. herbicide use (and vice versa). Not only do people abandon regions where (large-scale) agriculture dominates. Agricultural infrastructure, like smaller mills and dairy processing facilities, is given up, with severe consequences for crop diversity, farmer's independence and pricing.

Land grabbing elsewhere continues and creates specific cost advantages, and **international agricultural** trade has multiplied since the 19th century – now even including fresh fruits[56] and vegetables. As soon as an agricultural product seems to be profitable, farmers all over the world like to grow it or expand the respective production (e.g. asparagus, avocados, berries) creating over-production and the need for cost reduction. In addition, many **new pests and diseases** are being introduced into Europe, increasing the pressure on already susceptible cropping systems.

Newer drivers of pesticide dependency have emerged over the past decades, mostly due to market consolidation and specialisation:

- Large supermarkets define in detail aesthetic standards for fruits and vegetables, forcing growers to use pesticides for cosmetic purposes only (UBA 2020b). Requirements for a long shelf-life reduce the fruit and vegetable diversity.

- Commercial plant breeding is almost monopolised (Fortune Business Insights 2022) and partly under the control of pesticide companies.[57] Breeding programmes have been aimed at complying with the standardisation required by the food supply chain, not at robustness (Jaquet et al. 2022). The disappearance of traditional varieties has already led to an even narrower **genetic bottleneck**, threatening agrobiodiversity (Gmeiner et al. 2018).

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[56] Apples and bananas have been traded internationally for more than 100 years, but the trade in more sensitive fruits (e.g. berries) and vegetables is relatively new.

[57] BASF, Bayer CropScience/Monsanto, Syngenta (owned by ChemChina) and Corteva (a fusion of DowChemicals, Dupont [both pesticide producers] and Pioneer [seed producer]) develop, patent and market hybrid and genetically modified seed material.

- The introduction of **plant growth regulators (PGRs)**[58] in the 1960s in cereals created new dependencies and self-reinforcing mechanisms.

- In the same period, the **separation of animal and plant production** fostered narrower crop rotations and reduced the input of organic fertilisers important for soil biodiversity, thus promoting the use of mineral nitrogen.

- High annual subsidies (EU CAP) have motivated agricultural companies to make **high investments** in expansion, equipment and infrastructure (Frison 2021; Agrarheute 2021); in order to finance these investments, farms are forced to maximise rationalisation and focus on the most profitable crops and practices (e.g. herbicide use instead of mechanical weed control).

- Since the 1990s, publicly funded farm advisory services all over Europe have been largely replaced by **private advisory services** (Labarthe & Laurent 2013). Some of these services are directly connected to pesticide companies, while others receive commissions on pesticide sales after recommending their use. A recent study in Switzerland showed that growers advised by public extension services are more likely to apply preventive pest management measures, while farmers advised by private extension services are more likely to use synthetic insecticides (Wuepper et al. 2021).

- Decades of successful **lobbying of state actors** by promoters of pesticide use have led to ***an institutional lock-in*** (Hüesker & Lepenies 2022).

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[58] Plant growth regulators (PGRs) are used for changing plant physiology, e.g shorter and thicker cereal haulms to manage higher nitrogen inputs, reducing the number of flowers to have fewer but larger fruits.

Today, dependency on pesticides is higher than ever because of certain self-reinforcing mechanisms[59]:

Market consolidation: A (liberalised) market economy creates oligopolies on the supply and oligopsonies[60] on the demand side (for more information see Agrifood Atlas 2017). Although the producing farming sector has become more and more consolidated, there are still millions of farmers facing a limited number of buyers. Not only do many farmers have no control over the price of their products: They also try to outcompete each other. Highly influential market participants decide on the prices: Prices for important agricultural commodities are determined on the stock markets by large food processors[61] and dominating supermarket chains. In many cases, farmers do not know the price for the coming harvest until the harvest starts, making them very cautious on any extra spending during the growing season.

In the end, prices do not reflect environmental and social standards or external costs. On the stock market, genetically modified soybeans that are from recently converted Brazilian rainforest areas and sprayed with aeroplanes have the same price as European soybeans from a smallholder.

Race to the bottom in production costs: The common perception is that (national) agriculture is only competitive on the commodity market if production costs for each unit produced are lower than in other producing countries/regions. This delusion[62] leads to a race to the bottom (see also Benton & Bailey 2019).

The destructive competition between producers is not reduced to any great extent within the EU because social standards (e.g. living wages[63]) and taxation have not (yet) been harmonised.

The EU-harmonised pesticide authorisation programmes theoretically ensure a common EU standard, but every year many Member States grant exceptions for using non-approved (at EU level), highly toxic pesticides to maintain certain unsustainable practices.[64] In general, producers in countries without, or with low, environmental and social standards and a high level of corruption will always produce at lower costs than those with higher environmental and social standards.

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[59] Self-reinforcement: The availability of pesticides creates growing systems where pesticide use is absolutely essential. Commercial table apple production is one example, where very vulnerable varieties with strict property rights ("club varieties") are developed regardless of how many pesticide applications are needed to grow them.

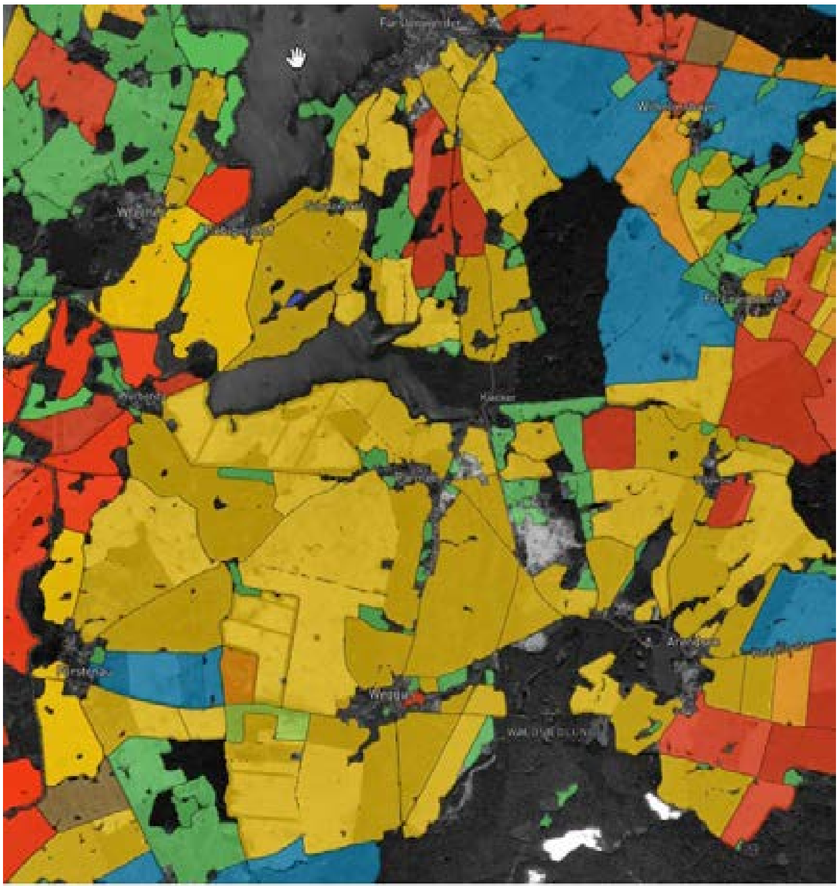
[60] An oligopsony is a market for a product or service which is dominated by a few large buyers.

[61] In the EU, three top food processors control 50% of the market (EC 2017).

[62] The total production volume of globally traded commodities like wheat and soybeans creates the price on the stock market. Large-scale producers (e.g. Brazil, USA) with "unlimited" land access determine the price. Western Europe, with its small and limited land access, can – on a free market – never compete with these production volumes.

[63] New EU rules for fair minimum wages are currently being discussed in the European Parliament.

[64] For example: soil disinfection with 1,3-dichloropropene in continuous monocropping of strawberries and vegetables.



MAIZE MONOCULTURE OF > 1000 HA (YELLOW FIELDS) AROUND THE BIOGAS PLANTS PARMEN AND FÜRSTENWERDER (DE, 2018)
Source: https://map.onesoil.ai/2018

The responses to these challenges – market interventions (contingencies, tariffs) and high amounts of farm subsidies (see Dhar 2021) – have stopped neither rural exodus nor environmental degradation incl. loss of biodiversity. Quite the opposite: The European Common Agricultural Policy (CAP) has accelerated each of these problems.[65] Land possession grants subsidies, and this fact has led to an increase in land prices (destatis 2019) and made agricultural land a target for speculation (Klöckner 2021). More and more agricultural land is now owned by financial co-operations (HighQuest Partners 2010; Bunkus & Theesfeld 2018) aimed at profit maximisation. How this influences pesticide use has yet to be investigated. If "foreign" ownership leads to short leasing periods for land,[66] like in the US or Argentina, a farmer leasing this land might not be very interested in any sustainable practice (Ponisio & Ehrlich 2016).

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[65] See, for example: "The crisis in the agricultural sector". Briefing of the European Parliament. September 2016.
[66] Currently, the duration of the lease and the payment per hectare are regulated differently in each EU Member State.

In the current economic setting, most conventional growers cannot substantially reduce pesticide use. They are forced to grow only the most profitable crops at the lowest cost (Sieling & Christen 2015; Hegewald et al. 2018). This situation leads to a smaller selection of profitable and/or indirectly subsidised[67] crops (energy maize, rapeseed for biofuel) and certain cereals,[68] compromising choices for wider crop rotation. In many regions, preventative agricultural practices have been abandoned. To avoid the accumulation of pest, weed and disease problems, it is best agricultural practice to pause cultivation of the same crop for at least three to four years on the same field. The profitability of rapeseed, however, has led to shorter cycles[69] (Hegewald et al. 2017; Hegewald et al. 2018) with severe consequences with respect to pest occurrence, pest resistance (Sieling & Christen 2015) and pesticide use. Crop rotation in energy maize has often been abandoned, and the consecutive maize monocultures have had adverse effects on biodiversity and potentially on groundwater quality.

In the context of intensification, valuable habitats have been sacrificed to increase production area (Treabe & Morales 2019; Denac & Kmecl 2021) compromising biological pest control.

Obviously, if all farmers are striving for more yield at lower cost, producer prices will continue to fall, speeding up a vicious cycle and creating not only a lock-in situation, but also an eternal lose-lose-lose situation for farmers, the environment and the rest of society (see Benton & Bailey 2019) – except for the consolidated businesses on the supply (pesticides, fertilisers, seeds, feed stock) and demand sides.

Thanks to the pressure from civil society, some ***“symptoms have been cured”***: stricter authorisation rules have reduced the number of acutely and chronically toxic pesticides. Although these are important achievements, these pesticides should not have been approved in the first place.

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[67] There are no crop-specific subsidies per hectare, but certain energy policies subsidise/support the fuel/electricity produced from agricultural commodities (e.g. blending mandates for biodiesel).

[68] Some cereals are threshed during harvest (wheat, barley, rye, triticale), while others are not (spelt, oats). The farmer can sell wheat, barley, rye and triticale directly from the field without further costs. This makes these cereals more popular, especially when threshing mills are too far to transport the produce cost effectively.

[69] http://www.agribenchmark.org/fileadmin/Dateiablage/B-Cash-Crop/Reports/RapseedReport-2020-complete.pdf

5 ESCAPING THE LOCK-IN

All attempts to reduce pesticide use and dependency in the EU have failed (except in Denmark). In general, the environmental performance of the EU has not improved substantially in any area.

No legislation, be it the "Nitrate Directive[70]", "the "Water Framework Directive", or the "Sustainable Pesticide Use Directive", has achieved the proposed targets, nor have the different strategies[71] on biodiversity[72] or the EU CAP (Bieroza et al. 2021). According to the European Commission, EU greenhouse gas emissions were reduced by 24% between 1990 and 2019 (EC 2022b), but it is very unlikely that this progress was the result of policy. The economic breakdown in the accession countries[73] and on the former GDR territory after 1989[74], along with various financial crises, probably caused the largest reduction in emissions. When taking into account "outsourced/relocated" CO_{2eq} emissions during the production of imported goods, the CO_{2eq} emissions caused by the EU may have actually risen (IDH 2020; Becquè et al. 2017; Figure C.11 Eurostat 2021).

The EU Commission's "Green Deal" and "Farm to Fork Strategy" appear to make even bigger promises (but see Box How to measure pesticide reduction) than the older inefficient policies but have (so far) offered hardly any new instruments. It is highly unlikely that the old objectives will be achieved simply by expressing more ambitious goals.

While all of the agronomic measures necessary to avoid pesticide use are available (see next section), the current policies will not be enough to reach a 50% pesticide reduction as announced by the Farm to Fork Strategy because:

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[70] "Overall, despite strong regional differences, the EU still has an unacceptable surplus of nitrogen in agricultural land, particularly in view of the resultant impacts on the environment." https://www.eea.europa.eu/data-and-maps/indicators/agriculture-nitrogen-balance-1/assessment

[71] The EU proposed the first strategy in 1998: see https://ec.europa.eu/environment/nature/biodiversity/policy/index_en.htm

[72] "Biodiversity on agricultural lands continues to decline, as insects, birds and rodents disappear. Meanwhile, large-scale industrial agriculture and forestry continue to further develop, despite conservation status of specific habitats." https://wilderness-society.org/eu-fails-to-meet-2020-targets-against-biodiversity-loss/

[73] "Overall emissions of the six greenhouse gases declined substantially in most countries in the region during the 1990s, mainly due to the introduction of market economies and the consequent restructuring or closure of heavily polluting and energy-intensive industries." https://www.eea.europa.eu/media/newsreleases/ghg-accession-en

[74] The baseline to measure CO2eq reduction is 1990 for the EU.

A) the current farming system is in a "pesticide lock-in"[75] – most farmers are forced to use pesticides; (see previous section, as well as Meynard et al. 2018; Zhanping Hu 2020 and sources within),

B) current policies do not address the economic drivers of pesticide use or promote the urgently needed changes with respect to international trade (e.g. border adjustment agreements), climate change, rural development and food policy, and

C) the political influence of powerful corporations and interest groups prevents any progress (e.g. O'Kane 2011). Hüesker & Lepenies (2022) use the term "institutional lock-in" for the cementing power of certain lobby groups in combination with regulatory ignorance, apathetic behaviour and the lack of political will among governmental actors.

Therefore, any initiative or programme that seeks to evaluate the possibilities of a pesticide-free European Union needs to analyse and answer the following questions:

1. What are the socio-economic drivers of pesticide use?
2. What agronomic alternatives to prevent pests, weeds and disease already exist?
3. What policy instruments are needed to make pesticide-free farming feasible?
4. What are common belief systems which support the pesticide lock-in, and how can these be changed?

[75] "The term "necessary use" (notwendiges Maß) is widely used to legitimise this system-related dependency, which means "the intensity of the use of PPPs that is necessary to secure the cultivation of the plants, especially against the background of economic efficiency" (Federal Government, 2013). This term, which is to be understood ideologically, suggests market-economy constraints which obviously do not allow the individual farmer any alternative to the "necessary" use of PPP" (UBA 2016)

5.1 AGRONOMIC MEASURES TO PREVENT PESTICIDE USE

It has long been known that pesticide use is the least effective method of pest, weed and disease control, because without preventative measures the pest will reappear in a high frequency.

The thousands of tonnes of lead arsenate, DDT, HCH, organophosphates, n-methyl carbamates, pyrethroids and neonicotinoids that have been applied over the past 100 years have not solved a single problem caused by arthropod pest species. All pest or disease problems that have disappeared to date have been eliminated by "non-lethal" means, mostly by biological control, resistant varieties, good practices (e.g. crop rotation) and changes in perception.

The fact that pesticide use would create a treadmill was already predicted in 1913 by Escherich, who reported on pesticides in the US and claimed that technical means, such as chemical control, have to be repeated year after year (Escherich 1913). Oerke (2006) confirms the inefficiency of pesticide use and states: ***"Despite a clear increase in pesticide use, crop losses have not significantly decreased during the last 40 years."***

Today, many arable organic farmers still apply preventative measures. Several of them incorporate new knowledge about soil biology and agroecology, as well as precision farming tools and improved mechanical weed control.

The following sections describe the six most important preventative measures and other important measures for preventing pesticide use. In general, these measures are also "climate friendly", reverse the loss of biodiversity, support rural development and benefit the farming community (see Poux & Aubert 2018 and Sirami et al. 2019).

1 REGENERATIVE SOIL MANAGEMENT

Sustainable agriculture is based on efficient soil management and the continuous improvement of soil quality. Soils with a high percentage of organic matter, an active soil biology and few disturbances develop a rich variety of disease-suppressing bacteria (Kremer & Li 2003; Peters et al. 2003). Such soils ensure high soil fertility and make crops less susceptible to insect damage (Altieri & Nicholls 2003; Altieri et al. 2012; Alyokhin et al. 2020). There are several methods for establishing and maintaining healthy soils: mob grazing,[76] crop rotation incl. intercropping, di- or polyculture including green manure (living mulch) and fertilising with organic material (compost, fermentation products) and reduced/minimal tillage. The soil should continuously be covered with vegetation. The use of synthetic chemicals, especially mineral nitrogen, potassium and pesticides, must be minimised. Experience in regenerative agriculture shows that well-managed soils ensure a high level of weed and disease suppression without major interventions, such as ploughing or mechanical weeding.

2 ROBUST VARIETIES

The selection of pest- and disease-tolerant varieties is a key principle in integrated pest management and should always have a high priority in any crop. The potential to reduce or eliminate pesticides is very large, even in high-intensity crops like grapes or apples. The pesticide-reduction potential is even higher when robust varieties are planted in “mosaic” patterns or as mixed crops (see also “Crop diversity” below). One of the largest organic winegrowers in Switzerland, for example, converted 65% of their vineyard area to fungi-resistant varieties and planted them in a specific pattern to avoid large genetic connectivity. The grower does not use copper or sulphur-based fungicides on this area, while the old varieties still require frequent spraying (Lenz 2020).

The selection of “mechanically” robust wheat can facilitate mechanical weeding. Some wheat varieties resist harrowing better than others, but it seems conventional breeders are not interested in this research area (Osman et al. 2016).

The availability of resistant varieties is generally good (and continuously improving), but a substitution in perennial crops is cost intensive and will need a longer period than in annual crops.

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[76] Definition of mob grazing: https://www.soilassociation.org/our-work-in-scotland/scotland-farming-programmes/mob-grazing/what-is-mob-grazing/

3 CROP ROTATION

Crop rotation is one of the oldest and most effective ways to regenerate soils and suppress unwanted organisms. A wide and well-thought-out crop rotation increases humus content (carbon storage) and biodiversity. Populations of harmful diseases, pests and weeds develop much more slowly, because the crop rotation interrupts certain interdependencies between crops, weeds and pests. A meta-analysis by Weissberger et al. (2019) showed that ***"increasing rotational diversity reduced weed density more under zero-tillage conditions (65%) than tilled conditions (41%), and did so regardless of environmental context and auxiliary herbicide use.*** Crop residues are often hosts to pathogens (e.g. Fusarium spec. on maize stubbles [see Kenngot et al. 2022]) or the hibernating pest stage. Alternating crops prevents the accumulation of such residues. In some crops, such as cereals,[77] sugar beet, potatoes, rapeseed and many vegetables, a production pause of 4 years (or more) at the same location is the best method for preventing the development of diseases and restoring the soil (Carter et al. 2009; Walters [ed.] 2009). Some crops incl. intercrops can actively suppress diseases, pests and weeds. Others, such as legumes, increase soil nitrogen, bacterial activity and thus also yield (Zou et al. 2015). Certain diseases can persist in soils for a long time and have a broad host spectrum. Therefore, the benefits of crop rotation are greater when consecutive plants are not botanically related. Every rotation management must be adapted to the local situation (Walters [ed.] 2009), but ideally ensure green soil cover throughout the entire year.

4 CROP DIVERSITY

Low genetic variability and the loss of diversity make the current cultivation system more susceptible to weeds, pests and diseases. Diseases and arthropod pests flourish in homogenic crop populations, while genetic variability and differences in nutritional levels (Wetzel et al. 2016) interfere with their development. In general, diversified cultivation systems show a high suppression of pests, weeds and diseases and reduced crop damage (Letourneau et al. 2011; Redlich et al. 2018; Ditzler et al. 2021; SARE[78]). A Europe-wide investigation (Martin et al. 2019) has shown that the number of field edges makes a large difference in natural pest control. Crop diversification also reduces the overproduction of individual crops and the economic risks associated with the effects of climate change. Ficiciyan et al. (2022) showed that a mix of robust tomato varieties under organic cultivation outperform conventional tomato production.

[77] With the exception of maize and oats.

[78] https://www.sare.org/wp-content/uploads/Cover-Cropping-for-Pollinators-and-Beneficial-Insects.pdf

There are different methods for preventing monocultures, which can also be combined:

1. **Mixing different varieties** of the same crop is the easiest way to break a monoculture and can have a positive effect on pest/disease pressure (Mundt 2002; Zhan & McDonald 2013).
2. Probably the most common form of di-culture is the use of undersown intercrops, such as clover, under the main crop.
3. Advanced forms of poly-culture mix different cultures (Fernández-Paricio et al. 2010), which is common in many traditional gardens, but also in multi-storey **agroforestry.**

Strip-cropping, relay cropping and pixel farming are recently developed methods of crop diversification. The availability of precision instruments (for example GPS steering guides) allows for the large-scale implementation of mixed cropping.

In general, growing more than one variety or crop on one field has several positive effects on pest, weed and disease pressures:

- **Dilution effect** – an increasing distance between sensitive plants slows down the rate of infection for fungal pathogens (Castro 2007; Finck et al. 2000; Sapoukhina et al. 2010; Skelsey et al. 2010). This effect also works against arthropod pests which prefer a homogeneous nutrient intake (Wetzel et al. 2016). Some selective pest species (larvae of some butterflies) will not develop further if they have to move over larger distances without their specific food.

- **Barrier effect** – the presence of disease-resistant plants represents a physical barrier against the movement of fungal spores (Bouws & Finck 2008; Shtava et al. 2021). Many arthropod pests or pest stages are not very mobile, and any non-host barrier they need to cross (see Mansion-Vaquié et al. 2019) costs valuable energy.

- **Enhanced plant defence** – when plants are "attacked" by pests or diseases, they emit biochemical compounds (biogenic volatile organic compounds [BVOCs]). Beneficial organisms are attracted by these compounds. Neighbouring plants may strengthen their defence mechanisms in response to a bio-chemical emission (Ameye et al. 2017; Nikovic et al. 2020). A presence of susceptible and less susceptible plants in a field aids this process. Push-pull farming systems use this technique.

- **Modification of the microclimate** – the presence of varieties or species with a different habitus (e.g. height, leaf position) can change the microclimate to create less favourable conditions for diseases (Castro 2007; Fernández-Aparicio et al. 2010).

- **Shade and / or competition effect** – weeds can be suppressed if different crops or other crops (e.g. clover) cover weeds by occupying the space or closing the canopy.

- **Repellent effect** – certain plants repel arthropod pests from neighbouring plants.

- **Provision of habitats** – inter-seeding with certain mixtures can feed natural enemies of arthropod pests of the main crop (Smith & Liburd 2015; Parolin et al. 2012; Iverson et al. 2015 Sunderland & Samu 2000), and dividing one large field into smaller strips (strip-cropping) creates many edges (see Martin et al. 2019), which benefits natural pest control (Alarcón-Segura et al. 2022), as well as pollinators.

5 ESTABLISH AND MAINTAIN BIODIVERSITY

The fact that birds, bats, amphibians and parasitising and predatory arthropods efficiently control pests has been known for a long time (Gloger 1858; Krafft 1880; van Lenteren 2006; Losey & Vaughan 2006; Cardinale et al. 2003). However, the rapid decline of biodiversity, the increase of field sizes and the frequent use of pesticides and fertilisers compromise biological pest control.

Research shows that annual flower strips can be highly effective in pest control and represent an alternative to the use of insecticides in cereals (Tschumi et al. 2015; Hickmann & Wratten 1996). Perennial/older flower strips can increase yields because the adjacent crop benefits from a larger diversity of pollinators[79] (Albrecht et al. 2020). Hedge and/or tree rows have multiple functions in plant protection: They stabilise the micro-climate, reduce the dispersal of aerial pathogens, present physical barriers for specific pests and offer habitats for beneficial organisms. They may also support adjacent crops with water and nutrients via their root-mycorrhizal system (mycorrhizal network).

Untreated areas with reduced fertilisation on the field favour general biodiversity and are also a valuable refuge for natural enemies (Nash et al. 2008; Sunderland & Samu 2000). These areas are particularly important in large fields. Non-crop areas, including all paths between permanent crop rows, should remain untreated.

Birds play an important role in insect control in orchards and other growing areas (Mols & Visser 2002). Providing habitats and/or nesting boxes, as well as perches and feeding places, for larger predators can create effective pest control (see García et al. 2020). Bats feed on night moths (such as apple codling moths, leaf miners), but so far there has been little experience in using them more effectively for pest control. Nevertheless, they must be protected and encouraged (Boyles et al. 2011).

Landscape elements and habitats (e.g. tree rows, hedges, wildflower areas and flower strips) need to be created and maintained on large, less diverse farms with large contiguous fields (Fiedler et al. 2008; Schmidt-Entling & Döbeli 2009; Landis et al. 2000; Langelotte & Denno 2004). Guides on plants that host and/or support beneficial organisms have existed for a long time (e.g. IOBC-WPRS 2004).

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[79] This applies to insect-pollinated crops.

6 NITROGEN REDUCTION

Nitrogen (N) is one of the most important nutrients needed for crop growth., which is why mineral fertiliser is one of the principal farm inputs on conventional farms. However, the production and use of synthetic nitrogen have numerous negative side effects (Erisman 2020), and the current overuse is generating high external costs[80]:

1. Its production is very energy-intensive and thus associated with high carbon emissions. Using the best available production technology, about 3.6 kg of CO_2 are emitted for producing one kg of nitrogen.[81] Common technologies still have a ratio of 10 kg of CO_2 for one kg of nitrogen (Chai et al. 2019)
2. In the field, nitrogen is partly converted into nitrous oxide (N_2O), a very potent greenhouse gas, ammonia (NH_4), an air pollutant, and nitrate (NO_3), a groundwater pollutant. High levels of inorganic nitrogen inhibit microbes that are essential to the sequestration of carbon and thus prevent humus accumulation.
3. Nitrogen may force farmers to use herbicides, depending on the cropping system, because the application of nitrogen also benefits weeds. In cereals, weeds may become even more competitive when certain plant growth regulators (PGRs) are applied, which is common practice. These plant growth regulators shorten the crop, but not necessarily the competing weeds, which then have better access to light (Pallutt & Augustin 2022).
4. Nitrogen forces farmers to use acaricides, insecticides and fungicides: Quickly available mineral nitrogen leads to rapid plant growth, while making the crop more vulnerable to aphids, spider mites and specific fungal diseases (e.g. mildews). (Zetsche et al. 2020) Normal rates of nitrogen application in combination with plant growth regulators may also increase dangerous levels of Fusarium toxins, especially in reduced tillage systems (Schöneberg et al. 2016). These mycotoxins are subject to regulation,[82] and higher concentrations reduce crop value drastically. The feared potato pathogen ***Phytophthora infestans***, the causal agent of potato late blight, causes much less damage in organic agriculture than in conventional agriculture because of reduced nitrogen availability (Ghorbani et al. 2004).

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[81] https://www.yara.com/crop-nutrition/why-fertilizer/environment/fertilizer-life-cycle/
[82] https://ec.europa.eu/food/safety/chemical_safety/contaminants/legislation_en
[83] Planophile growth versus erectophile growth.

A moderate reduction in nitrogen use of 20% already has multiple environmental benefits and can, depending on the cropping system fertilisation level, increase the farmer's gross margin (see Catarino et al. 2019; Colbach & Cordeau 2018) because potentially multiple external inputs are no longer needed.

OTHER PREVENTATIVE AGRONOMIC MEASURES

Numerous other preventative agronomic measures are equally important and usually common knowledge within a soil-climatic region:

Soil properties and climatic conditions define where each crop/variety can be grown. Growing crops/varieties outside optimal conditions causes a higher vulnerability, which is why **selecting suitable crops/varieties** is an important preventative measure.

Depending on the region and crop, the **proper timing of sowing**/planting can prevent certain plant protection problems. A later sowing of winter cereals can, for example, stop the proliferation of virus vectors (aphids and cicadas). Spacing also plays an important role: Wider spacing can prevent certain pathogens, but may also increase weed pressure. However, wider spacing may also allow for undersowing. Some wheat varieties supress weeds better than others because the leaf position[83] creates more shade.

Proper fertilisation is a key measure for preventing pests, weeds and diseases. Surpluses, as well as shortages, of nutrients and incorrect timing can cause phytosanitary problems. Calcium (Ca) is a very important (essential) element for the resistance of plants to diseases (Lecourieux et al. 2006; Messenger et al. 2000), but potassium (K) is a calcium antagonist – meaning that improper potassium fertilisation will inhibit calcium intake and reduce plant resistance. The overuse of potassium, especially in soils with a low pH, may also cause magnesium deficiency (Xie et al. 2021).

It is essential to look at each particular growing system in a holistic manner and focus on the benefits (revenue) throughout the crop rotation (if applicable) and not only on the main crop.

5.2 TECHNOLOGICAL APPROACHES

There are numerous technological solutions or even new farming systems which can prevent or strongly reduce the need for pesticides. For example, nets against arthropods are low-tech and used very commonly in vegetable cultivation. However technical plant protection should always be viewed as a second choice after preventative measures. Some newer and more sophisticated technologies may have adverse agri-social consequences, because they may not increase farm revenue but profit from agricultural producers.

Manual weeding has developed rapidly over the past decade, and there are a number of devices which are compatible with regenerative soil management (e.g. the Geohobel, roller crimper).

Weeding robots are also promoted by several stakeholders and may soon become a feasible alternative to heavier weeding equipment. However, compared to the simple, long-lasting "iron" in the field, robots are associated with high investment (STOA 2021) and maintenance costs, may increase dependency on service companies and exacerbate agricultural inequity (Herrero et al. 2021). More efficient manual weeding, incl. by means of robots, could have negative ecological effects. Weeds are an important part of arable biodiversity and a certain level of "weediness" is necessary for maintaining a diverse flora and fauna. Intervention (weed control) should only occur if certain damage thresholds are reached – that applies to chemical and non-chemical control.

Drones (unmanned vehicles) and other diagnostic technology may help to identify the areas where damages occur and reduce intervention to those areas.

Pheromones can interfere with the reproduction of specific pests (sexual confusion) or lure them into traps. Pheromones are highly effective against a number of specific pests, but do not directly interfere with non-target organisms. This control method still has a high potential.

Vertical/urban farming is a technologically advanced method of indoor farming. These highly controlled growing systems exclude pest and diseases and artificially create perfect growing conditions, but require considerable investment in material and almost sterile, laboratory-like conditions. The total energy and water balance, including the production of these high-tech systems, may be negative.

For some crops (apples, pears and potatoes) **solar farming/roofing** might be an interesting option in the near future. More solar panels are now being built on agricultural land, and experiments have already been conducted with solar panels that allow for underneath cropping. Solar roofing could therefore generate solar power and protect crops that are particularly vulnerable to rain or intense solar radiation (Mediterranean crops). Until now, these systems have not been designed to support crop protection, but that should be taken into consideration.

GENETIC ENGINEERING

Genetic engineering, including genome editing (e.g. CRISPR/Cas) (for overview see Menz et al. 2020), is being promoted as a technology for sustainable farming. The resistance of plants to pests and disease and the resulting reduction in pesticide use are only some of the more common unfulfilled promises.

The property rights on these technologies have already led, and will continue to lead, to a further decline of agrobiodiversity, with potentially severe global consequences. Genetic uniformity is a main driver of pesticide use and can endanger food security. The "great famine" in Ireland was caused by the introduction of a new pathogen to an extremely vulnerable, rather new growing system (repeated potato cloning of mainly two varieties[84] without crop rotation). In the past 60 years, traditional, open-pollinated varieties have already been largely replaced by commercial high-yielding and hybrid varieties (Gmeiner et al. 2018), and new forms of breeding may accelerate the decline, especially when genetic engineering is under the control of a few global (pesticide) companies.

Historically, breeding has been carried out by farmers, resulting in a high diversity of varieties adjusted to different climatic and soil conditions – in times of climate change, this manner of "crowd breeding" might be necessary. Genetic engineering, incl. CRISPR/Cas as centralised technologies, may have unforeseen negative trade-offs (e.g. Gujar & Peshin 2021).

The general question is whether society wants to embrace new, high-risk technologies to solve crises caused by human-made technologies and forced upon farmers by the same or similar interest groups.[85] These corporations have always used their economic power to install positive narratives about new technologies into the minds of the public and decision makers. And they have always used their power to create technological lock-ins with a high degree of farmer dependency (Clapp & Ruder 2020). To believe that "genome editing" will be an exception is more than naive.

Innovation is not synonymous with progress. Investing in solutions with an unknown outcome while feasible solutions exist shows a lack of foresight and violates the precautionary principle. Neve (2018), for example, proposes the genetic modification of black-grass ***(Alopecurus myosuroides)*** in spite of the fact that traditional measures (proper crop rotation) could also solve the weed problem (see Weisberger et al. 2019). Black-grass is only a problem in narrow cereal crop rotation and became herbicide resistant due to herbicide mis- and overuse (Pallutt & Augustin 2022).

[84] It is thought that, in that time, all potatoes in Europe were the clones of a few tubers that had been brought by the Spanish from South America to Spain. This means the genetic diversity was extremely narrow (Mann 2011).

[85] Some of the major companies that are active in the global seed market are pesticide companies, such as Monsanto, DowDuPont, Syngenta and Bayer CropScience.

When it comes to pesticide reduction in the European Union, the potential of these bio-technologies is nearly zero. More than 80% of the EU's pesticide use comprises herbicide and fungicide use. Most of this use could be avoided through simple agronomic measures, while genetic engineering has led – where used[86] – to a ***"herbicide lock-in"*** (Desquilbet et al. 2019), herbicide-resistant weeds and environmentally damaging pesticide use (Schulz et al. 2021; Gujar & Peshin 2021). Weeds and pathogens mutate continuously, and the past has shown that also many human-made "resistant" crop varieties have lost resistance within a short period of time (Tabashnik & Carrière 2017; Gould et al. 2018; Rimbaud et al. 2018).

Knowledge about genetics can certainly help to create more resilient cropping systems, for example, if growers knew more about how to mix and grow genetically unrelated varieties.

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[86] In the US, the use of glyphosate on crops increased from 13.9 million pounds in 1992 to 287 million pounds in 2016: https://investigatemidwest.org/2019/05/26/controversial-pesticide-use-sees-dramatic-increase-across-the-midwest/

5.3 FROM TARGET-SETTING TO ACTION

Significant pesticide reduction or pesticide-free agriculture as demanded by many NGOs, will not be realistic until we address the economic drivers of pesticide use. Agronomic measures for preventing pesticide use have existed for many decades and are usually known to the farmers (see previous section). However, they are not economically viable for "locked-in farmers", and they are not in the interest of powerful stakeholders.[87] The aim of agricultural policy must be to create a production system where the independent producers, not powerful buyers of agricultural commodities, determine the crops and varieties they grow and at what prices they are sold.

Any coherent strategy towards pesticide-free agriculture must also be viewed in the context of the entire agricultural system and the current global challenges: climate change, rural exodus (migration), loss of biodiversity and animal welfare. Without a comprehensive holistic approach and an understanding of how these areas are interconnected, none of the EU's sustainability goals in agriculture will be achieved (Dorninger et al. 2020).

Therefore, a pesticide-free European Union will require drastic changes in several policy fields:

- climate policy,
- agricultural policy (EU Common Agricultural Policy [CAP]),
- pesticide policy,
- international and domestic (EU) trade policy and
- other policies regarding education, research, breeding and advertisement.

Policy changes must serve five main objectives:

1. increasing the costs of current, unsustainable and externally costly agricultural practices through:
    - pesticide taxation,
    - increasing authorisation costs and
    - carbon pricing,

[87] One powerful interest group seeks to profit from agriculture by selling inputs (pesticides, fertiliser, seeds, machinery) and services, while the other powerful interest group (retailers, feed and food processors) seeks to maximise profit margins through low purchasing prices. The latter has an interest in constant overproduction, which gives them advantages in price negotiations.

2. increasing farm income from diversified, pesticide-free production through:
   - changes in CAP subsidies (CAP reform),
   - the support of direct marketing and
   - the support of local and regional value chains,
3. making non-chemical alternatives more feasible by
   - adjusting depreciation,
4. strictly regulating the current, unsustainable agricultural practices by creating coherence in the pesticide policy, and
5. protecting sustainable production from competition by unsustainable production by improving domestic (EU) and international trade rules.

The measures for achieving objectives 1 through 5 are described in the following sub-sections.

PESTICIDE TAXATION

A pesticide levy is an essential economic instrument for internalising external effects and creating a comparative advantage for sustainable production. A levy on pesticides can achieve a significant pesticide reduction and generate government revenues, which can support further pesticide reduction measures, compensate for external costs or reduce labour costs in agriculture.

In Denmark, the current pesticide tax is based on the toxicity and environmental behaviour of a pesticide product. A previous taxation concept did not show the desired effect. After the tax reform starting in mid-2013, some pesticides became less expensive per ha dose, while more hazardous pesticides became more expensive. As a result, farmers substituted highly toxic pesticides with less toxic pesticides. The amounts of pesticides sold decreased substantially. The overall area treated with pesticides did not decrease, but that was not the aim of the tax, because Denmark already has a comparatively low treatment index. Figure 20 shows that the treatment index[88] (red line) did not decline, while the overall amount and the amounts of highly toxic pesticides (pesticides with a Toxic Load Indicator Score > 100) decreased (Möckel et al. 2021).

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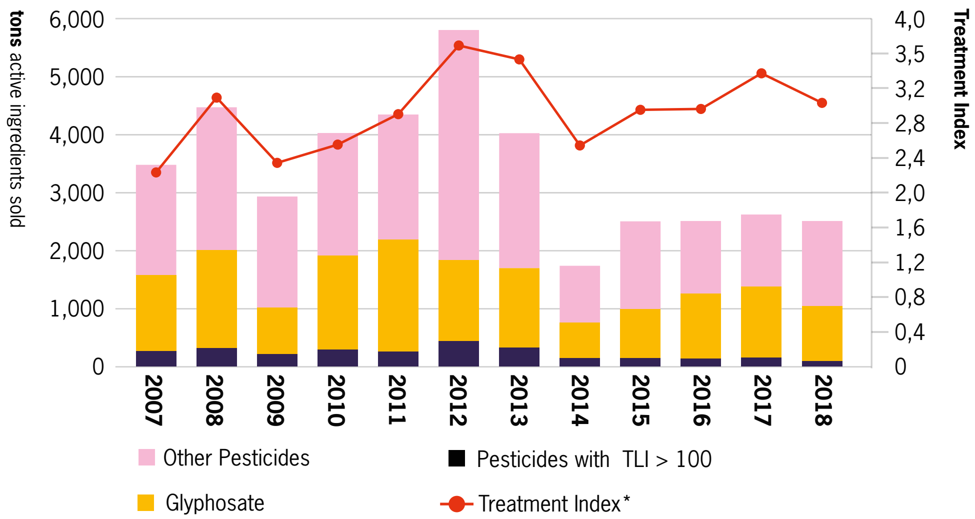
[88] Number of all doses sold by individual active ingredient divided by productive area (arable crops & permanent crops).

Figure 20:
PESTICIDE USE[89] IN DENMARK 2007-2018



*Neumeister´s calculation (2022), only pesticides sold throughout all years

The Danish tax had no negative consequences on Danish agricultural productivity (MST 2018; Neumeister 2019; Möckel et al. 2021).

A dynamic database model developed by Neumeister 2022 together with the Helmholtz-Centre for Environmental Research (UFZ) of Leipzig University for comparing the outcomes of different taxation schemes clearly shows the advantages of more elaborated taxation schemes. The ***ad valorem***[90] taxes often proposed are unsuitable for encouraging substantial pesticide reduction.

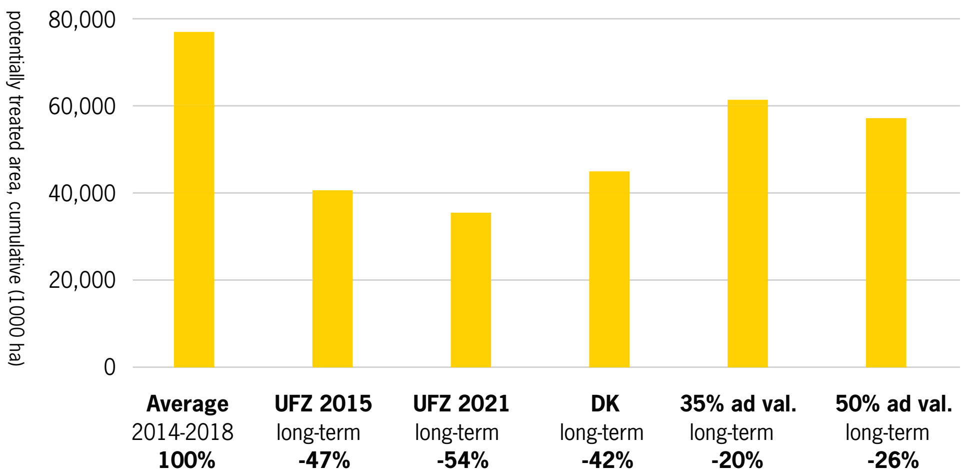
An elaborated, but still relatively simple taxation scheme[91] based on the environmental efficacy of a pesticide, the human toxicity and specific uses shows the highest pesticide reduction (over 50%) compared to other schemes (Möckel et al. 2021). Figure 21 shows the area treated with pesticides for different tax schemes in Germany (model results). The first column on the left presents the average area treated (cumulative) between 2014 and 2018, while the other columns show the reduction results as calculated by the model. An ***ad valorem*** tax of 35% or 50% does not bring about a significant reduction.

[89] Only agricultural pesticides sold throughout all years (excluding potential declines caused by the deregistration of pesticides).

[90] Adding a certain percentage to the value/price of a product.

[91] The UFZ concept for a levy is based on the maximum application rate during a growing season, the human toxicity reflected by ADI (Acceptable Daily Intake), AOEL (Acceptable Operator Exposure Levels) values and the use type.

Figure 21:
AVERAGE AREA TREATED IN 2014-2018 IN GERMANY AND REDUCTION BY TAXATION SCHEME



Higher pesticide prices do not automatically lead to higher production costs, because there is a rather high percentage of unnecessary pesticide use. Reductions, to a certain degree, may lead to higher or even higher farm revenues. In many arable crops, a 40% reduction of treatment frequency may not show any negative effects on revenue (Lechenet et al. 2017). Pesticide costs will also be reduced if growers stop broadcast spraying and only spray areas where estimated damages exceed the acceptable threshold – this also reduces the risk of resistance. A pesticide tax is an excellent instrument for reducing economically unnecessary pesticide applications, promoting integrated pest management and avoiding pest, disease and weed resistance.

A pesticide tax could be established at national level. However, not only would an EU-wide taxation be fairer: it would also have a much bigger impact. The European Commission already has the power to demand taxation and can define details. One example is the Energy Taxation Directive (ETD), and another is the Tobacco Taxation Directive.

INCREASING COSTS OF AUTHORISATION AND LEGISLATION

The national authorities charge fees for the authorisation of pesticides. These fees do not always cover all costs (European Parliament 2018), and the costs that are not covered by fees are external costs. Increasing these fees to a level that would cover all expenses[92] could solve certain shortcomings of the authorisation system (see box: ***"Shortcomings of the EU's pesticide-authorisation system"***) and internalise external costs. Fees on the national level should also cover all costs for on-farm inspections, the monitoring of pesticide advertisement, food surveillance and environmental monitoring for the entire duration of the authorisation. This would further internalise external effects.

Many of the tasks at European level regarding pesticide authorisation and other legislation (e.g. setting of maximum residue levels in food) are not covered by fees (ibid). The costs of these tasks, as well as costs by EU authorities, such as the EFSA, ECHA and European Commission, need to be budgeted and incorporated into the fee system.

CARBON PRICING

Agriculture is currently the only human activity which has the potential to sequester atmospheric carbon without major technological advances (Poore & Nemecek 2018). However, currently EU agriculture is not a carbon sink, but a significant emitter of CO_{2eq}. Open-field agriculture in the EU alone accounts for 3.7% of the total EU energy consumption, mostly from non-renewable energy sources (Paris et al. 2022).

"Carbon pricing", incl. pricing for other climate-relevant gases, needs to be adjusted in such a way that energy-intensive inputs, especially mineral nitrogen, and emissions become much more costly, while carbon sequestration is incentivised. A price of €180 per tonne of CO_{2eq} would reflect the current external costs (UBA 2018). Farm inputs and agricultural commodities imported from third countries must be included in a carbon pricing scheme to discourage unfair competition.

Specific forms of grazing, agroforestry and new hedges/tree rows could be included in the pricing system (e.g. via carbon credits for agricultural holdings) in a way that benefits agriculture and the environment (UNEP 2019).

Smart carbon pricing would support specific agronomic measures for preventing pesticide use: e.g. through **nitrogen reduction** and the **re-establishment of biodiversity**.

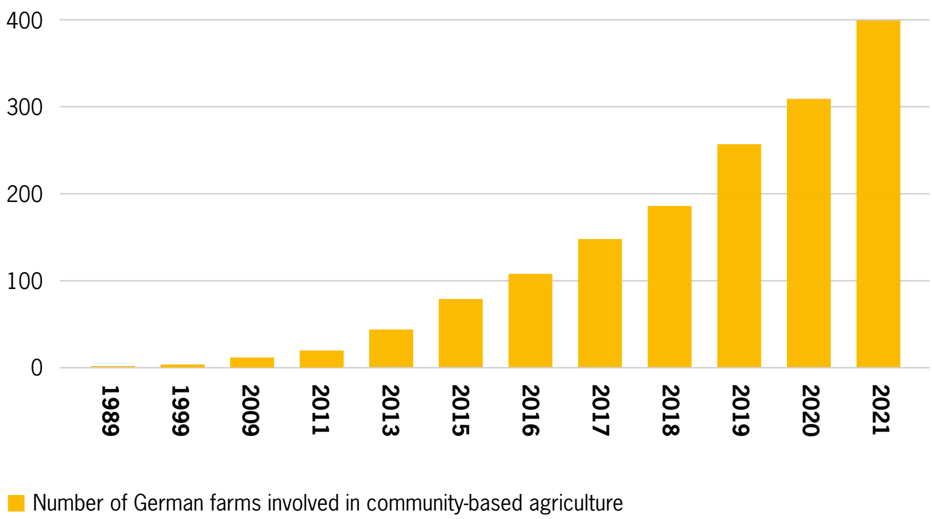
[92] As required by Article 74 of Regulation (EC) 1107/2009.

SUPPORT OF DIRECT MARKETING

Although direct marketing accounts for a very small percentage (2% in 2015) of the entire food supply chain (EC 2015), it is one of the major economic instruments for generating higher prices, increasing crop diversity and avoiding the supermarkets' unacceptable standards for aesthetics.[93] The most common form of direct marketing is the farmers' market and the on-farm shop. Vending machines, deliveries via subscription and "crowd farming" have also become more common.

In Europe, the popularity of community supported agricultural (CSA), a special form of direct marketing, has been increasing (see Figure 22 for Germany). This form of agriculture decouples market prices from production and gives farmers a high degree of flexibility. It is also common that consumers in such co-operatives come for field days and volunteer, for example, with weeding or other tasks. Nearly 100% of these farms are organic.[94]

Figure 22:
NUMBER OF COMMUNITY-BASED FARMS IN GERMANY 1989-2021



In some regions, arable growers cooperate with bakeries and, together, drive innovation. In the German state of North Rhine-Westphalia, for example, a cooperative project involving a health insurance provider with several growers and bakeries now produces high-protein bread with a high content of pulses.[95] This system allows farmers to integrate a beneficial leguminous crop into the crop rotation and to demand a better price. In Berlin, oat "milk" from regionally produced oats is now being marketed.[96]

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[93] An "ugly" fruit box system already exists as a direct marketing concept: https://etepetete-bio.de/diebox; https://www.misfitsmarket.com/; https://www.imperfectfoods.com/ugly-fruit-and-veggie-box

[94] Personal communication with the organisation Netzwerk Solidarische Landwirtschaft.

[95] See website of Rheinische Ackerbohne e. V.: https://www.rheinische-ackerbohne.de/

[96] See https://www.kornwerk.com/

Oat is a drought-tolerant (summer) cereal that, unlike wheat and barley, is very robust and can widen narrow crop rotations. The key to direct marketing is to actively bring together the regional production of agronomically valuable crops and the market, incl. processors.

Currently, most agricultural companies are mainly primary producers, and many cannot add other economic activities without additional resources.

Supporting direct marketing financially and institutionally would support specific agronomic measures for preventing pesticide use: **robust varieties**, **crop diversity**, **crop rotation** and **regenerative soil management.**

SUPPORT OF LOCAL AND REGIONAL VALUE CHAINS

Financial support (CAP) needs to be dedicated to revitalising local/regional food processing and helping create cooperatives.

In the recent past, cereals and oil seeds were usually milled locally, and dairy products were produced regionally. Due to consolidation, the number of mills and dairy facilities has been dramatically declining. The same is true for meat and sugar processing. The large concentration of food processing facilities has a direct impact on the cropping system. Certain crops will not be integrated into a crop rotation and crop diversity, because it is not feasible to transport the harvest over longer distances (e.g. sugar beets, green maize), while the density of certain crops is higher near large processors. In addition, there are certain thresholds under which buyers will not purchase and collect the harvest. This means that a small agricultural company for which transport is not feasible cannot diversify the production alone if the harvested volume of a particular crop is below a certain amount. More local or mobile mills must be re-established throughout Europe to allow for regional and diverse production.

Many fruit and vegetable growers are extremely restricted by the cosmetic standards of retailers – “ugly” fruits, small fruits and fruits with a non-standardised colour or even colour distribution are not accepted. Food processing can be one way to generate income from non-standardised harvest and reduce dependency on retailers. Smaller farmers have more marketing power if they create cooperatives. Local/regional food processors and innovation must be supported, especially in rural areas with little agro-industrial infrastructure.

The political goal of carbon neutrality creates many chances for rural development by food processing because agriculture, especially agroforestry, can be a provider of carbon neutral energy – a 10-meter-long hazel hedge can provide not only nuts and environmental services (incl. plant protection), but also about 20,000 kWh of energy per year (Crossland 2015). Locally produced wood could be used to generate electricity, as well as heat, and both could be used to process agricultural produce.

Supporting local and regional value chains could promote specific agronomic measures for preventing pesticide use: **robust varieties**, **crop diversity**, **crop rotation** and the **re-establishment of biodiversity**.

REFORM OF THE EU COMMON AGRICULTURAL POLICY (CAP)

The Common Agricultural Policy (CAP) of the European Union is the most powerful economic instrument in agricultural policy and has large impacts on nature conservation and rural development. For decades, CAP has been shaping agriculture. Each year, over €50 billion are transferred as subsidies from citizens to the EU agricultural sector. The claimed purpose of the CAP is – equivalent to the US Farm Bill – to counterweight the destructive race to the bottom (see Section 4) caused by competition and to financially support EU farming. In reality, large landowners have received about 80% of the subsidies (EU factcheck 2019). A large percentage of the subsidies have been allocated to areas with high CO_{2eq} emissions (Sown et al. 2020).

In 2020 over 3,600 people from the scientific community demanded a major reform of the CAP, because the environmentally and socio-economically damaging ***"business as usual"*** is no option for the future (Pe'er et al. 2020). The signatories called for fundamental changes to the CAP, because they feared that sustainability goals would not be achieved.

The new CAP period 2021–2027 has been intensely debated over the past few years and will come into effect in 2023. The 2023-2027 CAP period foresees some changes regarding direct payments, voluntary eco-schemes and "conditionality", previously known as "cross compliance". Direct payments per ha have been reduced, and growers can now receive more subsidies by implementing so-called "eco-schemes" (EC 2021). The Farm to Fork objective of a 50% pesticide reduction is not integrated into CAP 2023-2027. This means that one of the most powerful economic instruments in the EU will not be used to achieve goals set by the European Commission.

Therefore, it is completely unclear whether the new CAP measures for the period 2023 to 2027 will achieve any reduction in pesticide use.

Some suggested eco-schemes (e.g. agroforestry, agroecology, carbon farming, pesticide-free farming) have a potential to substantially reduce pesticide use, but there is no prognosis on how many farmers will adopt which type of “eco-scheme”. Receiving lower payments or even abstaining from direct payments might be more feasible than implementing additional “eco-schemes” or meeting new conditions (top agrar 2022). It is also likely that farmers will apply for subsidies for “eco-schemes” which they have already integrated into their production. However, the Member States are responsible for working out the details with respect to implementation.

The further development of the CAP after 2027 is even more unclear. The results of the coming years (post 2023) will be decisive.

According to the German scientific advisory board “Agricultural Policy, Sustainable Land Management and Development of Rural Areas” from 2005, the direct payments of the Common Agricultural Policy (CAP) are unsuitable for a long-term sustainable income policy. Measures based on income policy should, in accordance with the subsidiarity principle, be better incorporated into national tax and social policy. A fixed monthly basic income for farmers and farmworkers might be a more feasible option than a CAP which causes numerous negative externalities. The common agricultural policy could then develop into an economic instrument for additional incentives for environmental services, rural development and animal welfare.

For the objective of a pesticide-free European Union, the following changes in subsidies should be (re-)considered:

Direct and indirect subsidies (e.g. promotion of meat consumption [Greenpeace Europe 2021]) for meat and dairy production must be abolished.

Basic payments per hectare must change to payments for rural labour and be allocated towards the production of climate-friendly, healthy human food. Currently, a vegetable grower with 10 ha and 20 workers receives ten times less subsidies (basic payments) than a 100ha silage-maize farm with two workers. Shifting payments to labour would also allow for higher minimum wages in agriculture and could ideally also eliminate the slave-like labour conditions[97] in the fruit and vegetable sector.

[97] The labour conditions in the fruit and vegetable sector are described as slave labour/forced labour by many organisations.

Direct marketing and local food processing must be much more strongly supported to decouple farming from international competition and improve income levels and livelihoods in rural areas.

Specific agri-environment measures or production systems must become a condition for any subsidies:

- annual and/or perennial flower strips
- habitat restoration and creation of new habitats (e.g. hedges)
- managed fallow

Conditionality must include the following:

- obligatory intercropping between each arable crop
- permanent maintenance of a green cover between the rows in perennial crops
- crop rotation

Crop rotation in arable monocropping should ideally have at least five crops with an **equal land share**. Similar crops, like triticale, wheat, barley and rye, have to be considered as one crop, because a "self-rotation" of these cereals has no positive effect on preventative plant protection – they are all sensitive to Fusarium spp. and support the development of weed problems with grasses like black-grass or wild oat. Each rotation should include two years of a legume-grass/herb-cover crop or fallow. This legume-grass crop/fallow has the purpose of recovering soil biology and structure, storing carbon and, above all, eliminating certain weed and pathogen issues. The legume-grass crop should be used for grazing, mulching or composting.

ADJUSTING DEPRECIATION

Financial public support and taxation should be made coherent in order to achieve the overarching goal of sustainable agriculture.

Some of the suggested measures for reducing the need for pesticides or substituting pesticides require higher investments, especially if producers want to invest in direct marketing or food processing. In some cases, specific agri-environment subsidy schemes require investments in certain equipment. The tax depreciation system does not always encourage such investments and can reduce the acceptance. Depreciation periods should be aligned with the subsidy period (or vice versa) (Böcker et al. 2019).

Adjusting depreciation could support specific technological measures for preventing pesticide use: e.g. **manual weeding, incl. weeding robots.**

IMPROVING DOMESTIC (EU) AND INTERNATIONAL TRADE RULES

In the current market economy, where product prices do not reflect external costs, agricultural producers with low social and environmental standards are more price competitive than producers with higher social and environmental standards.

A legal framework must be established with **rules on mandatory human rights and environmental due diligence**. Such a legal framework would also avoid so-called potential "leakage" effects (see Bereille & Gohin 2020), where stricter national standards lead to substitution by imports from countries with lower standards. At EU level, the Renewable Energy Directive (RED) has already shown that certain standards for reducing ***indirect land use change*** (ILUC) can be required from exporters/importers of certain agricultural commodities. This needs to be systematically implemented for all imported agricultural commodities and all farm inputs and must include environmental and social standards. Third countries (non-EU) must be equally able to protect their agricultural production from unfair competition by EU-subsidised overproduction.

The creation of Directive (EU) 2019/633 on unfair trading practices in business-to-business relationships in the agricultural and food supply chain is an example of a policy that addresses specific problems resulting from monopsonies causing a ***"significant imbalances in bargaining power between suppliers and buyers of agricultural and food products"***. The insight of the European Union (see EU Directive 2019/633) that ***"in an agricultural policy environment that is distinctly more market-oriented than in the past, protection against unfair trading practices has become more important (...)"*** is certainly a step in the right direction.

On an international level, trade in agricultural commodities must be revised. Economists and organisations like the World Trade Organization (WTO) must rethink and redefine the concept of "comparative advantage". A country does not have a comparative advantage when it overuses public goods (water, air, atmosphere) and natural resources and permits asocial labour conditions. These forms of exploitation should be economically considered as illegitimate subsidies and become subject to WTO restrictions. The right of future generations to live in a "clean" environment was confirmed in 2021 by the German court of justice, and this legal perspective must be integrated into international trade law.

CREATING COHERENCE IN EU PESTICIDE LEGISLATION

In the European Union, pesticide policy is largely harmonised, and all Member States are obliged to implement legislation on a national level.

Three pieces of legislation must support the EU phase-out of pesticides:

1. pesticide authorisation and the national implementation (Regulation EU No. 1107/2009),
2. the sustainable pesticide use directive 2009/128/EC[98] and the national implementation, especially the crop-specific definition of integrated pest management (IPM), and
3. Regulation EU No. 369/2005, setting maximum residue levels (MRLs) for pesticides in food.

Each of these regulatory instruments has numerous shortcomings (e.g. see box ***"Shortcomings of the EU's pesticide-authorisation system"*** below), but the complete lack of coherence might be the largest obstacle. The Sustainable Use of Pesticides Directive, for example, made integrated pest management (IPM) mandatory – and the most important principle in IPM is the prevention of pest control intervention:

Article 14[99]: ***"Member States shall take all necessary measures to promote low pesticide-input pest management, giving wherever possible priority to non-chemical methods, so that professional users of pesticides switch to practices and products with the lowest risk to human health and the environment among those available for the same pest problem."***

However, the directive does not demand that currently authorised pesticide applications (indications) which violate the principle of IPM or encourage pesticide use be withdrawn.

Two future tasks in pesticide policy should be:

A) developing strong national, legally binding IPM rules for each crop, including "crop rotation laws", e.g. longer mandatory fallow periods as well as the choice of varieties, and gradually withdrawing all treatments/ indications of chemical pesticides that would lead to the violation of these rules. **According to IPM, pesticide use should be the last resort, reserved for cases of emergency, and all pesticide policies must be in line with this aim.**

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[98] For an overview, see PAN Europe: https://www.pan-europe.info/eu-legislation/directive-sustainable-use-pesticides

[99] Directive 2009/128 on establishing a framework for Community action to achieve the sustainable use of pesticides, see https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009L0128

B) revising all authorised indications. A gradual de-authorisation/withdrawal of authorisation is necessary for numerous indications/uses:

1. use of plant growth regulators (PGRs) in cereals. The use of PGRs in cereals promotes nitrogen overuse and continued pesticide use.
2. use of fungicides against soil-borne pathogens and insecticides against aphids, both of which allow for the violation of general IPM principles.
3. indications which only serve cosmetic purposes: the control of pests which only affect the appearance or only serve marketing purposes, e.g. treatments for carrots, kohlrabi, citrus fruits etc. to create blemish-free greens, leafage and/or peels at the point of sale,
4. insecticide/acaricide indications when existing beneficial organisms can sufficiently control the pests, when appropriate habitat is provided. This would encourage growers to establish on-field biodiversity and eliminate herbicide use.
5. all herbicide authorisations starting with all uses on non-productive areas, maize and cereals.
6. all indications where cost, availability and/or dangerous discomfort may make the use of the required personal protective equipment (PPE) unfeasible.[100]

Preventative measures for the most important pests, pathogens and weeds have been known for decades – they are, taking into consideration a full cost analysis, much more economical than chemical control.

Most National Action Plans (NAP) developed by the Member States to implement directive 2009/128/EC ***"lack ambition and fail to define high-level, outcome-based targets"*** (European Parliament 2020, p. 5). The key question is whether a revision of the National Action Plans (NAP) would lead to a substantial improvement. Most drivers of pesticide use cannot be addressed by national policy alone, and therefore, delegating all responsibilities to the Member States will not achieve the necessary results. The European Commission, European Parliament and Member States need to work together to develop milestones, targets and detailed action plans (see Section 7 below). This will require the establishment of new form of dialogues and an independently moderated process which builds on an agreement towards common goals and involves trust-building and long-term involvement (see Barzman & Dachbrodt-Saaydeh 2011). In the next several years, the impacts and mitigation of climate change will fundamentally affect agriculture and human food consumption. Other challenges to be addressed are the loss of biodiversity, environmental eutrophication, rural exodus and animal welfare. It is therefore of utmost importance that the milestones and targets for pesticide use be coherent with other overarching goals. As already stated in Section 5.1, most agronomic measures which prevent pesticide use also solve other environmental problems caused by agriculture.

[100] For reference, see Garrigou et al. 2020.

Regulation EU No. 369/2005 setting maximum residue levels (MRLs) must be modified accordingly. The meaningless term ***"good agricultural practice"*** must be replaced with a meaningful integrated pest management (IPM). According to the current wording of the regulation ***"MRLs should be set at the lowest achievable level consistent with good agricultural practice for each pesticide with a view to protecting vulnerable groups such as children and the unborn."***

The lowest achievable MRLs should therefore be set at the analytical limit of detection (LOD) because most residues can be avoided by strictly applying IPM or organic methods. However, ***"good agricultural practice"*** in the meaning of the current regulation refers to an ***effective pesticide application***. The MRL is based on the highest residue left in a commodity after a "proper" application. Whether or not the application could have been avoided by other measures plays no role. The regulation therefore undermines the sustainable pesticide use directive and needs to be amended. An amendment of this kind would also have positive implications for international trade with more sustainable produce.

The current **pesticide-authorisation** system defines (insufficiently - see Box below) the acceptable toxicity of a pesticide and fails to eliminate all external costs. Certain external costs could be avoided by a stricter authorisation system. The testing of pesticides in food and the environment (incl. groundwater) is very costly and will always be required for certain pesticides/applications.

National authorities should therefore incorporate expected external costs into the authorisation of pesticides (see above). This could be a simple scoring system where certain results can lead to the withdrawal of approval, higher taxation and/or stronger restrictions.

According to the International Code of Conduct on the Distribution and Use of Pesticides developed by the Food and Agriculture Organisation (FAO), which is acknowledged by the pesticide industry, ***"all advertising should be legal, decent, honest and truthful."*** And furthermore: ***"All statements used in advertising are technically justified (...) and truly reflect the outcome of scientific tests and assessments."*** (FAO 2010).

There is currently no EU policy that requires an effective control of pesticide advertising, in spite of the fact that the Code of Conduct requires that the competent authorities ***"examine and approve the application for pesticide advertising"*** (ibid.).[101] Opening any agricultural magazine or website targeting conventional farmers reveals that most pesticide advertisements violate the Code of Conduct. Syngenta, for example, maintains a bonus

[101] Article 66 (Advertising) of Regulation [EC] No 1107/2009 is much weaker than the FAO Code of Conduct and does not require control by authorities.

programme,[102] where pesticide purchases are rewarded with premiums, although the Code of Conduct clearly says that ***"advertisements and promotional activities should not include inappropriate incentives or gifts to encourage the purchase of pesticides"*** (ibid.).

The "self-regulation" promoted by voluntary codes obviously fail when authorities have no resources or legal power to enforce these codes. Considering that the control of pesticide advertisements would generate high external costs, a prohibition of pesticide advertisement equivalent to the prohibition of tobacco advertisement (Directive 2003/33/EC) should be considered. Member States can **prohibit pesticide advertisements** in accordance with Article 66(3) of Regulation [EC] No 1107/2009. Any costs associated with the control of advertisements must be covered by authorisation fees and/or pesticide taxation (see above).

OTHER POLICY MEASURES

EDUCATION

Many preventative agronomic measures and non-chemical alternatives exist, but available knowledge and know-how often does not reach the growers. For example, there is a large knowledge gap regarding the relationship between the use of mineral fertilisers, soil biology and the increased vulnerability of crops.

The topic of applied agricultural entomology must be included in the education of growers and farm technicians. It must be ensured that anyone responsible for crop protection is able to determine damage threshold (requirement within IPM) and identify the relevant natural enemies, along with their impacts and habitat needs. The knowledge exists (e.g. IOBC-WPRS 2004) but must be applied. Relevant scientific journals like Biological Control, Applied Ecology and the Journal of Integrated Pest Management publish research on alternatives to pesticides, but it is not accessible to smaller-scale farmers, owing to the language barriers and time constraints. Therefore, independent extension services must be the link between science and agricultural practice, "translating" scientific knowledge for farmers. Public extension services (advisory services) need more resources and incentives for continuous learning. Improvements in extension services could be funded by the pesticide levy/tax (see above). Specific farms which successfully practice regenerative agriculture and/or agroecology should be selected and receive additional funding for outreach and farm-to-farm training.

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[102] See Syngenta: https://www.bonusland.de/

SHORTCOMINGS OF THE EU'S PESTICIDE-AUTHORISATION SYSTEM

Although the EU's pesticide-authorisation system has been improved in recent decades, civil society including scientists (for overview see Bozzini 2017[103] and/or Storck et al. 2014; Hendlin et al. 2020 Robinson et al. 2020), the European Parliament (2018) and the European Commission (EC2017a, EC2017b, EC2020c) have identified numerous shortcomings. Some of these shortcomings have severe adverse effects on human health and the environment. The literature on this topic is exhaustive. Therefore, the main shortcomings are listed without further explanation.

Three types of shortcomings can be observed:

1. SHORTCOMINGS WITH RESPECT TO THE OBJECTIVES/SCOPE OF THE REGULATION

A. conflicts with other EU environmental legislation and EU policies,
B. inconsistency with the objectives and provisions of the regulation,
C. failure to comply with general or environmental principles,

2. SHORTCOMINGS WITH RESPECT TO THE IMPLEMENTATION

A. lack of transparency and neutrality (see e.g. McDaniel et al. 2005) (conflict of interests in former state laboratories, EU authorities, especially the EFSA),
B. risk assessment based on studies conducted by the manufacturers of pesticides,
C. standardised Good Laboratory Practice (GLB)[104] are "blind" for adverse effects outside of the protocol,
D. very slow reassessment process -> some pesticides have not been evaluated against EU standards established more than 15 years ago,
E. extension of approval of pesticides meeting the hazard criteria for exclusion,
F. misuse of "emergency authorisations" (EC 2017b, Hernandez et al. 2019),
G. lack of procedure to assess and manage newly recognised environmental and health risks.

3. SHORTCOMINGS WITH RESPECT TO THE SCIENTIFIC RISK ASSESSMENT PRIOR TO AUTHORISATION

(see Schäfer 2012; Reuter & Neumeister 2016 Schäffer et al. 2018; Simon-Delso 2018; Clausing 2019; Schäfer et al. 2019; Zaller & Brühl 2019; Sánchez-Bayo & Tennekes 2020; Sgolastra et al. 2020; Weisner et al. 2021)

A. indirect ecological effects on the trophic web (food web) in the agroecosystem are not assessed,
B. neglect of combination or cumulative effects. Food, pesticide users and the environment are contaminated with hundreds of chemicals, and populations are exposed to many stressors. A crop is usually treated several times, receiving multiple pesticides within a season – the factor of frequent use is ignored in risk assessment,
C. insufficient assessment of the final pesticide product,
D. insufficient or no assessment of (time-) cumulative and/or sublethal exposure,
E. species selection for non-target organisms is too narrow,
F. use of inaccurate statistical methods in the assessment of chronic toxicity,
G. no assessment of developmental immunotoxicity (DIT) and developmental neurotoxicity (DNT),
H. assumption of "proper use" and use of efficient personal protection, while in reality there is a high rate of non-compliance and inefficiency of protective clothing (Garrigou et al. 2020).

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[103] The Annex of the document by the European Parliament (2018) contains much of the book by E. Bozzini (2017).
[104] Consistent with the OECD principles of good laboratory practice.

RESEARCH

A broad knowledge of preventative pest-control methods and other control methods already exists. There are some significant knowledge gaps regarding certain bottom-up effects, especially regarding the relation of certain nutrients, the soil food web and pests and diseases. Furthermore, little is known as to how pests and diseases spread in more heterogenic landscapes due to nutritional differences. What is also needed is more research on pheromones for arthropod control and how to make their use more feasible. Private breeding companies have always assumed an unlimited availability of chemicals and created susceptible varieties. Independent breeding (research) programmes meeting the objective of pesticide-free farming are needed (Jaquet et al. 2022).

The focus of research, however, should be on social, economic and political questions: How to overcome socio-economic lock-ins in agriculture, how to create independent farming and attractive rural life and how to disentangle politics from corporate interests. Hu (2020) suggests that a (...) "restriction of the influence of special interest groups in policy system could be an effective instrument for mitigating pesticide dependence." The question of how to disempower the powerful corporations and organisations that are profiting from the tremendous externalities needs to be answered.

One of the key measures suggested in Section 7 is to organise citizen assemblies/councils as forums for open citizen dialogue (consumer-producer dialogue). The input of social and political scientists and legal experts is needed on

A. how to facilitate Europe-wide discussions on the trade-offs and compromises in food production and food consumption, and
B. how to legally implement recommendations made by citizen dialogues.

WITHDRAWAL OF APPROVAL FOR HIGHLY VULNERABLE VARIETIES

Crop varieties are approved by national authorities. Vulnerability to specific pests and diseases is not a criterion for approval. The respective criteria must be developed and applied. A new variety should not be allowed if its cultivation requires pesticide use at levels that are higher than or just as high as an existing variety. Each grower should have full transparency about the vulnerability and potentially associated plant-protection costs for each variety.

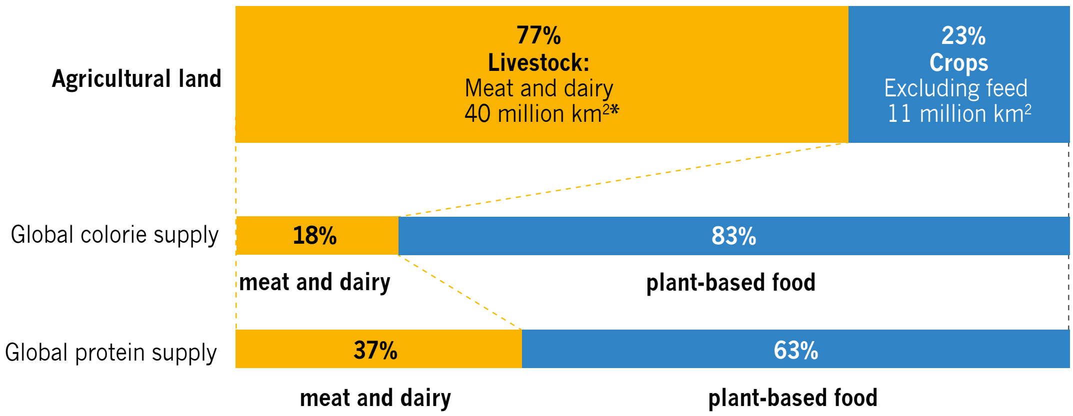
[97] The labour conditions in the fruit and vegetable sector are described as slave labour/forced labour by many organisations.

6 CHANGING BELIEF SYSTEMS

Over the past several decades, specific belief systems about pesticides and the current agricultural production system have been installed into the minds of the public, agricultural economists and farmers. The most common narrative is still that food security can only be ensured by large-scale farming, which is dependent on pesticides, mineral fertilisers and genetic engineering. In countries like the US, where this form of (subsidised) agriculture dominates, food insecurity should be history. It is not. More than 10% of the US population frequently experiences hunger, because many families cannot afford to buy food (USDA 2022). Poverty, not a shortage of production, is the driver of hunger in most countries.[105]

Most of the global agricultural production is not even intended for direct human consumption. About 82% of the calories for direct human consumption are produced on 23% of the available agricultural land. The remaining 77% of the agricultural land is used for producing animal feed and eventually provides 18% of the global calorie supply.[106]

Figure 23:
LAND AREA UTILISED FOR ANIMAL- AND PLANT-DERIVED CALORIES AND PROTEIN



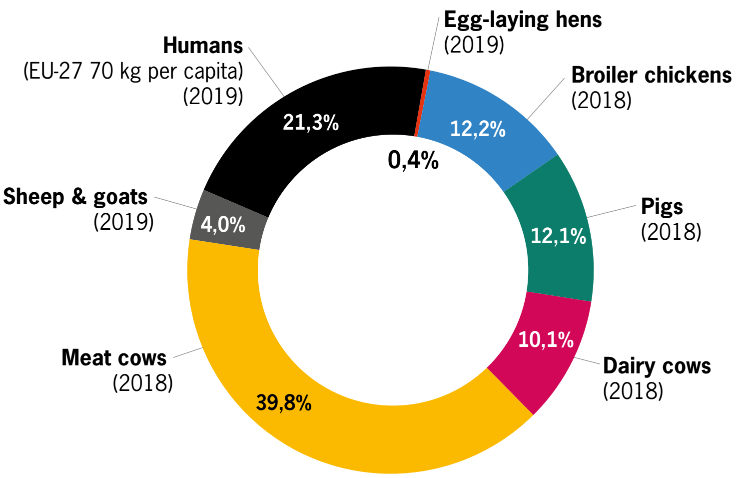
*this includes grazing land for animals and arable land use for animal feed production

(diagram redrawn from https://ourworldindata.org/agricultural-land-by-global-diets)

[105] https://www.bread.org/what-causes-hunger
[106] https://ourworldindata.org/agricultural-land-by-global-diets

In the European Union (EU 27), about 7 billion farm animals[107] are maintained annually, versus 0.45 billion humans. There are twice as many pigs living in the EU-27 as children.[108] When adjusting the figures to body weight,[109] the results suggest that almost 80% of all agriculture inputs is used for feeding farm animals (see Figure 24). The farm-animal-to-human weight ratio is approximately 3.5:1.

Figure 24:
BIOMASS/WEIGHT DISTRIBUTION OF "FARM" ANIMALS AND THE HUMAN POPULATION IN THE EU



The resources (feed, water, medicines) for maintaining this large amount of animal biomass are immense. A total of 14.5 million hectares of land (see Sporchia et al. 2020 for 2017) are needed each year just to feed the 140 million pigs. This figure is approximately equivalent to the arable land area of Austria, the Czech Republic, Germany and Denmark combined (see Eurostat). A report by Greenpeace Europe shows that 63% of the EU's arable land is dedicated to feed production (Greenpeace 2019).

Because current industrial agriculture mainly feeds animals, the energy balance is negative (Cassidy et al. 2013; Salmberg et al. 2016). African and Asian farmers are more energy efficient in their food production than

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[107] See Eurostat tables under "Livestock and Meat" (t_apro_mt).
[108] About 140 million pigs annually versus about 68 million children (2019) below age 15.
[109] A dairy cow weighs, on average, 650 kg, a meat cow about 670 kg, a broiler about 2.5 kg, a pig about 120 kg and an egg-laying hen about 1.5 kg (live weights).

Europeans (Cassidy et al. 2013). Research in the Netherlands showed that, in 2015, about 7.8 gigajoules of energy were needed to produce one tonne of food with an energy equivalent of 3.4 gigajoules (Smit 2018). A recent analysis by Paris et al. (2022) showed that annual energy use in EU open-field agriculture is at least 1431 PJ. Depending on the crop, energy input ranges from 15 GJ/ha to 25 GJ/ha.

Each year, the current EU population produces 80 million tonnes of food waste,[110] not counting the amounts remaining on the field due to cosmetic imperfections or low prices. A large percentage of the population suffers from severe health issues related to over-nutrition and malnutrition (Baumann 2021; WHO Europe 2022). WHO Europe recently concluded: (...) ***unhealthy food environments result from changes in the global food supply (for instance, in the European context, heavy subsidies, both national and EU-funded, on the production of meat, dairy and sugar make them relatively cheaper and more available population-wide); they are now the major drivers of unhealthy diets, obesity and related NCDs***[111] (ibid. page 63).

On a global scale, the hidden costs of the food industry are estimated to be between US$6 trillion (UN Food Systems Summit 2021 and US$16 trillion (Nature editorial 2019) per year. The claim that agriculture produces affordable food seems to be in stark contrast to the reality when all hidden costs are considered. Essentially, the proponents of "modern" agriculture have a contrafactual understanding of achievement.

On 11th February 2022 one of the leading German agrarian magazines (***top agrar***) published an article on the Farm to Fork Strategy. The headline was[112]: ***"50% less plant protection. EU-Commission gets serious."*** This was not the first headline where chemical pest control was equated to plant protection. And the German ***top agrar*** is not the only publication using this rhetoric. For decades, books on plant protection have focused almost exclusively on chemical pest control, and most conventional farmers have been systematically taught that pesticides are the ultimate pest and weed control method (see Amberger 2021).

Since the establishment of the pesticide industry, pesticides have been promoted in agricultural magazines, books and fairs as being safe and the absolute premium for the control of pests, weeds and diseases. Pesticide reduction or regulation, they assert, would cause "yield shocks". High yields "at all costs" are still the main goal of many (irrational) farmers. Results from surveys in Denmark indicate ***"that farmers are more concerned about loss of yield than about environmental and health risks when they consider***

[110] In the EU, around 88 million tonnes of food waste are generated annually, with the associated costs estimated at €143 billion (FUSIONS 2016).

[111] NDCs: noncommunicable diseases (added by the Neumeister (2022))

[112] Translated by Neumeister (2022) from "50% weniger Pflanzenschutz. EU-Kommission macht Ernst".

the use of pesticides" (Pederson et al. 2012 p. 14). The pesticide industry systematically uses the justified[113] fear of farmers to influence decision making.

Pesticide companies regularly hire private "think tanks" which suggest an association with university research to support their claims. Monsanto, the main producer of glyphosate, for example, secretly[114] hired the Institute for Agribusiness in Giessen, which published a study showing that the de-authorisation of glyphosate in the EU would lead to billions of euros in welfare losses. The same institute had also published previous articles on behalf of the pesticide industry (e.g. Schmitz et al. 2011) when regulations were threatening to affect pesticide sales. While the main author was a professor at Giessen University, the Institute for Agribusiness is a private enterprise which had been renting meeting rooms at the university (Gießener Anzeiger 2019).

Section 3.1 referred to a study financed by Syngenta and Bayer CropScience which describes the severe negative impacts of banning three seed-coating insecticides throughout the EU. When the ban was implemented, none of the scenarios became reality, which was foreseeable considering the fact that the entire study was based on false assumptions and non-calibrated economic models. At the time when the industry study was written, some bans were already in place in Germany, not showing any impact on yield (Neumeister 2013). The clients and authors of the report ignored the evidence and predicted a strong decline of maize and rapeseed yield responsible for high welfare losses.

The Wageningen University[115] recently released two publications related to pesticide policy. One study (Bremmer et al. 2021) was commissioned by the pesticide lobby organisations CropLife Europe and CropLife International, and the other (STOA 2021) by the European Parliament.[116] One author participated in both reports.

The report by Bremmer et al. (2021) reflects on the Green Deal incl. pesticide reduction and must be viewed in the context of the clients: a lobby paper with the aim of influencing decision making in favour of the clients. The paper does not meet scientific standards or contribute to knowledge gain.[117] The objective is to create fear and outrage among farmers and insecurity among non-expert decision makers and eventually to prevent certain political action.

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[113] Since most farmers have no control over the price they will achieve, any potential yield loss may result in income loss.

[114] LobbyControl later revealed the ties between Monsanto and the Institute for Agribusiness in Giessen (see https://www.lobbycontrol.de/2019/09/fleischkonsum-und-biosprit-lobbybotschaften-mit-professorentitel/)

[115] The current president of Wageningen University & Research is a board member of Syngenta, one of the largest multinational pesticide companies.

[116] Researched at the request of the Panel for the Future of Science and Technology (STOA) and managed by the Scientific Foresight Unit, within the Directorate-General for Parliamentary Research Services (EPRS) of the Secretariat of the European Parliament.

[117] The authors did not interview a single agricultural holding in Europe. Instead, they asked institutional experts to fill out a questionnaire.

In general, the consultants, including Wageningen University & Research working on behalf of the pesticide industry, rarely analyse empirical evidence[118] outside of their client's scope. They usually develop unrealistic cases[119] and/or scenarios, e.g. total pesticide bans without alternative, preventative plant protection. They then often consult anonymous experts to predict yield/ha losses[120] based on these scenarios and use these predicted yield losses in non-calibrated equilibrium models. The results are more or less always similar: high welfare losses, increasing consumer prices, income losses for farmers, land use changes in third countries etc. These results are usually presented on a meta-level, giving the studies a lack of transparency. The external costs of pesticides, or of the food production system as such, are never discussed by these consultants, and potential benefits of policy changes are neglected.

The ECPA report "Low yield II" published in 2020 is only one example of the remarkably low-quality of the research. The authors discussed neither the existence of preventative measures to avoid pesticides nor the large pesticide reduction achieved in Denmark. In addition, the uses of several pesticides discussed in the report had already been phased-out for several years, but the authors did not verify assumed yield losses using empirical data. For example, the use of neonicotinoids in Greek cotton had already been prohibited[121] in 2013 by Regulation 485/2013, and no yield decline was observed – quite the opposite – yields per ha were, on average, about 200 kg higher in the six years after the ban than in the six years before the ban.[122] Nonetheless, in 2020 the ECPA predicted a 40% yield decline for Greek cotton if neonicotinoids were banned.

Bremmer et al. (2021) address, without further explanation, another common fear among agricultural producers and the food industry: the fear that the Farm to Fork Strategy could lead to more mycotoxins.

A comprehensive comparison of thousands of organic and conventional samples showed that organic produce almost always contains lower levels of mycotoxins than conventional produce (Neumeister 2015). Preventive measures (especially robust varieties & crop rotation), the exclusion of plant growth regulators (PGRs) and a reduction of mineral nitrogen are more effective in lowering mycotoxin levels than chemical control in vulnerable growing systems. Fungicide use may even increase mycotoxin load (D'Mello

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[118] Bremmer et al. 2021, for example, completely ignore the fact that, despite large scale (4 mill. ha) obligatory set-aside in the past, the EU remained a net exporter of cereals (see Aretè 2008).

[119] In the report by Bremmer et al. 2021, for example, a one-hectare "hobby" farm was used as a representative farm to extrapolate and evaluate the economic effects of the Green Deal on citrus production in Europe.

[120] Yield/ha losses do not necessarily imply income losses. A lower yield can be more profitable when expenses for inputs are reduced.

[121] Only uses as seed coatings were allowed in Greek cotton (personal communication with Prof. Athanassiou), and regulation 485/2013 specifically prohibited such uses.

[122] See cotton yield data: https://www.icac.org/DataPortal/DataPortal?MenuId=23

et al. 1998; Drakopoulos et al. 2021). A field experiment by Bissonnette et al. (2018) also showed higher mycotoxin levels in wheat grain when the wheat was treated with fungicides than the control.

The perception of the efficacy of pesticides by the farming sector should be generally revised (see e.g. Skevas & Oude Lansink 2014; Salomé & Blancard 2022). A study involving almost 1,000 French farms (arable, conventional and commercial) showed no positive relationships between herbicide use and productivity for 71% of the farms (Lechenet et al. 2017). Weeds did not represent a constraint on crop production because herbicide use could be compensated by alternative preventive and curative measures, as also shown in a simulation by Colbach and Cordeau (2018).

Promoters of pesticide use often refer to lower yields in organic farming, where pesticide use is restricted. In organic farming, yields are mainly limited by nutrient availability, not necessarily by pests, weeds or diseases. Many phytosanitary problems play no role in organic agriculture because plants are less vulnerable (e.g. Möller et al. 2007) and the natural biological control functions better. Despite moderately lower yields, organic agriculture is often more profitable than conventional agriculture, and many organic farms are drivers of a vibrant rural life.

When comparing yield statistics, a geographic bias must also be considered. Many organic farms grow crops under less favourable soil/climatic conditions (Röös et al. 2018), because under these conditions only organic farming in combination with direct marketing is competitive and profitable. In addition, many organic farmers still grow highly bred varieties with small root systems created for fast mineral fertiliser uptake,[123] because suitable varieties for lower-input/organic farming are not sufficiently available (Niggli et al. 2016; Feledyn-Szewczyk et al. 2020). Modern "elite" wheat varieties have lost the ability to form symbioses with important mycorrhizal fungi, which are responsible for the uptake of nutrients, fostering healthy plant growth (Jaquet et al. 2022). In nutrient-limited organic systems, these varieties will not yield sufficiently.

However, profitability, as well as national (and rural) welfare (full cost accounting incl. external and hidden costs), should be the indicator for successful agriculture. Yield and yield increase are unsuitable parameters for measuring agricultural performance. Much of the permanent social and economic agricultural crisis in industrialised countries has been caused by decades of overproduction. To reduce costly overproduction, governments began restricting agricultural production as early as in the 1930s in the US and the 1950s in Canada, France and Germany (Traulsen 1967). Many proponents of modern agriculture fail to mention that almost all industrial countries subsidise farming because oversupply reduces producer prices

[123] These varieties often have small root systems and are not suited to uptake nutrients from deeper levels.

in such a way that farmers cannot make a living. Globally, the agricultural sector receives US$700 billion in subsidies each year (Scown et al. 2020). It has long been known that yield decline would benefit farm income (see Pearce & Tinch 1998).

The organic sector's attempt to produce the same amounts per hectare as conventional agriculture (e.g. Niggli et al. 2016) is more than questionable. The high yields achieved in conventional farming are associated with unacceptable social and environmental side effects and cannot be the benchmark for sustainable production. It is more important to secure a

HOW TO MEASURE PESTICIDE REDUCTION

Pesticide use is associated with a variety of risks (see Section 3.2), and because of this variety of risks, the reduction targets proposed by the European Commission will not induce the necessary change. For example, a 50% pesticide reduction by quantity as called for by the Farm to Fork Strategy would be possible by switching from high-dose pesticides[124] to low-dose pesticides (e.g. pesticide use in Denmark see Figure 20). This would certainly not reduce pesticide dependency or promote a low-input pest management system as called for in Article 14 of the Sustainable Use Directive (SUD). The most effective risk reduction is the reduction of exposure by not using pesticides (see Article 1 of Council Directive 89/391/EC[125]). Strategies for avoiding pesticide use are described in Section 5.1). Therefore, the reduction targets and indicators should be based on the reduction and measurement of treatments and/or treated hectares.

Calculating the number of hectares treated or doses sold for pesticides with specific hazards or by specific hazard group (see Neumeister 2020a; Möckel et al. 2021) is not complicated. Authorities have access to all relevant data, such as pesticide properties, permissible application rates, quantities sold per active ingredient and/or product and hectares planted per (main) crop. This data must be published. Pesticide's sales are emissions and sales data by active ingredient fall under the right of information (Bundesverwaltungsgericht 2019). Different indicators must be developed for different objectives: The annual size of **untreated areas** might be a suitable indicator for biodiversity risk reduction, while the number of applied/sold doses of pesticides with specific health risks (total and by crop) is a better indicator for human exposure. Sales or use of toxic dose units (sold doses by lethal doses or other end points) for different non-target organisms might be suitable for an assessment of eco-toxicity. Authorities must be required to publish all necessary data in a manner that civil society and the scientific community can develop and apply the appropriate and specific indicators.

For measuring policy effectiveness, indicators must be developed and used which exclude reduction effects not related to the Farm to Fork Strategy. The drought of 2018/2019, for example, reduced the need for fungicide and herbicide use, which was noticeable in the reduction in pesticide sales in several Member States.

The Farm to Fork Strategy calls for a reduction in the use of pesticides with a higher risk (baseline 2015-2017). **Most authorisations of high-risk and high-use[126] pesticides have expired in recent**

[124] The analysis of sales data in Germany, France and the Netherlands (unpublished) shows that high-use pesticides like sulphur, kaolin, phosphonates and fosetyl-al (all of lower toxicity) contribute more to the HRI than highly toxic, low-dose pesticides.

[125] EU Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC). OJ L 183, 29.6.1989, p.1.

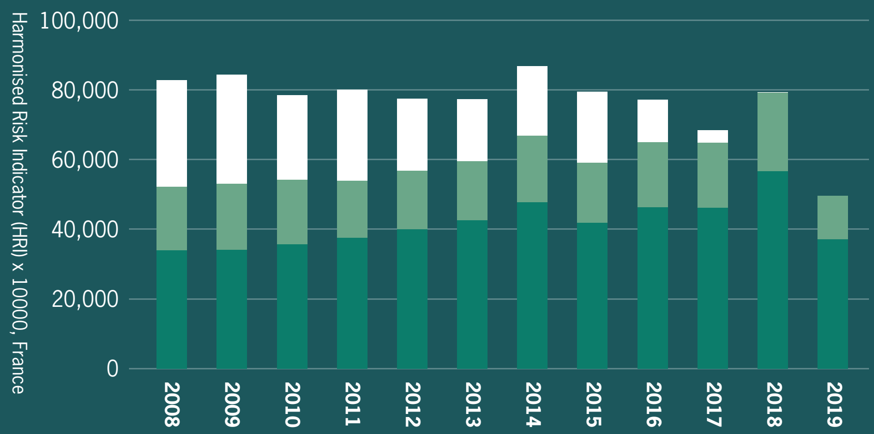
[126] E.g. mancozeb, chlorothalonil, epoxiconazole, isoproturon, prochloraz and dimethoate.

specific level of production to ensure food security without exclusively focussing on per area yields: ***"Yield, however, is largely irrelevant to determining whether people are fed (...)"*** (Poniso & Ehrlich 2016.)

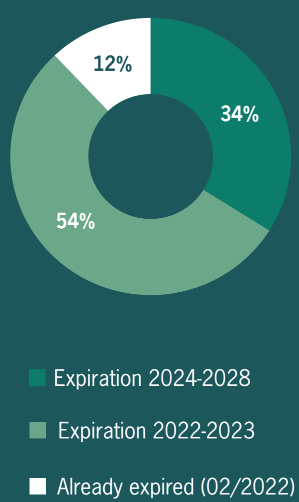
There must be a new international discussion as to how a coordinated production decline in industrial countries would reduce the external costs of food systems in such a way that it would create a win-win-win-win situation for all farmers, farm animals, the environment and consumers/taxpayers.

years, and all "Candidates of Substitution" (if not extended) will expire by 2028 (see EU Pesticide Database). The expected reduction will not be a result of the upcoming Farm to Fork Strategy. Figure 25 (bar chart) shows French pesticide use between 2008 and 2019 as evaluated using the Harmonised Risk Indicator (HRI). **All high-risk pesticides with a risk factor of 64 were reduced to nearly zero, simply because the EU authorisation expired.** The pie chart in Figure 25 shows the distribution of all pesticides with an HRI of 16 sold in France in 2017 by year of expiration. The authorisations for all pesticides used in 2017 with an HRI of 16 are set to expire soon. Some pesticides might be re-approved, but those losing authorisation need to be evaluated specifically.

Figure 25:
FRENCH PESTICIDE USE EVALUATED USING THE HARMONISED RISK INDICATOR 2008-2019



SALES OF PESTICIDES WITH HR 16 IN 2017



(diagrams created by Neumeister (2022) based on French sales data and Eurostat guidelines HRI [Eurostat 2021])

7 ACTION PLAN FOR A PESTICIDE-FREE EU

The previous sections of this report have described how agriculture became dependent on pesticides, what the current use situation in the EU is and what the major economic impacts of pesticide use are. They also explained the causes of the pesticide lock-in and why attempts to reduce pesticide dependency fail. Agronomic solutions and a set of instruments for escaping the lock-in have been discussed.

In this section, the agronomic measures and policy will be considered together on a crop/crop-group level, which will help set priorities and develop S.M.A.R.T. (specific, measurable, attainable, relevant and time bound – see Pe'er et al. 2020) targets.

The objective of reducing pesticide use by 50% as proposed by the EU Commission's Farm to Fork Strategy does not meet the S.M.A.R.T criteria, and there is a certain likelihood that it would not bring about a greater reduction in pesticide use than the current policy.

The experience in France (see section on pesticide use in France) and from 10 years of the "Sustainable Use Directive" and other environmental policies has shown that defining objectives and creating weak legislation without enforcement are not sufficient to achieve change.

Setting targets is not politics. Twenty years of unsuccessful environmental policy have shown that the top-down approach taken by the European Commission is not effective. It is not enough to create legislation and set meaningless targets when problems become urgent, while delegating all tasks and costs to resisting Member States.

An EU vision and action plan for a sustainable future agricultural system with clear objectives, milestones and actions must be developed. This is the only way out of the lock-in. An action plan of this kind should be the result of a consensus within European society. However, this would require a policy approach called "open government[127]".

The traditional stakeholder consultations and roundtables have blocked any progress, because the stakeholders who are responsible for the institutional lock-in are omnipresent and too powerful. Hüsker & Lepenies (2021) describe how dialogues around pesticides are often designed: ***"Powerful actors (state & industry) set the agenda for the process, inviting political opponents (NGOs) without giving these stakeholders real influence. When NGOs exit in protest, they are blamed for not participating"*** (ibid p. 190).

To achieve progress, the results of citizen dialogues (citizen assemblies/councils) representing consumers and land users but excluding the influence of specific stakeholders must be established. The conclusion of these dialogues must be mandatory for governments.

The next figure illustrates objectives (pesticide-free production by crop group) and milestones (policy instruments) for a possible action plan. Policies measures to be implemented on MS level have grey shapes, while red shapes show policies at EC level and violet shapes indicate instruments for both levels: MS/EC.

To reach each objective and milestone, a detailed list of actions including responsibilities must be defined.

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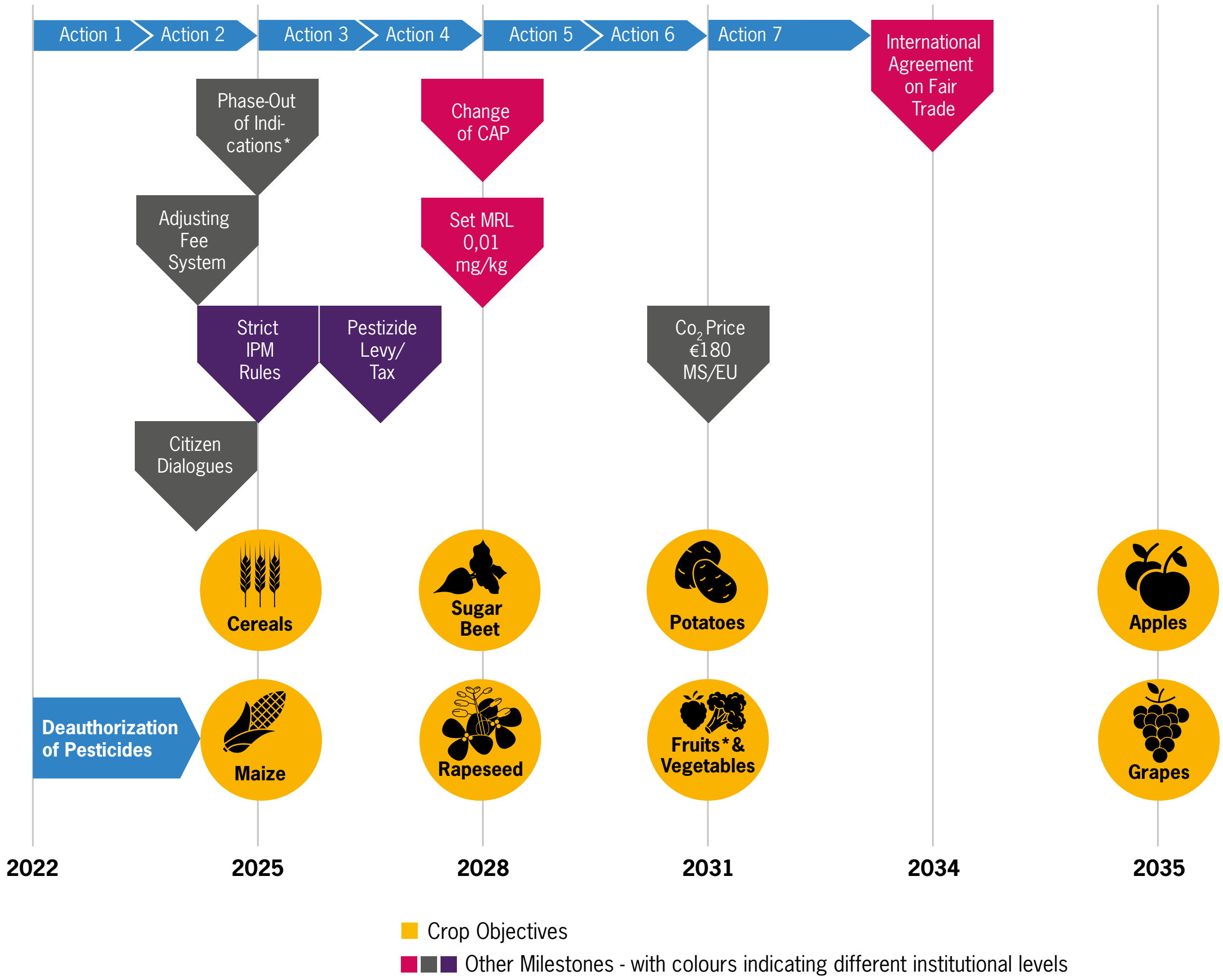
[127] According to the OECD (2016) "open government" is "a culture of governance based on innovative and sustainable public policies and practices inspired by the principles of transparency, accountability, and participation that fosters democracy and inclusive growth."

Figure 26:
MODEL OF A PESTICIDE-REDUCTION PLAN WITH CROP OBJECTIVES



7.1 "DESIGN BY CHOICE"

When proposing complex modifications to EU agriculture, it is essential that consideration be given to climate change and its mitigation, along with rural development and the ongoing loss of biodiversity. Climate change and its mitigation will fundamentally change agriculture and human nutrition. The former and current unsuccessful agricultural and environmental policy can only be described as "Design by Chaos". Attempts have been made to solve problems with a patchwork of "strategies" and/or weak legal instruments once they have already become urgent. The precautionary principle, as well as the socio-economic drivers of environmental degradation and rural exodus, has never been properly addressed.

In the next ten to fifteen years, the effects of climate change will become increasingly pronounced. Higher summer temperatures and water shortages in the Mediterranean region will adversely affect the current fruit and vegetable production. Shifts to other, more resilient growing systems such as agroforestry, permaculture and/or solar farming[128] are possible solutions. Part of the production may migrate to more favourable climates. Mitigation measures will affect agriculture: Prices for fossil fuels and nitrogen will (most likely) increase sharply. Consumer preferences are already changing, the number of vegetarians and vegans has been steadily increasing, and plant-based meat and dairy substitutes are becoming more mainstream[129](even in China, a main importer of meat from Europe [The Guardian 2021]). This trend must continue.

Climate-friendly nutrition, as well as pesticide-free farming, requires that the arable crop area used for pig and poultry feed be reduced substantially.

The assumption that current European meat consumption and export quantities can be maintained or even extrapolated to other countries contradicts all Sustainable Development Goals (SDGs). The type of feed used for cows and other grazing animals also needs to change. A shift from grazing on peat and peaty soils to grazing on arable, mineral soils is a prerequisite to achieving a carbon-neutral agricultural system. Future agriculture will require a much higher share of legume-grass crops in the crop rotation, which should be used for (mob-)grazing of grazing animals or as mulch, for example, in strip-cropping systems.

The area planted with pulses (peas, beans and lentils) for human consumption needs to increase.

A higher proportion of land must transition to agroecological infrastructures which may not directly produce commodities but contribute to the proper functioning of agroecosystems. This will certainly reduce agricultural output but result in many benefits, considering the current overproduction, with all of its negative externalities (Poux & Aubert 2018). The publication “Ten Years For Agroecology (TYFA) modelling exercise” (ibid.) provided a model for what agriculture and nutrition could look like.

Any policy aimed at pesticide-free agriculture[130] needs to evaluate and address each crop and crop group against the backdrop of all future challenges (see below). Most of the current crop area in Europe is cultivated with crops where pesticide-free production is achievable with a few agronomic adjustments (e.g. cereals and maize). Crops where a reduction in pesticide use presents a greater challenge (e.g. grapes, apples) are grown on a small area.
The next figure shows the distribution of the cultivated area (without permanent grassland [meadows][131]) by the main crop groups.

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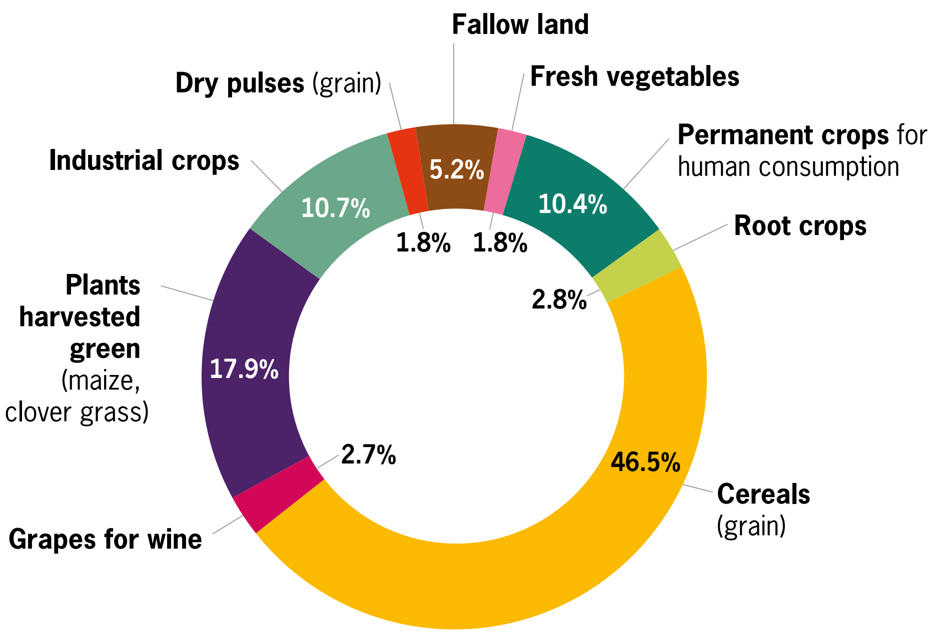
[128] Where specifically designed solar panels provide shadow and thus reduce heat stress.
[129] How meat and dairy alternatives are moving from niche to normal -> https://www.businessinsider.com/sc/why-meat-dairy-alternatives-are-so-popular-2020-12?r=DE&IR=T
[130] Relates to the area treated, not to risk or amounts used. Only “basic substances” would be permitted (Reg. 1107/2009/EU), sulphur, carbon dioxide [post-harvest use], pheromones and authorised microbials.

Crops which should be eaten most often for a healthy and climate-friendly diet (BZE 2022; Willett et al. 2019) (vegetables, fruits, nuts) momentarily occupy only about 12% of the EU crop area.

The largest area is occupied by cereals, of which more than half is used as animal feed. Plants harvested green (usually used for animal feed or biogas production) and industrial crops (oil seed crops, mainly for fuel) cover about 30% of the EU's agricultural land. Grapes for wine (2.7%) occupy more space than fresh vegetables.

Figure 27:
DISTRIBUTION OF AGRICULTURAL LAND USE (ARA & PECR) BY CROP GROUP



(diagram by Neumeister (2022) based on Eurostat 2022)

The following tables show the outlook (future), agronomic measures and political instruments for each crop/crop group shown in Figure 27.

[131] Code J000 in Eurostat.

FRESH VEGETABLES
incl. melons and strawberries

Current land share **6%**

Pesticide free in years **9**

FUTURE:
An environmentally friendly, healthy diet requires an **increase in vegetable consumption.**[132] Climate change will require a change in the geographic distribution of production and more regional production. The production areas need to increase especially in Northern Europe and near the consumers.

AGRONOMIC MEASURES:
Regenerative soil management, mixed cropping, crop rotation, robust varieties, use of nets against insects, enhancement of biological control, mechanical weed control, "vertical/urban" farming.

POLITICAL INSTRUMENTS:
All. Especially financial support for direct marketing and labour-intensive, non-chemical control methods. CAP reform towards income support for labour not for land possession. Cumulative maximum pesticide residue level at 0.01 mg/kg (Regulation 396/2005). Withdrawal of registrations (indications) for cosmetic purposes.

PERMANENT CROPS FOR HUMAN CONSUMPTION
(tree fruits, berries, nuts, olives etc.) (excluding grapes for wine and apples)

Current land share **6%**

Pesticide free in years **9**

FUTURE:
An environmentally friendly, healthy diet requires an increase in fruit and nut consumption. Climate change will require a change in the geographic distribution of production and more regional production. The production areas need to increase especially in Northern Europe and near the consumers. The use and maintenance of traditional orchards is required.

AGRONOMIC MEASURES:
robust varieties, mixed cropping, especially agroforestry, enhancement of biological control, mechanical weed control, grazing, use of pheromones.

POLITICAL INSTRUMENTS:
All. Especially financial support for direct marketing (community-based agriculture) and for more labour-intensive, non-chemical control methods. Cumulative maximum pesticide residue level at 0.01 mg/kg (Regulation 396/2005). Withdrawal of registrations (indications) for cosmetic purposes.

[132] https://www.chathamhouse.org/2021/02/food-system-impacts-biodiversity-loss/summary

ROOT CROPS POTATOES

Current land share **1,4%**

Pesticide free in years **9**

FUTURE:
Human consumption as staple food may further decrease because of the limited nutritional value. Use of industrial starch as renewable resource may increase. Climate change will require a change of the geographic distribution of production and more regional production. Part of potato production might be replaced by sweet potatoes (Ipomoea batatas) which are better adjusted to heat stress. Growers in Northern Europe have already started cultivating sweet potatoes.

AGRONOMIC MEASURES:
mix of robust varieties, rotation pause of ≥ 4 years, strip-cropping with higher plants as neighbouring crops, N-reduction and change to more targeted fertiliser applications (CULTAN, compost), wider spacing, early planting and early harvesting (before late blight occurs), enhancement of biological control, mulching or mechanical weed control, technological innovations (solar roofing).

SUGAR BEETS

Current land share **1,4%**

Pesticide free in years **7**

FUTURE:
A healthy diet requires a substantial decrease in sugar consumption.[133, 134] Sugar beets are currently grown on some of the most fertile soils in Europe. These areas should be dedicated to the production of healthy food: vegetables and pulses.

AGRONOMIC MEASURES:
mix of robust varieties, rotation pause of ≥ 4 years, enhancement of biological control, mechanical weed control, technological innovations (weeding robots).

POLITICAL INSTRUMENTS:
All. Support for and approval of a wide range of resistant varieties.

CEREALS

Current land share **46,5%**

Pesticide free in years **3**

FUTURE:
Much of the cereal grains produced in Europe is used as animal feed (see e.g. Sporchia et al. 2021, Greenpeace 2020) alcoholic beverages and bio-energy (together 70%). These uses must substantially decrease.

AGRONOMIC MEASURES:
Crop rotation incl. pauses of ≥ 3 years between mono-cropped cereals transferring soil-borne pathogens (barley, rye, wheat, triticale). No wheat cultivation directly after maize. Delayed sowing (winter cereals), early sowing (summer cereals). Use of a mix of robust varieties. Under sowing green manure. N-reduction. No use of plant growth regulators. Wider spacing. Integration of set-aside periods with clover-grass mixtures, which could be used for grazing, mulching, composting. Flower strips in regular distances to enhance biological insect control, strip cropping, mechanical weed control if needed.

POLITICAL INSTRUMENTS:
All and withdrawal of all authorisations of plant growth regulators, insecticides and fungicides in cereals within 3 years.[135] Legal restriction of disease-prone rotations (e.g. cereals after maize).

[133] https://www.who.int/elena/titles/guidance_summaries/sugars_intake/en/
[134] Planetary Health Diet - BZfE
[135] In Swiss IP (Integrated Production), the use of Plant Growth Regulators, fungicides, insecticides and specific herbicides has long been forbidden.

PLANTS HARVESTED GREEN MAIZE

Current land share **6%**

Pesticide free in years **3**

FUTURE:
Maize harvested green (for silage) is used as animal feed or for "biogas" production.
With the needed reduction in animal numbers, the crop area needed for animal feed will be reduced. For biogas production, alternative plants or plant mixtures for maize must be identified and rotated with maize.

AGRONOMIC MEASURES:

Crop rotation, under-sown cover crops, strip cropping, mechanical weed control.

POLITICAL INSTRUMENTS:
All. Integrate mandatory under-sown cover crops in IPM and in CAP cross-compliance. Withdrawal of herbicide authorisation within 3 years. Research and promotion of alternative biogas plants (e.g. mixtures of sunflower, hemp, Silphium perfoliatum, Solanum tuberosum, sun hemp, miscanthus).

INDUSTRIAL CROPS

Pesticide free in years **6**

FUTURE:
Rapeseed is mostly used for biofuel. The future of biofuel is uncertain. Private vehicles with conventional engines will play a smaller role in the future.

AGRONOMIC MEASURES:
Crop rotation incl. pauses of ≥ 3 years between rapeseed and also between sugar beet and rapeseed. N-reduction and more targeted fertiliser applications (e.g. CULTAN[136]). Strip cropping, flower strips, control of volunteer rapeseed in following crops and neighbouring fields. Large spacing between rapeseed fields. Delayed sowing, intensive stubble cultivation. Elimination of crucifer weeds as potential host in crop rotation.

POLITICAL INSTRUMENTS:

All. Development of pheromones for non-lethal control of major pests.

WINE GRAPES

Current land share **2,7%**

Pesticide free in years **14**

FUTURE:
While wine grapes are adapted to warm and dry conditions, climate change will most likely negatively affect the current production area. Part of the production might shift towards the north.

AGRONOMIC MEASURES:
Use of pheromones and increase in biodiversity between the rows. Complete conversion to nitrogen fertilisation by leguminous (nitrogen-fixing) herbs wherever possible. Change to fungi-resistant cultivars. Mixture of cultivars. Aeration by manual de-leafing.

POLITICAL INSTRUMENTS:
All. Support for development and promotion of fungi-resistant cultivars.

[136] CULTAN = Controlled Uptake Long-Term Ammonium Nutrition.

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