Towards Green Chemistry - a case study of PFAS in agricultural uses

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Wageningen, September 2025

Stichting Huize Aarde

The stichting Huize Aarde (Home Earth Foundation) works on sustainable development through innovation, knowledge development and knowledge sharing.

WU Environmental Policy Group

The Environmental Policy chair group (ENP) aims to advance scientific understanding of the social and political dimensions of sustainable environmental transformations.

Wageningen Food & Biobased Research

Wageningen Food & Biobased Research (WFBR) develops insights and technologies that support companies, governments and other research institutes in creating innovative solutions for a healthier, more sustainable and prosperous world.

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Wageningen Science Shop collaborates with non-profit groups in society by organizing research projects that find answers to their questions, free of charge. Our goal is to empower groups in society by engaging them in scientific research and to create direct, positive change together.

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Preface

Current economic prosperity is heavily dependent on the use of industrial chemicals, whose production and large-scale application continue to rise significantly each year. A group of substances that has recently attracted much attention are the persistent per- and polyfluoroalkyl substances (PFAS). While these substances have contributed to economic welfare, they have also caused unexpected and often poorly understood effects on the environment and human health. The enormous costs of remediation are largely borne by society and shifted to future generations. According to ChemSec (2023), the economic damage caused by PFAS is estimated to be a thousand times greater than their global market turnover.

Monitoring of harmful effects typically begins only after such substances have already been placed on the market in large quantities and across multiple applications. Historical examples include asbestos, lead, DDT, PCBs nicotine, BPA, phthalates, ethinylestradiol, neonicotinoids and synthetic polymers. In the development and authorisation of these products, industrial applicability and market potential were often prioritised, while potential side effects on food safety, public health, and ecosystems were systematically underemphasised. Structural causes include insufficient interdisciplinary knowledge exchange, a market model focused on short-term returns, the influence of vested interests, and reactive policymaking. These lessons have been extensively documented in the reports Late Lessons from Early Warnings (EEA, 2001; 2013).

The ongoing research project "Learning from PFAS" by the Home Earth Foundation (stichting Huize Aarde) aims to raise awareness of the urgency and necessity of a transition towards an ethically responsible and green chemistry. Such a transition will require not only technological innovations but also systemic changes in production, consumption, and recycling practices, with major implications at the socio-economic as well as behavioural levels.

Student projects, conducted under academic supervision, play an important role in this awareness process. Their work helps motivate society to take decisive steps towards more ecological and ethically sound product development. The Home Earth Foundation will use the results to inform further research and communication. We would like to express our gratitude to the students, their supervisors, and the staff of the participating science shops for their valuable contributions.

Commisioners Alfons Uijtewaal en Margarita Amador,
Home Earth Foundation (stichting Huize Aarde)

Executive summary

Per- and polyfluoroalkyl substances (**PFAS**) have become ubiquitous in soil, water, air, animals and humans. Human exposure to PFAS through food and drinking water in most EU countries now exceeds the safe limit set by the European Food Safety Authority. PFAS emissions stem from many applications across many sectors and across all stages of a product's life cycle.

In this report we explore PFAS uses and alternatives in agricultural applications with an objective to better understand the potential of two novel chemicals governance frameworks - the *Safe and Sustainable by Design* (**SSbD**) framework and the *Essential Use concept* (**EUC**) - to facilitate a transition away from the use of PFAS in agricultural applications and as potential pathway to greener chemistry.

The project consisted of a year-long, iterative, interdisciplinary research process involving faculty researchers of WUR, three MSc-level student consultancy teams, and a diverse advisory board. The research was based on expert interviews, scientific literature, and publicly available policy and data. We contrasted existing chemicals regulations with our interpretation of SSbD and EUC in the context of agricultural uses. Reflecting on the process we observed that all three student groups were at times overwhelmed by the complexity of the PFAS issue. The students were very motivated to 'do something' and be part of finding a solution. But with PFAS there are no easy solutions, which made the work all the more complex and at times emotionally challenging.

From the mapping of PFAS pathways in agricultural applications we highlight the following findings:

- PFAS are sometimes used as active ingredients of a Plant Protection Product (**PPP**), but also feature as co-formulants. One type of safener (fluxofenim) is also a PFAS.
- PFAS containing PPPs typically break down into short-chain PFAS like TFA, which are very mobile.
- There is insufficient data to determine the relative contribution of the countless PFAS pathways into farm and food.
- Farms located near a PFAS emission hotspot have higher levels of atmospheric PFAS deposition and ground water, which can be transferred to produce. However, nowhere in The Netherlands are PFAS-free soils or water.
- Due to the diffuse nature of PFAS emissions, reducing PFAS concentrations in food will require addressing all the sources of PFAS across all sectors, rather than just one or two main sources.

From considering the farmers' perspective on PFAS we highlight the following findings:

- Advisors play a key role in which products are used by farmers as well as quantity, timing and combination with other products
- In The Netherlands, some agricultural advisors are associated with specific PPP producers while others are independent. They tend to 'err on the side of caution' in advising on PPP quantities.
- Strawberry farmers typically use various PFAS containing PPPs. Quite a few alternatives exist, including organic PPPs.
- The strawberry farmers that were interviewed have low awareness of specific chemical ingredients in their PPPs. They prioritise 'what works', and due to costs and labour involved they minimise product applications.
- The strawberry farmers that were interviewed have high trust in the CTGB (authorisation agency for PPPS) and advisors who recommend products, provided it is legal and it works.

From exploring the potential of the EUC we highlight the following findings:

- The EUC aims to provide principles for EU policy to help phase out the so-called "most harmful substances" for "non-essential uses" and minimized and substituted for other uses.
- While EUC is not explicitly part of current PPP legislation, a similar logic is already built in where most harmful substances are banned, while exemptions for specific situations are regularly made.
- Potatoes are an example of a crop requiring very frequent application of various PPPs, leading to resistant pests and pathogens. Products containing PFAS therefore play an important role in these conventional intensive potato farming systems.

- While PPPs, including PFAS containing ones, may be seen as essential within a conventional farming system, alternative farming systems exist. This raises questions about the level at which 'essentiality' should be defined and how assessments can be harmonized.
- PFAS-containing fluopyram would not currently classify as most harmful and would not have to be substituted. Lambda cyhalotrin contains a most harmful substance and would need substitution. Alternatives are less effective.

From exploring the potential of the SSbD framework we highlight the following findings:
- Product development in accordance with SSbD principles ensures that design, functionality, safety and sustainability are evaluated in an integrated process, starting from the very beginning of the development process. This voluntary framework ensures safety and sustainability of the final product, but also of raw materials, intermediates, and potential emissions, are taken into account during product development.
- SSbD places the responsibility for understanding the potential emissions throughout the value chain at the (chemical) product developer. In current legislation, approval procedures for PPPs also require the product developer to provide information about potential emissions. It is not yet clear to what extent SSbD would change this.
- SSbD is significantly more strict than current PPP legislation concerning product safety. For example, respiratory sensitation Cat I or specific organ toxicity upon repeated exposure (STOT-RE Cat I) are hazards based on which an SSbD process would not allow the use of the ingredient(s) causing the hazard.
- SSbD is also more strict than current PPP legislation concerning environmental aspects. Ingredients which fulfil PMT or vPvM criteria cannot be used under SSbD (not taken up as criterion in PPP regulation yet). Moreover, alternatives for materials that are hazardous for the ozone layer or for materials that hinder re-use or recycling must be used if available.
- Current legislation on PPPs considers emergency use as a separate type of use. If SSbD is to be used for regulating PPP approval, emergency use should be considered as well.

We conclude that a transformation to green chemistry requires multiple transformations in political, economic, social, technological, environmental, and legal aspects of chemicals governance. Based on the case of PFAS in agricultural applications, we identify the following drivers for green chemistry (Figure 1).

We recommend that the commissioner Stichting Huize Aarde contribute to, and help facilitate, the fundamental societal debates on essential use (what is 'essential') and SSbD (defining social and economic sustainability), leveraging their expertise and knowledge in pharmacy, philosophy and environmental chemistry. We recommend that further research would include scenario analysis to explore pathways towards green chemistry, for which some of the drivers in this report can be used as starting point.

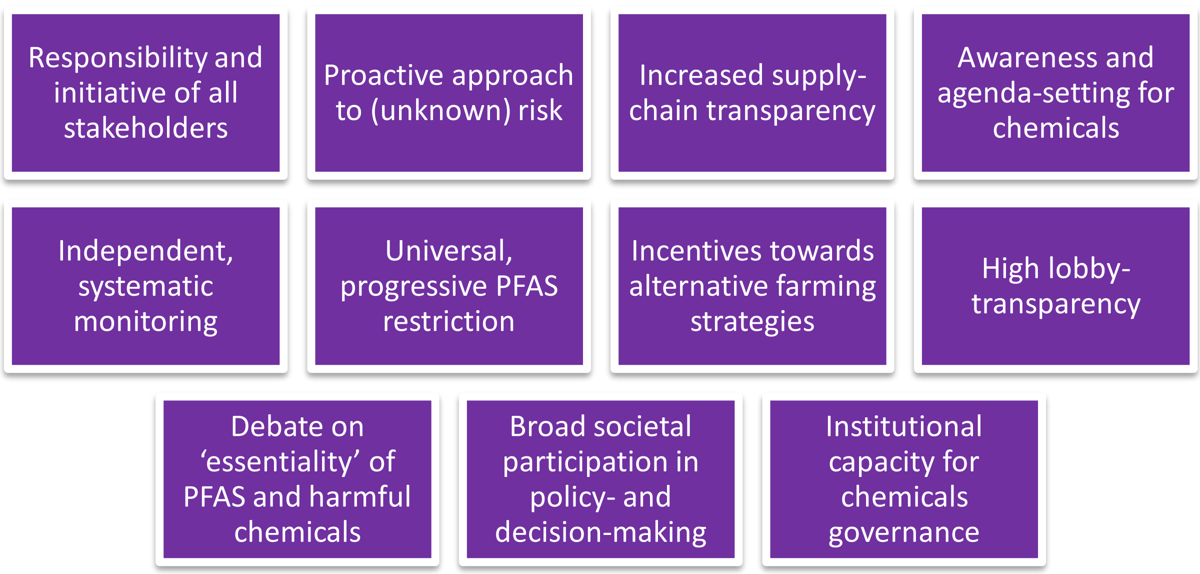

Figure 1 Drivers for a transformation to green chemistry on the basis of implementing SSbD and EUC.

Nederlandse samenvatting

Per- en polyfluoralkylstoffen (PFAS) zijn alomtegenwoordig in bodem, water, lucht, dieren en mensen. De blootstelling van mensen aan PFAS via voedsel en drinkwater overschrijdt in de meeste EU-landen nu de veilige grenswaarde die is vastgesteld door de Europese Autoriteit voor Voedselveiligheid (EFSA).

PFAS-emissies zijn afkomstig van vele toepassingen in vele sectoren en in alle fasen van de levenscyclus van een product. In dit rapport onderzoeken we het gebruik van PFAS en alternatieven in landbouwtoepassingen met als doel een beter inzicht te krijgen in de mogelijkheden van twee nieuwe governancekaders voor chemicaliën – het *Safe and Sustainable by Design* (**SSbD**)-kader en het *Essential Use-concept* (**EUC**) – om het gebruik van PFAS in landbouwtoepassingen te kunnen afbouwen en als mogelijke route naar groenere chemie.

Het project bestond uit een iteratief, interdisciplinair onderzoeksproces van een jaar, waarbij faculteitsonderzoekers van WUR, drie adviesteams van masterstudenten en een diverse adviesraad betrokken waren. Het onderzoek was gebaseerd op interviews met experts, wetenschappelijke literatuur en openbare beleidsregels en data. We vergeleken de bestaande regelgeving voor chemicaliën met onze interpretatie van SSbD en EUC in de context van landbouwkundig gebruik. Terugkijkend op het proces merkten we dat alle drie de studentengroepen soms overweldigd werden door de complexiteit van het PFAS-probleem. De studenten waren zeer gemotiveerd om 'iets te doen' en mee te werken aan het vinden van een oplossing. Maar met PFAS zijn er geen gemakkelijke oplossingen, wat het werk des te complexer en soms emotioneel uitdagend maakte.

Uit onze inventarisatie van PFAS-routes in landbouwtoepassingen komen de volgende bevindingen naar voren:

- PFAS worden soms gebruikt als actieve ingrediënten in een gewasbeschermingsmiddel (**GBM**), maar komen ook voor als coformulant. Minstens één type ‘safener’ (fluxofenim) is ook een PFAS, wellicht bestaan er nog meer.
- PFAS-bevattende GBM's worden doorgaans afgebroken tot PFAS met een korte keten, zoals trifluorazijnzuur. Deze moleculen zijn typisch zeer mobiel.
- Er zijn nog onvoldoende gegevens beschikbaar om te kunnen beoordelen wat de relatieve bijdrage aan PFAS-emissies is van middelen die in de landbouw, veeteelt en visserij worden gebruikt.
- Boerderijen in de buurt van een hotspot voor PFAS-emissies hebben vaak te maken met een hogere PFAS-concentratie in de atmosfeer en in het grondwater. Dit kan (deels) worden overgebracht op de geproduceerde waren. Nergens in Nederland zijn er echter PFAS-vrije bodems of water.
- Door de diffuse aard van PFAS-emissies zijn er talloze routes naar de boerderij en de voeding. Om de PFAS-concentraties in voedsel te verminderen, moeten daarom alle bronnen van PFAS in alle sectoren worden aangepakt, in plaats van slechts één of twee hoofdbronnen.

Uitgaande van het perspectief van boeren op PFAS, komen de volgende bevindingen naar voren:

- Landbouwvoorlichters en adviseurs spelen een belangrijke rol bij het gebruik van producten door boeren, evenals de hoeveelheid, timing en combinatie met andere producten.
- In Nederland zijn sommige landbouwvoorlichters verbonden aan specifieke producenten van GBM, terwijl andere onafhankelijk zijn. Ze nemen vaak het zekere voor het onzekere bij het adviseren over de hoeveelheid GBM, wat betekent dat hun advies voornamelijk is gericht op het maximaliseren van de oogst.
- Aardbeientelers gebruiken doorgaans verschillende PFAS-bevattende GBM. Er bestaan behoorlijk wat alternatieven, waaronder biologische GBM.
- De geïnterviewde aardbeientelers zijn zich weinig bewust van de specifieke chemische ingrediënten in hun GBM. Ze geven prioriteit aan 'wat werkt' en vanwege de kosten en arbeid die ermee gepaard gaan, minimaliseren ze het gebruik van GBM.
- De geïnterviewde aardbeientelers hebben veel vertrouwen in het Ctgb, dat GBM autoriseert, en in adviseurs die producten aanbevelen, mits deze legaal zijn en werken.

Uit het verkennen van het potentieel van het EUC komen de volgende bevindingen naar voren:

- Het EUC beoogt principes te bieden voor EU-beleid om de zogenaamde "meest schadelijke stoffen" geleidelijk af te schaffen voor "niet-essentiële toepassingen" en deze te minimaliseren en te vervangen voor andere toepassingen.
- Hoewel het EUC niet expliciet deel uitmaakt van de huidige wetgeving voor GBM, is er al een vergelijkbare logica ingebouwd waarbij de meest schadelijke stoffen worden verboden, terwijl er regelmatig vrijstellingen voor specifieke situaties worden verleend.
- Aardappelen zijn een voorbeeld van een gewas dat zeer frequent gebruik van verschillende GBM vereist, wat ook leidt tot snelle resistentie ontwikkeling. Daarom vervullen alle beschikbare producten, ook de PFAS-bevattende producten, een belangrijke rol in deze conventionele intensieve aardappelteeltsystemen.
- GBM, waaronder PFAS-bevattende, kunnen soms als essentieel worden beschouwd binnen een conventioneel landbouwsysteem. Er bestaan echter ook alternatieve landbouwsystemen. Dit roept vragen op over het niveau waarop 'essentialiteit' moet worden gedefinieerd en hoe beoordelingen kunnen worden geharmoniseerd.
- Fluopyram is een PFAS maar zou momenteel niet als *most harmful* worden geclassificeerd. Het zou daarom niet hoeven te worden vervangen volgens het EUC. Lambda-cyhalotrine is een zeer schadelijke stof en zou moeten worden vervangen. Alternatieven zijn minder effectief.

Uit het verkennen van het potentieel van het SSbD-raamwerk komen de volgende bevindingen naar voren:

- Productontwikkeling volgens de SSbD-principes zorgt ervoor dat ontwerp, functionaliteit, veiligheid en duurzaamheid worden geëvalueerd in een geïntegreerd proces, vanaf het allereerste begin van het ontwikkelingsproces. Dit zorgt ervoor dat de veiligheid en duurzaamheid van het eindproduct, maar ook van grondstoffen, tussenproducten en potentiële emissies, tijdens de productontwikkeling in aanmerking worden genomen.
- SSbD legt de verantwoordelijkheid voor het in kaart brengen van de potentiële emissies in de gehele waardeketen bij de (chemische) productontwikkelaar. In de huidige wetgeving vereisen goedkeuringsprocedures voor GBM ook dat de productontwikkelaar informatie verstrekt over potentiële emissies. Het is nog niet duidelijk in hoeverre SSbD hierin verandering zou brengen.
- SSbD is aanzienlijk strenger dan de huidige wetgeving inzake GBM wat betreft productveiligheid. Zo zijn ademhalingssensitiviteit categorie I of specifieke orgaantoxiciteit bij herhaalde blootstelling (STOT-RE categorie I) gevaren op basis waarvan een SSbD-proces het gebruik van de ingrediënt(en) die het gevaar veroorzaken, niet zou toestaan.
- SSbD is ook strenger dan de huidige wetgeving inzake GBM wat betreft milieuaspecten. Ingrediënten die voldoen aan de PMT- of vPvM-criteria kunnen niet worden gebruikt onder SSbD (nog niet opgenomen als criterium in de PPPR). Bovendien moeten, indien mogelijk, alternatieven worden gebruikt voor materialen die schadelijk zijn voor de ozonlaag of voor materialen die hergebruik of recycling belemmeren.
- De huidige GBM wetgeving beschouwt noodtoestemming als een apart type gebruik. Als SSbD wordt gebruikt voor het reguleren van de goedkeuring van GBM, moeten ook principes voor noodtoestemming worden heroverwogen.

We concluderen dat een transformatie naar groene chemie meerdere transformaties vereist op politiek, economisch, sociaal, technologisch, ecologisch en juridisch vlak. Op basis van de casus van PFAS in landbouwtoepassingen en de verkenning van de SSbD en EUC benaderingen, identificeren we de drijfveren voor groene chemie zoals afgebeeld in Figure 2.

Wij adviseren de opdrachtgever Stichting Huize Aarde om bij te dragen aan de fundamentele maatschappelijke debatten over essentieel gebruik (wat is 'essentieel') en SSbD (de definitie van sociale en economische duurzaamheid), en deze te helpen faciliteren door gebruik te maken van hun expertise en netwerk op het gebied van farmacie, filosofie en milieuchemie. Wij adviseren om in nader onderzoek scenarios te ontwikkelen om de mogelijkheden voor groene chemie verder te verkennen in gesprekken met de diverse belanghebbenden. De drijfveren die hierhieronder zijn beschreven kunnen hiervoor als uitgangspunt dienen.

Figure 2 Drijfveren voor de transformative naar groene chemie, gebaseerd op implementatie van de SSbD en EUC

1 Introduction

The Home Earth Foundation (stichting Huize Aarde) works on sustainable development through innovation, knowledge development and knowledge sharing. They approached the Wageningen Science Shop to investigate what lessons can be learned from the ongoing PFAS pollution scandal. In 2021 and 2023, RIVM found that PFAS are now ubiquitous in the living environment: in soil, water, air, animals and humans. Exposure to PFAS through food and drinking water in the Netherlands now exceeds the safe limit set by the European Food Safety Authority (EFSA) in 2022. Long-term exposure to PFAS has been linked to endocrine disruption, developmental problems in children, immune problems, liver and kidney damage, elevated cholesterol levels and cancer (Fenton et al., 2021a; Schepens et al., 2023). The Home Earth Foundation wonders what challenges and opportunities exist to develop a sustainable green chemistry strategy for the future, to make sure we learn from the mistakes of the past.

The European Commission introduced the Green Deal in 2019, which outlined the Commission's commitment to safeguarding citizens and the environment from harmful chemicals through the management of hazardous chemicals like PFAS to ensure a toxic-free environment. Subsequently, in 2020, the Commission unveiled the Chemical Strategy for Sustainability (**CSS**), acknowledging the special attention needed for PFAS due to mounting evidence of water and soil contamination and their impact on human health (COM (2020) 667). The Strategy defines PFAS as substances of concern with the potential to be harmful to human health and the environment. They are also seen as hampering the recycling of PFAS containing products for safe and high-quality secondary raw materials in a circular economy. The headline intervention flowing from the CSS is the PFAS restriction proposal under REACH regulation (ECHA, 2023).

In this report we focus on PFAS in agricultural applications, in particular pesticides. The use of PFAS-containing pesticides (plant protection products and biocides) leads to direct emissions of persistent chemicals into the environment, and those chemicals cannot be removed effectively or efficiently. Moreover, the market share of PFAS-containing pesticides increases year-over-year in the EU. Currently, active substances in pesticides are governed by Regulation (EC) No 1107/2009 (PPPR) and Regulation (EU) No 528/2012 (BPR) and are exempted from the PFAS restriction proposal under REACH. As a result, they receive less scrutiny in the recent PFAS discussions at EU level. Finally, because pesticides are an intrinsic component of conventional farming systems for food production, this case study confronts us with our apparent reliance harmful chemicals for essential societal functions.

Two new frameworks for understanding and addressing chemicals have emerged in the EU policy landscape:

- The **Safe and Sustainable by Design** (SSbD) framework has been created to help transform from a traditional way of thinking (in which performance and potential margin are much more important than any other factor) to a design process that fits better within a circular economy (European Commission, 2022). This can be applied to materials that are used in all sectors, including agriculture. In essence, it is an iterative process in which product design and assessment of safety, environmental sustainability and socio-economic sustainability are done simultaneously for the material under review and all materials that are used or created through the lifecycle.
- The **Essential Use Concept** (EUC) is an approach that stems from the Montréal Protocol. It has been revitalized by the EU mentioning it as an integral part of the CSS (European Commission, 2024). The essential use concept (EUC) should guide what chemicals can or should be used for which applications in upcoming EU Regulations. In short, the so-called "most harmful substances"[1] should be fased out for non-essential uses and minimized and substituted for as far as possible in other uses.

In this project we aim to assess the potential of the SSbD and EUC frameworks in the transition away from PFAS uses in the agricultural sector and for green chemistry that takes environmental and health impacts of chemical mixtures more seriously.

[1] Criteria for most harmful substances are very similar to those of 'substances of very high concern' (SVHC), as defined in REACH article 57. The main difference is the inclusion of mobility as a criterion in MHS but not in SVHC.

1.1 Objective

The objective of the study was to better understand the potential of two novel chemicals governance frameworks - Safe and Sustainable by Design framework and the Essential Use concept - to facilitate a transition away from the use of PFAS in agricultural applications. The study aimed to identify preconditions for how national and EU stakeholders can ensure that human health and the environment become more important factors in deciding if a chemical is allowed to be used.

1.2 Research questions

In consultation with the Home Earth Foundation, the following main research question was formulated: What are the preconditions for a transition away from the use of PFAS in agricultural applications when applying the Safe and Sustainable by Design framework and the Essential Use concept?

The subquestions were formulated as follows:

1. What are the agricultural sub-sectors that make use of PFAS chemicals in significant quantities?
2. How do sector/stakeholder's take position in the PFAS restriction debates?
3. To what extent can PFAS residues found on fruits and vegetables be traced back to the various PFAS applications in their production?
4. What are the strengths and weaknesses of PFAS alternatives, seen from the perspective of society, farmers and the environment?
5. What are the limitations and strengths of applying the EUC to pesticides?
6. What are the limitations and strengths of applying the SSbD framework to pesticides?

1.3 Reading guide

This report combines the results obtained by three groups of students into a single product. In Chapter 2, we explain how student groups were formed, how they gathered the data that is behind this report, and how the advisory board was set up. Chapter 3 provides some background information about PFAS usage in agricultural applications. This information forms the basis for the students' research projects. In Chapter 4 we highlight the main outcome of the project, consisting of preconditions required for and drivers towards safer use of chemicals. Chapter 5 provides some more details from the individual student assignments and Chapter 6 draws conclusions and recommendations based on these.

2 Research process

2.1 Project approach

In this project we explored the potential of two novel chemicals governance frameworks - the *Safe and Sustainable by Design* (SSbD) framework and the *Essential Use* concept (EUC) – in the context of reducing PFAS uses in the agricultural sector. We have chosen this approach for several reasons:

- Both frameworks are designed with the aim to support a transition to safer and more sustainable use of chemicals;
- Both frameworks are not yet set in stone or anchored into standards. Therefore, input from third parties on the potential effectiveness could still affect their final shape;
- Assessing the suitability of using one of these frameworks for a purpose like approval of plant protection products is a challenging yet demarcated task that can be executed by an interdisciplinary student group.

2.2 Working with student groups

An important principle of the science shop is to involve students in addressing the commissioners questions. We did this by writing proposals for WUR MSc Academic Consultancy Training (ACT). ACT is a compulsory course at WUR where students from across disciplines and programmes work in a group of 6-8 students on real-world, transdisciplinary complex problem cases from external partners. They are closely supervised by an academic advisor and a coach. Students sign in for a topic and the first call resulted in two ACT teams, and a second (different) call resulted in a third ACT team.

In the calls for students (see Annex 1), we asked for mapping of PFAS uses and alternatives, investigating the perspectives of farmers and other stakeholders, and policy analysis (including an exploration of the Essential Use principles). We kept the topics relatively broad to encourage the ACT teams to further narrow down the scope for their specific project and alignment with their expertise and interest. Within the boundaries of the research questions set in the call, this could be a specific EU country or level of public administration, a specific agricultural application (such as pesticides), or a specific agricultural product (such as strawberries).

2.3 Data collection

All student groups relied on publicly available datasets, product fact sheets, academic literature, grey literature and policy documents. In addition, all groups did interviews with a varying range of respondents (see Table 1).

Table 1 Overview of interviews for data collection in the student projects

ACT group	Number and type of interviews
PFAS pathways in agricultural applications	8 expert interviews, primarily academic
PFAS and the farmers' perspective	Semi-structured interviews with 10 strawberry farmers
PFAS and policy developments	Semi-structured interviews with 8 experts representing diverse relevant stakeholders

While societal interest in PFAS was widespread at the start of the project, little research was available on PFAS in PPPs. This made it challenging for students to find even basic information on chemical ingredients in

PPP products. Only after the project was finished did more information become available, for example a recent CLM flyer about which PFAS are approved as ingredients in PPPs in NL (Leendertse et al., 2025). Despite the challenges of a lack of data, the students succeeded in developing well-founded conclusions and recommendations.

2.4 Advisory board

Finally, the project coordination benefited from an active and involved advisory board. We met several times during the course of the project, both online and in person, to get feedback on ideas, to discuss findings from student work and to plan a closing event where the outcomes of the project are shared. We are thankful for the valuable contributions of

- Astrid Hendriksen (Director Honours programme, WUR)
- Sandra Reynaers (Dutch Water Authorities, UvW)
- Fons Röttgering (Dutch Water Authorities, UvW)
- Esmée de Graaf (Crop Health group, WUR)
- Jacco van Haveren (Program manager Safe and circular biobased products, WUR)
- Henk Jans (Environmental doctor)
- Jelmer Buijs (Independent researcher, owner of Buijs agroservices)
- Alanya den Boer (Coordinator Wageningen Science Shop & Citizen Science)
- Lèneke Pfeiffer (Coordinator Wageningen Science Shop)

3 Background: PFAS in agricultural applications

PFAS are a group of chemicals composed of a fully (per) or partly (poly) fluorinated carbon chain connected to different functional groups (Organisation for Economic Co-operation and Development (OECD), 2021). This class comprises a diverse range of compounds that share the common feature of the 'per'-fluorinated carbon chain(Cousins et al., 2020) The strong bond between the carbon and fluorine gives PFAS properties which makes them very suitable for various industrial applications. Their properties include among others an exceptionally high resistance to high temperatures, oil and water repellence, and ability to act as surfactant, which make them useful for a broad range of applications (Glüge et al., 2020; SWD 249, 2020).

The chemical structure of PFAS causes their persistence in the environment, which is why PFAS are often labelled as 'Forever Chemicals'. Their persistence results in long-term exposure associated risks such as bioaccumulation potential, mobility, long-rate transport potential, and more (Cousins et al., 2020; Glüge et al., 2020; SWD 249, 2020)). PFAS have gathered significant global concern regarding their impact (Brennan et al., 2021; Cousins et al., 2022). Some of the larger molecules will partially degrade and thereby form small PFAS which are persistent in the environment (SWD 249, 2020). Although a vast majority of PFAS have not undergone a toxicological characterisation (Sonne et al., 2023; Spyrakis & Dragani, 2023), most of the well-studied PFAS are considered toxic or contribute to baseline toxicity (Fenton et al., 2021b; Rudin et al., 2023; SWD 249, 2020).

PFAS are used in products for agriculture; some of the product categories in which PFAS have been found are:

- Fertilizer and seed coatings
- Veterinary medicines (active ingredients, but also reaction agents or solvents)
- Chemical analysis (trifluoroacetic acid (TFA) as solvent in chromatography)
- Plant Protection Products (PPPs)
- Protective clothing (for application of PPPs)
- Parts of machines and lubricants

The EU PFAS restriction proposal considers PFAS as a group of chemical substances which have to be phased out all at the same time. This should prevent the substitution of a PFAS chemical by a similar one that is not yet regulated. The restriction proposal takes into account that, for some applications, no alternatives exist yet. PFAS usage in such applications will be derogated for eight years, after which a revaluation is performed to check for new alternatives.

However, there are several sectors and product categories that are exempted from REACH regulations. This is the case for active substances in Plant Protection Products (PPP), Biocidal Products (BP) and Medicinal Products (MP), (BAuA et al., 2025).

4 Drivers for green chemistry

In this chapter we present the main outcome of this project. It consists of an overview of the drivers towards a transformation to green chemistry. This is based on two frameworks that were introduced to operationalise several goals of the European Union's Chemicals strategy for Sustainability: the Safe and Sustainable by Design framework and the Essential Use concept. We draw on the findings, discussion and recommendations from the student teams as reported in more detail in chapter 5.
Our analysis highlights that the effectiveness of these emerging governance frameworks is contingent on a range of Political, Economic, Social, Technological, Environmental, and Legal factors. In other words, the principles or frameworks in themselves are not enough. Their effectiveness depends on *how* they are implemented and therefore this section highlight the need for a more fundamental transformation in chemicals governance which will take the environment and human health more seriously in decisions about allowing PFAS and other potentially harmful chemicals onto the market. We identified these drivers:

a. **Responsibility and initiative** is needed across all public and private units and levels, including farmers, consumers, producer and retailers. Due to the diffuse nature of PFAS pollution, there is not a single tap to close but thousands, requiring all stakeholders to act (see 5.1).
b. **Awareness raising and agenda setting** are key towards creating momentum for the transformative change required (see 5.1.3; 5.2.2).
c. A **proactive approach** based on the precautionary principle ensures (unknown) risks are considered in the entire product chain, even if emissions or risk occur elsewhere in the chain (see e.g. 5.3.3; 5.1.4).
d. This requires a **full supply chain transparency** so producers, manufacturers, farmers, consumers and public offices have a valid knowledge base to assess risks (see 5.3.2; 5.1.4).
e. The knowledge base can only come about through **independent, systematic monitoring of PFAS** across environmental matrices of air, water and soil, humans and other organisms (see 5.3.4; 5.1.3; 5.2.3).
f. At this point in time, only a **Universal PFAS restriction**, in contrast with a substance by substance approach, can curb the growing emissions, even if such a group-based approach risks banning some less harmful PFAS (see 5.1.4; 5.2.3; 5.3.4).
g. For farming, a sector where use of harmful chemicals is often considered 'essential', **strong incentives** towards more sustainable farming practices should be put in place, rather than increase the reliance on PPPs (see 5.1.4; 5.2.3; 5.3.4). PFAS alternatives in agricultural uses go beyond substituting substances, but should entail switching to different farming systems, different strategies for pest control management, or prioritizing pest resistance more in seed breeding and selection.
h. For adaptive policy-making to reflect societal priorities and scientific insights, **high transparency of lobby** is needed. The coupling of the strong agricultural-, chemical- and pharmaceutical lobbies for continued use of PFAS are a threat for achieving the objectives of the EU green deal, including the implementation of SSbD principles (5.1.4; 5.4.3).
i. The **debate on 'essentiality' of PFAS** needs to happen at societal level and address fundamental values of society. While some uses can legitimately be categorised as 'essential', many other uses can be eliminated and replaced with other substances, even if this means a slight penalty in product performance (5.3.4).
j. The **active involvement of diverse stakeholder groups,** that goes beyond formal consultation procedures that are often dominated by coordinated industry response, towards active involvement in decision-making. This is underpinning all the other drivers (see 5.1.4; 5.2.3; 5.3.4).
k. **Institutional capacity** for reshaping and expanding hazard, environmental, social and economic assessments in line with more precautionary approaches (see 5.3.4; 5.4.3).

These drivers can often be implemented in various ways. For example, the required supply chain transparency can be seen as a scale ranging from full external public supply chain transparency, to being partially transparent, and only *internally* to those in the product chain. And the debate on the 'essentiality' of PFAS and similarly harmful yet useful substances, can be organised at different levels and varying rates of participation of varying groups of stakeholders.

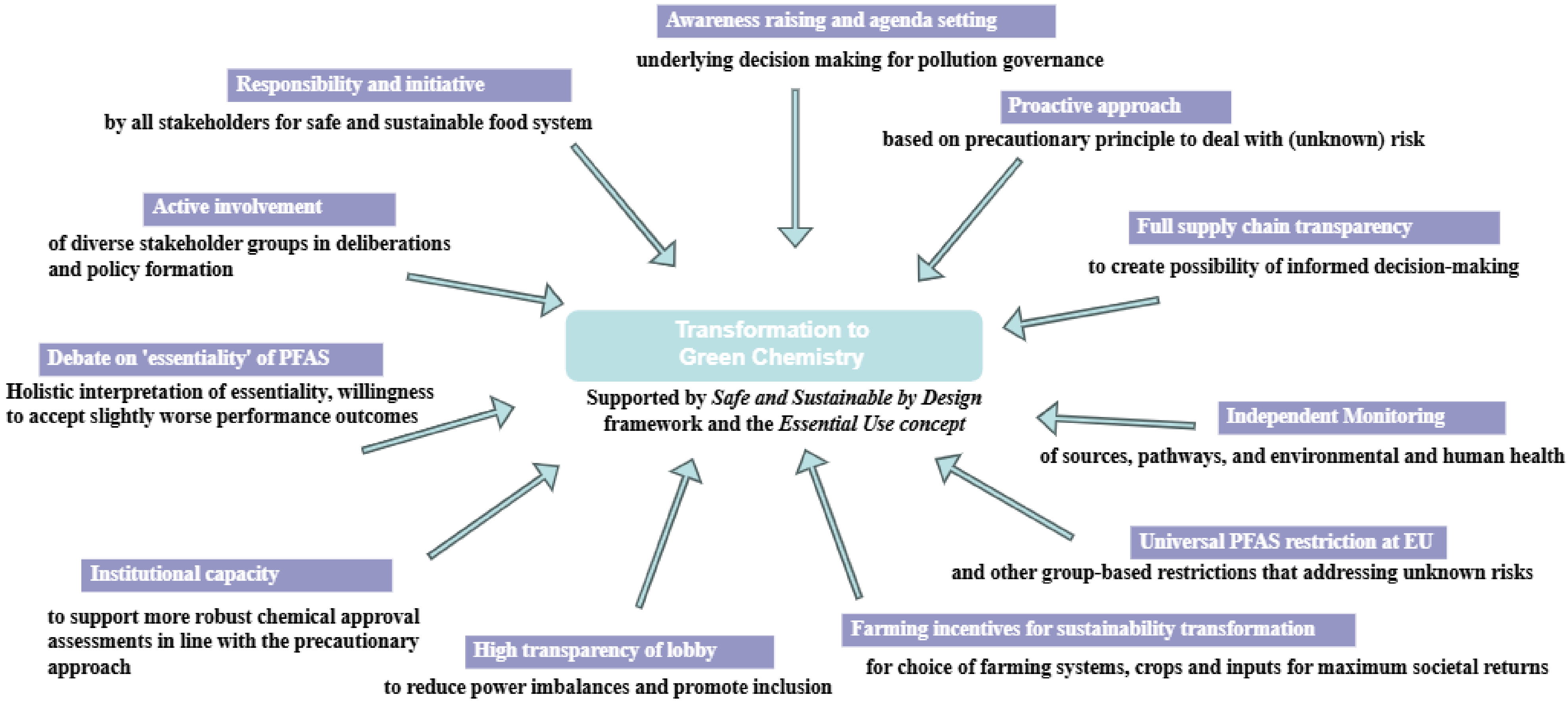

Figure 3 Overview of drivers for Green Chemistry- the preconditions for SSbD and EUC to be effective

Figure 3 shows a visualisation of the main drivers for a transformation to Green Chemistry- supported by SSbD and EUC – as identified in this science shop project. These drivers shape the possibility for a sustainable and healthy agricultural sector in the long term, without adverse effect from chemical mixtures on environment and human health, as is the objective of the SSbD and EUC. For the objective of green chemistry, all drivers would ideally be maximised. However, the distribution of costs and benefits of pursuing these drivers will differ for stakeholder groups, and there are significant societal trade-offs to consider. For example, while monitoring is generally important to know the state of the environment and how it is affected, one cannot monitor 'everything everywhere' and smart choices need to be made. This holds true for all drivers and these trade-offs need to be considered.

5 Detailed results

In this chapter we summarise the findings of three Academic Consultancy Training MSc student teams, as well as the findings from the involved WUR researchers. The first section highlights the diversity and interactions of PFAS pathways connecting farm to fork, addressing RQs 1-3. The second section explores the farmers' perspective and decision-making, addressing RQs 2 and 4. The third and fourth section explore the implications of applying an 'essential use' concept, as well as applying the Safe and Sustainable by Design (SSbD) framework, in the approval processes for PFAS containing PPPs. These parts address RQs 2,4 and 5.

5.1 PFAS pathways in agricultural applications

The goal of the first ACT student project (Boonen et al., 2025) was to map the PFAS pathways of a conventional mixed farming system in the Netherlands. This required addressing the following sub-questions:

> **What are the relative contributions of PFAS pathways in a conventional mixed farming system in the Netherlands?** In order to understand how PFAS is found in the human food chain stemming from agricultural systems, it is important to understand the connections between the different PFAS pathways.
>
> **What influence do policy regulations have on PFAS pathways in the Netherlands?** It is important to know the legislative terms for the pathways of PFAS in the Netherlands. This allows for an assessment of the extent of uncontrolled usage and, consequently, how the country's policy affects the use and, therefore, the concentration of PFAS in living organisms.
>
> What are the knowledge gaps we found during our research on PFAS pathways of a conventional mixed farming system in the Netherlands? When the knowledge gaps in current research are known, more insight might be gained on how to identify and address these gaps. This also has implications for policy recommendations.

5.1.1 Interactive map

The group combined research into different environmental matrices (land, water, atmosphere) with arable farming pathways (Pesticides, food crops) and animal farming pathways (pharmaceuticals, animal feeds, and livestock products). These pathways were visualised in an interactive online map that can be accessed here: https://prezi.com/p/00fkz6w6-tis/mixed-farming-system/?present=1. Figure 4 **Figure 4**shows a screenshot of the main page of the interactive online map created as the main product in the ACT project.

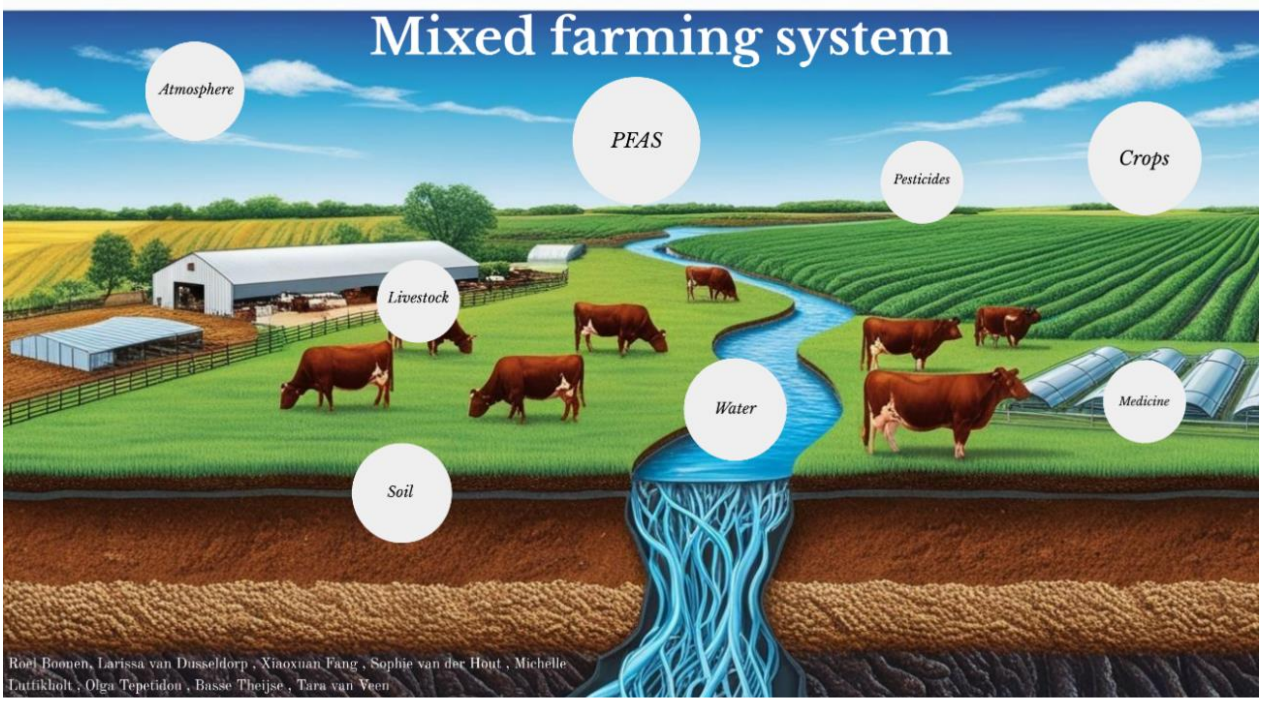

Figure 4 Screenshot of the interactive Prezi showing the most important PFAS pathways in a mixed farming system. Accessible via https://prezi.com/p/00fkz6w6-tis/mixed-farming-system/?present=1 (Boonen et al., 2025)

5.1.2 Interactions

Students highlighted the importance of the interactions between the various PFAS pathways across environmental matrices. Soil transfers PFAS to the water, and from there, through droplets, they return to the soil by travelling through the atmosphere. However, this interactive cycle can become even larger, as PFAS can travel and return to any point through other ecosystems, such as a crop field or a livestock farm. More specifically, a PFAS molecule that a plant takes up can end up in the food chain either directly or indirectly through animals. Animals that consume contaminated food can return PFAS to the soil through manure, and these substances can then follow the same cycle again. Figure 5 illustrates all these interactions, highlighting the need to explore all the PFAS pathways to limit contamination.

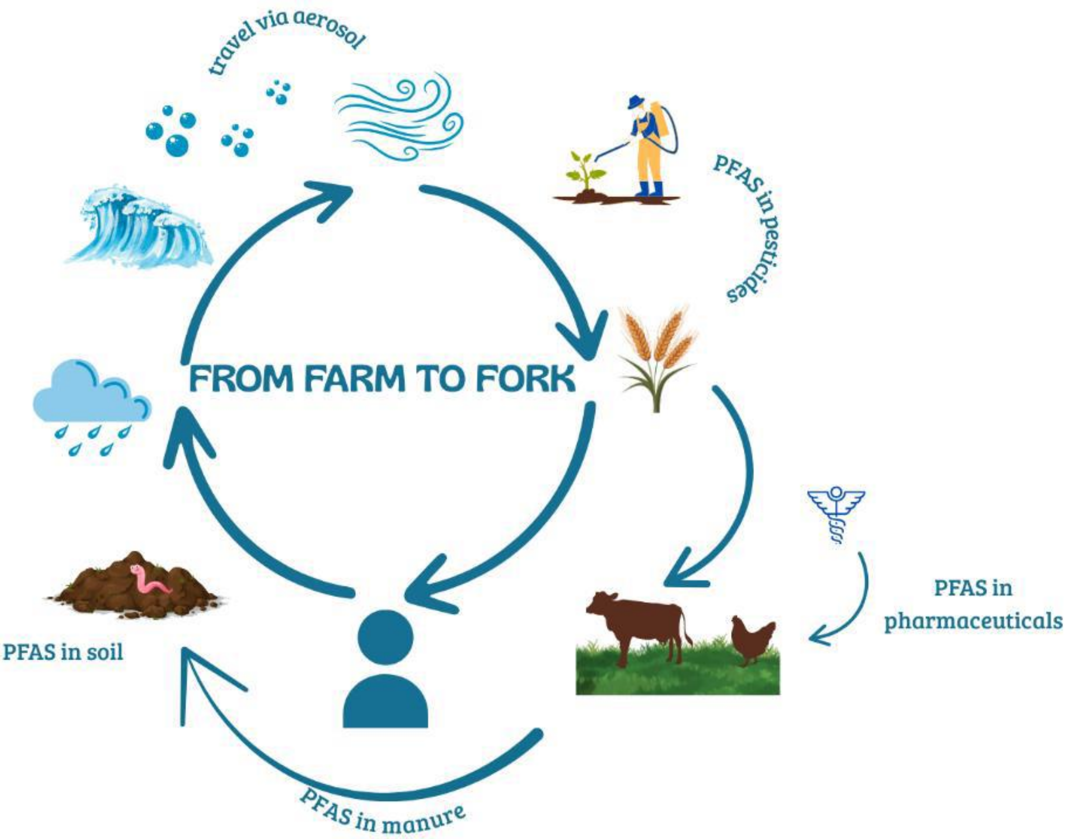

Figure 5 Visualisation of interaction of PFAS pathways (reused from Boonen et al., 2025)

5.1.3 Knowledge gaps

The following knowledge gaps were highlighted by the group:

1. Lack of research and regulation in unvalued pathways

Current research and regulation mainly focus on the human-related or other valued pathways, while PFAS concentrations and behaviour in certain less important pathways remain largely unresearched or unregulated.

2. Limited transparency of monitoring data

Monitoring data from the government website is difficult to access for the public, which limits the assessment and quantification of PFAS dynamics across exposure pathways.

3. Insufficient focus on short-chain PFAS

Short-chain PFAS such as trifluoroacetic acid (TFA) are frequently detected at high concentrations in the environment, and they are persistent and potentially harmful to humans and the environment. However, there is a big gap in the research on their toxicity, environmental behaviour, and exposure risks. This is highlighted by the advise that Ctgb provided earlier this year to the Minister of agriculture, asking to formalize the reassessement of PPPs that may form TFA upon environmental degradation.

4. Poor understanding of PFAS dynamics in specific scenarios
Due to the diversity of PFAS structure and multiple environmental factors, PFAS dynamics in the environment are highly complex. The behaviour of PFAS in the environment is highly scenario-dependent, making it difficult to summarize their trajectories across different environmental compartments or within biological systems.

5.1.4 Recommendations

The ACT team strongly recommends advocating for a complete ban on PFAS, despite the potential trade-offs. In support of, and in addition to that central message, the team visualized their recommendations in Figure 6. It includes putting part of the responsibility for environmental risks back at chemical producers. They highlight the need for systematic monitoring as well as more research to address knowledge gaps that currently hinder effective policy making. Finally, they recommend involving society and farmers in dialogue and deliberation.

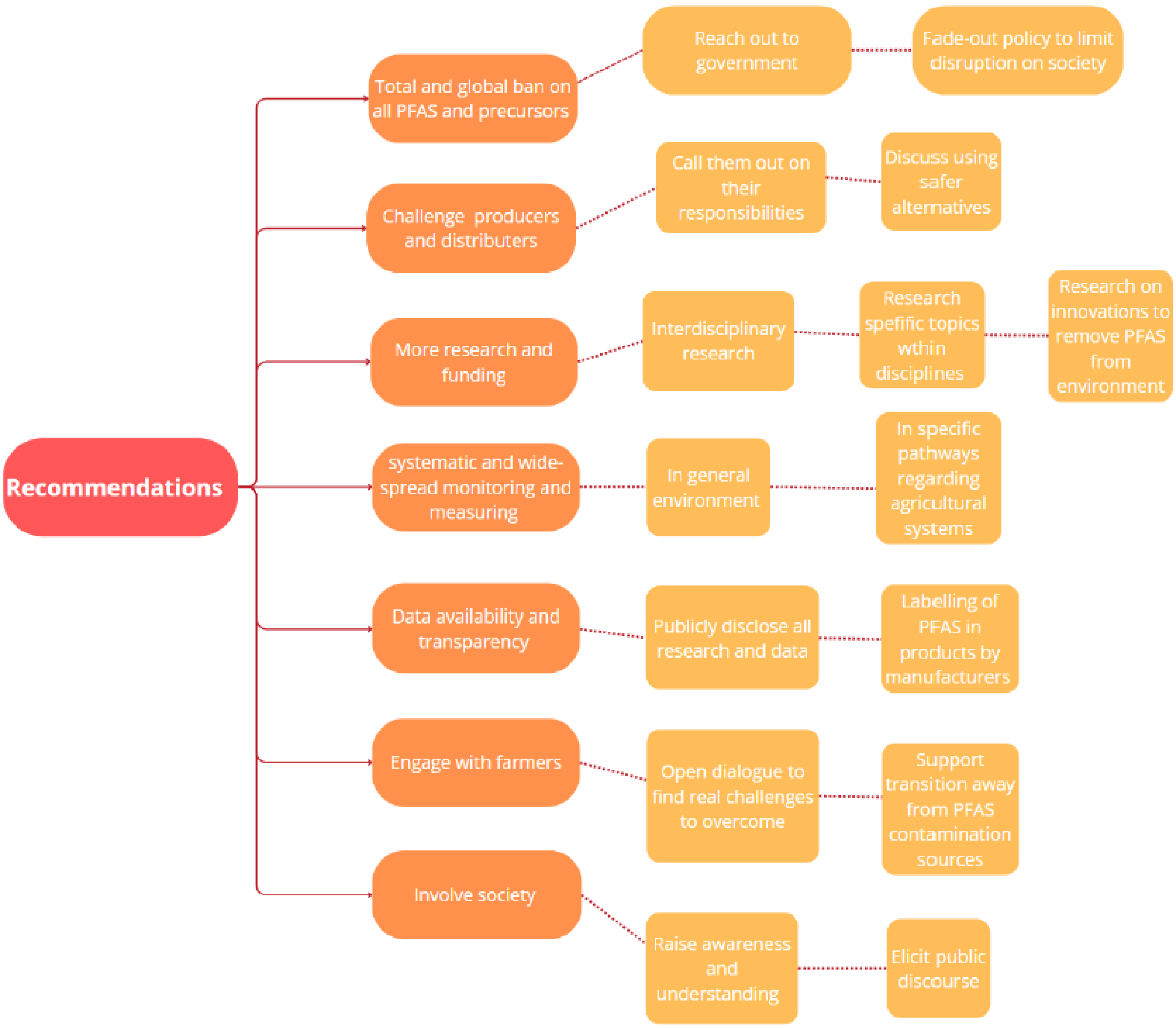

Figure 6 Visualisation of recommendations from ACT project work (reused from Boonen et al., 2025)

5.2 PFAS and the farmers' perspective

This ACT project (Tsapikouni et al., 2025) examined the challenges strawberry farmers would face in transitioning to PFAS-free plant protection products (PPP) as part of the broader momentum to phase out PFAS. PPP's containing PFAS are widely used in the strawberry farming sector, which can pose long-term risk related to human health and the environment. Due to the persistence and bioaccumulation of PFAS chemicals, PPP's containing PFAS used in the strawberry farming sector can end up in the environment and do not break down over a long period of time. The consultancy team relied on in-depth desk study and semi-structured interviews with 10 strawberry farmers. The research questions and main results are given below.

5.2.1 Overview of PFAS in PPPs used in strawberry

- What are similar chemical alternatives for PFAS in PPP in agricultural farming practices?
- Which PFAS-containing pesticides do not have a PFAS-free alternative, and could therefore be considered 'essential' in horticulture?

One of the most important diseases in strawberry crops are fungal infections, specifically Botrytis Cinerea ("gray mold") (Yang et al., 2023). To deal with this challenge, strawberries farmers use some chemical compounds (PPP) containing PFAS, specifically a mixture of fluopyram and trifloxystrobin (Amiri et al., 2013). Although these fungicides have been an effective way to control this disease, they can cause serious "3R" problems (Resistance, Resurgence and Residue).

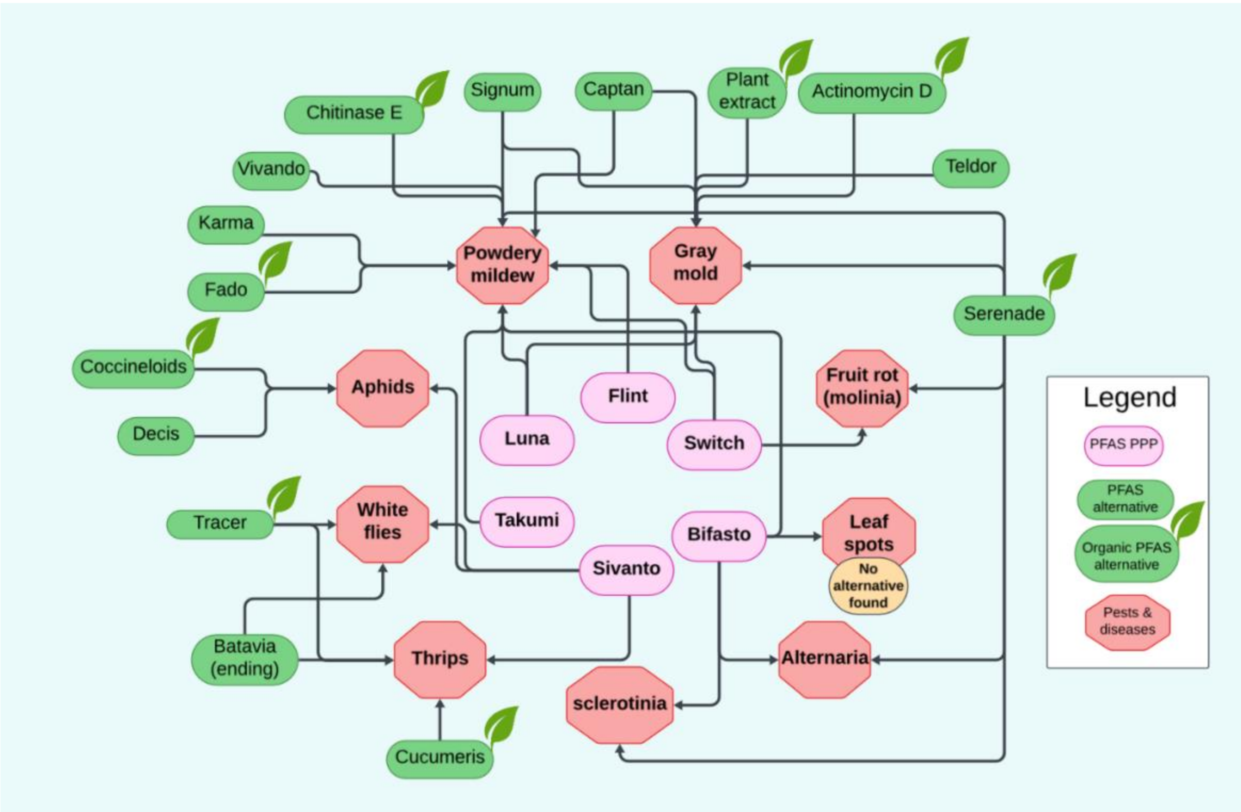

Figure 7 Scheme that displays which PPPs containing PFAS (purple) and PFAS alternatives (green) can be used too counter which pests. This figure was first published in the ACT report by (Tsapikouni et al., 2025)

Figure 7 synthesizes answers from interviews with farmers. The figure shows which pests are the mentioned by the farmers to be the most common pests in strawberry farming in the Netherlands. For each of these, the figure then summarizes which PFAS-containing PPP the farmers mentioned to use, and which synthetic and organic alternatives they use or know of. This figure shows that for most of the common pests, PFAS-free alternatives are available, although it does not inform about the effectiveness of the alternatives.

5.2.2 Farmers’ awareness of PFAS in PPP

- What are the opportunities and threats when switching to PFAS-free alternative PPP’s?

Interviews with farmers revealed several key issues. While farmers seem to have a general understanding of PFAS and its environmental and health impacts, most of them are unaware that their PPP contains PFAS. Farmers’ decisions on PPP are influenced by cost, effectiveness, contracts with buyers, consumer preferences, and government regulations. Although the interviews revealed that many of the strawberry farmers use PPP’s with PFAS, at the same time some of them already use chemical and organic alternatives and seem to be willing to switch to PFAS-free PPP if they prove as effective. Our findings suggest that while farmers are open to adopting PFAS-free PPP and new, resistant strawberry varieties, the transition depends on the efficacy, economic viability, influence by advisors and consumer acceptance of these alternatives. Figure 8 shows the decision-making network influencing farmers.

5.2.3 Bottlenecks in agricultural farming practices concerning moving away from PFAS pesticides

- How do the bottlenecks influence the choices in the decision-making process of farmers in moving away from PFAS pesticides?

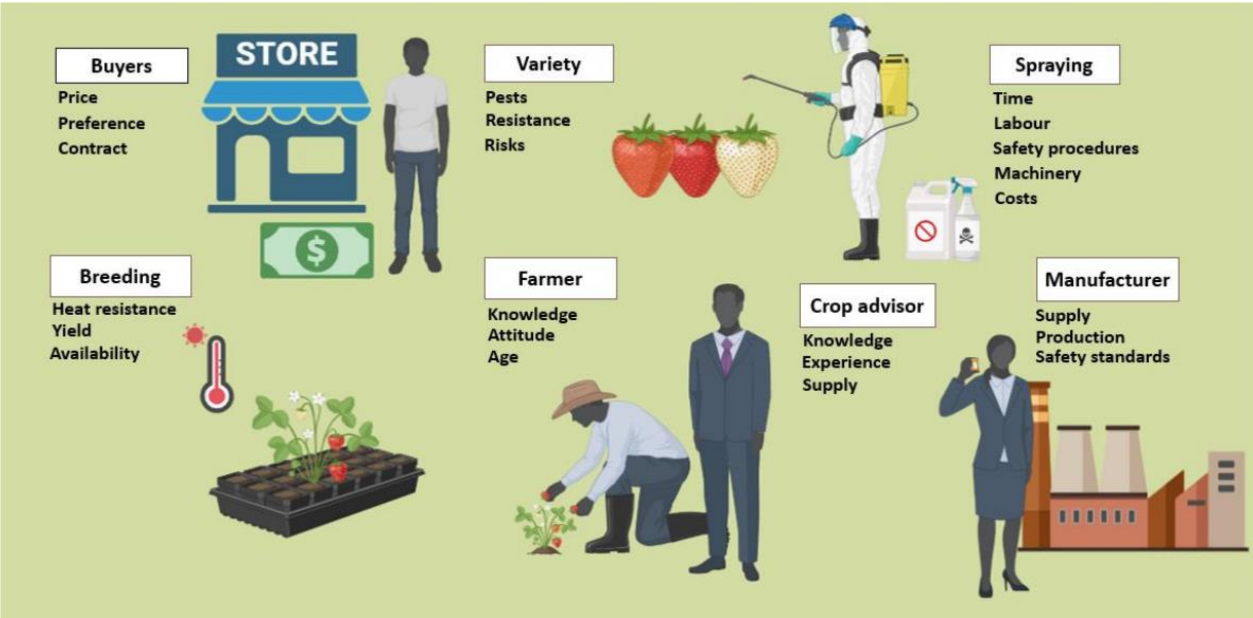

Figure 8 Factors involved in Farmers’ decision-making regarding PPP, mentioned in interviews (reused from (Tsapikouni et al., 2025))

Comprehensive plans to phase out PFAS in PPP’s should include clearer product information, support for alternative solutions, and promotion of PFAS- free farming practices. Engaging farmers in discussions with stakeholders, including the government, advisors, and PPP manufacturers, is essential to facilitate this transition and protect the environment and public health.

Also, consumers and retailers seem to have a pivotal role. Consumers preferences on the characteristics are taste, looks and smell influence a choice of variety. For the retailer, ensuring good shelf life and firmness is of utmost importance. These characteristics ensure that the fruits are easy to handle and reach their destination with minimal losses.

Discussion and conclusion

PPP’s containing **PFAS are widely used** in the strawberry farming sector, which can pose long-term risk related to human health and the environment. Due to the persistence and bioaccumulation of PFAS chemicals, PPP's containing PFAS used in the strawberry farming sector can end up in the environment and hardly break down over a long period of time.

Strawberry farmers have a general understanding of what PFAS chemicals are, but many of the **farmers are not fully aware and informed** about the presence of PFAS in the PPP's they use. This lack of knowledge of the farmers is associated with the **little transparency present in the labels of the PPP.** In most cases only the active compound is mentioned, while the **co-formulants or additives are undetermined** due to limited research and trade secrets.

The current understanding of the sources of PFAS in agricultural products is just the tip of the iceberg, highlighting **the need for further research**.

From our research we found that **moving away from PFAS in PPP runs into several obstacles,** including the challenge of balancing product effectiveness with cost efficiency. In facilitating this transition, **advisors seem to play a pivotal role** due to their frequent and direct contact with the farmers, which fosters trusted relationships between them.

Additionally, as the government agencies control the new regulations, we propose fostering **dialogue among governmental agencies, advisors, and farmers** to facilitate the removal of existing barriers 30 hindering the transition away from PFAS in PPP. By engaging in collaborative discussions, the government and advisors can develop clear pathways towards a PFAS-free future in strawberry cultivation, ensuring alignment with agricultural sustainability goals.

In conclusion, the main goal of this ACT project was to remove the thresholds that stand in the way of moving away from PPP containing PFAS. Considering the lack of available information, our primary research contributed by providing new knowledge, and a clearer view when it comes to the factors that influence the decision-making web of the farmers.

5.3 PFAS and the Essential Use concept

This ACT project (Evans et al., 2025) focused on the governance side of the story. The students explored how application of the Essential Use Concept (EUC) in legislation related to the approval of plant protection products (PPPs) could affect the use of active substances that are or contain per- and polyfluoroalkyl substances (PFAS). With that, they contribute mainly to research question 4 in this project.

In the Netherlands, around 5% of PPPs contain PFAS(Adema, 2024), and testing of produce in the period 2011-2021 found PFAS in 14.0% of the fruits and 7.1% of the vegetables. PFAS can be used in PPPs as an active substance or an additive, meant to improve properties such as longevity, specificity, or effectiveness of the PPP. While beneficial on the one hand, PFAS are also persistent pollutants. Some accumulate in the environment or in living organisms, and some pose health risks such as genotoxicity, organ toxicity, and endocrine disruption.

The use of materials that have both beneficial properties and bear potential health risks or environmental risks needs to be evaluated. Currently, for approval of PPPs and ingredients thereof this is mainly done in a risk assessment by a notified body. Essential use could provide a different view on the importance of risks in such an evaluation, potentially creating a different outcome. In this project, the primary objective was to evaluate the essentiality of specific PFAS compounds used in PPPs within the Dutch agricultural sector. A secondary aim was to understand the perspectives of stakeholders on essentiality. The last aim was to inform relevant policymakers on the possibilities and effects of applying the essential use concept to limit the use of PFAS. Hereafter follow the highlights from the report written by the WUR students; where necessary WUR researchers added onto the information from this report.

5.3.1 EU policy context & Essential Use Concept

The EU has developed an elaborate set of regulations, directives and communications to govern PPPs and their components. These are covered by Regulation 1107/2009 concerning the placing of plant protection products on the market and related documents, as summarized on an EU website[2] about food safety. In general, the students considered the existing PPP regulations to be fit for their specific purpose; establishing rules for the authorisation of active substances, their pre-approval testing, acceptable uses of the substances, as well as labelling requirements, amongst many other guidelines. Moreover, the regulations' coverage exceeds active substance alone. Safeners and synergists are likewise covered by many of the same requirements.

The essential use concept (EUC) should guide what chemicals can be used for what applications. So-called "most harmful substances" are to be fased out for non-essential uses and minimized and substituted for as far as possible in other uses. To assess which uses are essential, two criteria were set. As stated in the EU Communication on essential use(Guiding Criteria and Principles for the Essential Use Concept in EU Legislation Dealing with Chemicals, 2024), a use of a most harmful substance is essential for society if:

1. The use is necessary for health or safety, or is critical for the functioning of the society, and;
2. There are no acceptable alternatives.

More detailed explanations are provided in the same communication (Guiding Criteria and Principles for the Essential Use Concept in EU Legislation Dealing with Chemicals, 2024) for terms as 'most harmful substance', 'necessary for health or society', 'critical for the functioning of the society', and 'acceptable alternatives'. These remain however still rather broad and thus multi-interpretable, as they should be applicable in a range of Regulations. A final version of the concept should thus either be much more precise, or leave this definition open for societal debates.

The students concluded that the concept of essential use comes as an appreciated development, whose targeted deliberations may prove useful in limiting non-essential uses of the most harmful substances. However, their attempts at applying essential use have shown that it may prove time-consuming at best and ambiguous at worst, therefore by itself not leading to major changes in allowance of most harmful substance usage in the EU.

5.3.2 Applying the essential use concept on the selected AS

- **Fluopyram in PPPs for strawberries**

Fluopyram is a preventive fungicide of the broad-spectrum type (*Luna Sensation*, n.d.; Veloukas & Karaoglanidis, 2012). Fluopyram acts by inhibiting succinate dehydrogenase (SDH), an enzyme complex found in all species that have mitochondria. In strawberry farming, it is used to target the mitochondria of the grey mould, referred to as all species of Botrytis (*Botrytis* spp). Fluopyram and trifloxystrobin are the active ingredients of the fungicide Luna Sensations (*Luna Sensation*, n.d.). For the delivery of nematocidal effects, both ingredients are required in the product.

The substance is not listed as a most harmful substance. For this reason, applying the essential use concept would not change the result of an assessment concerning the use of fluopyram as active ingredient in PPPs. Fluopyram is a PFAS according to the OECD definition (Wang et al., 2021), as it contains two CF_3-groups, and the essential use concept is supposed to support phasing out non-essential uses of PFAS (Silke Gabbert & Arianne de Blaeij, 2024). In this light, the essential use concept can be used to evaluate the potential to phase out fluopyram as active substance in PPPs.

Fluopyram can be seen as necessary for health and safety, as it allows for "sustaining basic conditions for human or animal life and health" (Guiding Criteria and Principles for the Essential Use Concept in EU Legislation Dealing with Chemicals, 2024), since it is a PPP contributing to the provision of sufficient food. This is a strict interpretation of the criterion of sustaining basic conditions for human or animal life and health. Discussions on a different level may consider elements such as the need for society to grow all varieties of a plant in all climate zones and agriculture systems, which could also affect the need for this specific PPP in strawberry cultivation.

[2] https://food.ec.europa.eu/plants/pesticides/legislation-plant-protection-products-ppps_en

Synthetic, natural, and biological alternatives are available to control *Botrytis*. Several synthetic alternatives have been shown to effectively inhibit the fungus (e.g. pyrimethanil, fludioxonil, boscalid), with up to 100% efficacy; however, testing was carried out in laboratory conditions and might not reflect field conditions (Kim et al., 2016; Llanos & Apaza, 2018). The synthetic alternatives mentioned here are toxic or potentially toxic for specific organs and might therefore classify as most harmful substance themselves and thus not be considered acceptable alternatives. Other alternatives have shown lower performance and in the context of this report it could not be evaluated if this could be acceptable for society.

- **Lambda-cyhalothrin in PPPs for potatoes**

Lambda-cyhalothrin is an insecticide approved for use in all 27 EU member states and is a recognised candidate for substitution (*EU Pesticides Database - Active Substances - Active Substance Details*, n.d.). The use considered here is its application in potato farming, where it prevents root damage by insects from the *Elateridae* family (wireworms). Lambda-cyhalothrin can be seen as necessary for health and safety, similar to the reasoning for fluopyram, when using a strict interpretation of the criterion that it allows for sustaining basic conditions for human or animal life and health.

The students concluded that lambda-cyhalothrin is a most harmful substance because of its endocrine disrupting properties. However, it is not listed as such in the dedicated list of endocrine disruptive chemicals maintained by ECHA. As long as that is the case, lambda-cyhalothrin will not be considered as being endocrine disruptive in a re-assessment for use as an active ingredient in PPPs (due in 2026). In 2023, the latest version of the review report for the active substance lambda-cyhalothrin was released by the EU Standing Committee on Plants, Animals, Food and Feed, in which the statement is that the substance is not classified or proposed to be classified as carcinogenic category 2 or toxic for reproduction category 2 (*Final Review Report for the Active Substance Lambda-Cyhalothrin in the Standing Committee on Plants, Animals, Food and Feed*, 2023). In that document several data gaps are also identified (e.g. concerning metabolic products, biomagnification, and long-term risks); when this data becomes available, the assessment may change direction.

There are synthetic alternatives that target wireworms but do not use lambda-cyhalothrin. This concerns the following three compounds: carbendazim (EU approval expired in 2014), isofetamid (approved in some EU countries but not NL), and fenpyrazamine (approved in all EU countries). There are also some non-synthetic alternatives, being pyrethrins, neem oil, and Integrated Pest Management strategies. None of these alternatives have shown similar efficacy. There is a lack of information for most of the alternatives regarding their economic impact, effects on humans or animals' health, and environmental consequences. These aspects can only be judged in a proper and formal assessment in which stakeholders such as PPP advisors and farmers provide insights in the practicalities of the use the examined PPP.

In conclusion, there is still much room for interpretation of the criteria for essential use, other than the safety aspects. The safety aspects as proposed in the EUC are in general similar to that in current PPP legislation. It is therefore unlikely that an assessment following the EUC will generally be less strict than current legislation. Based on the information available to us, it is however uncertain if the additional criteria will significantly affect the PPP approval process results. Therefore it is still unclear to us if the EUC will lead to giving a higher priority to environmental and socio-economic sustainability of chemicals when assessing their placement on the market.

5.3.3 Discussion: strengths and weaknesses of the Essential Use Concept for evaluating the approval of PPPs and ingredients thereof

Strengths, seen from the zero-pollution point of view:

- The recently proposed concept of essential use provides a **standardised, structured and common method** for assessing the essentiality of a substance.
- The essentiality concept considers specific uses of "most harmful substances". The concept facilitates efficient regulatory decision-making as it does not discriminate between sectors (Kastalie Bougas et al., 2022).
- The concept of essential use not only considers other chemicals as alternatives but provides **room for non-chemical alternatives** to be considered.

- Based on the Communication of the European Commission, nothing can be considered an "essential use", if safer alternatives are available.
- It is not possible to substitute a harmful substance with another harmful substance when complying to essential use.
- Essential uses will have to be periodically reviewed, taking into account all new information that becomes available. Furthermore, substitution plans may be required for uses that are considered essential first but for which future substitution is likely possible.
- The essential use concept considers the wider societal impact, stemming from the prohibition of the use of a substance. By assessing the degree to which the function of a substance is critical to society, the criteria imply that the socio-economic consequences for the different stakeholders of a hypothetical ban on a substance need to be analyzed during the essentiality assessment. This can lead to significantly different conclusions than those in a risk assessment based solely on technical aspects.

Drawbacks, seen from the zero-pollution point of view:
- An authorization for use of a substance in a PPP implies that this substance is not a most harmful substance, and an authorization includes use criteria and thresholds as well as maximum residue levels. Using essential use as the basis for an evaluation would not lead to a more comprehensive technical evaluation, as all these aspects are also covered in legislation that is in force.
- The broad scope of essentiality criteria will likely lead to lengthy evaluations. To fully determine the essentiality of fluopyram as an active compound used to combat fungi and nematodes, the students estimated that approximately nine PPP formulations need to be evaluated. Each essential use evaluation will require debates with stakeholders, hence a slow authorization process is to be expected. Moreover, the students identified thirteen distinct chemical alternatives, four biobased pesticides and IPM strategies that could provide a similar function to fluopyram. The hazards, environmental and socio-economic effects of all of these have to be assessed in an essential use evaluation.
- One of the main criteria for the essential use concept is that the substance must be "necessary for the health, safety and/or critical for the functioning of the society" to be further considered in the assessment. This kind of information can be obtained by conducting a socio-economic analysis (SEA). SEA analysis also takes a significant amount of time, as it involves stakeholder involvement and feedback processes.
- SEA analysis could be significantly skewed in favour of PPPs already on the market due to the advantage of established production lines and sales networks. Introducing a new alternative would require a considerable amount of time to scale production and reduce costs, potentially labelling it as less viable.
- Stakeholders were skeptical about whether the "essentiality concept" will have any tangible impact. They did not consider the concept to be connected to PPP legislation. Furthermore, stakeholders had varying perspectives on what constitutes an essential PPP. One striking inconsistency was that ChemSec believed the "essentiality concept" to be a step in the direction of a future with less chemicals, while CropLife NL argued that it may lead to a more simplified authorisation process for PPPs. Similar contradictory opinions were identified concerning the safety of PPPs and the strictness of current legislation. A concern shared by many stakeholders is in the limitations of biological alternatives and the non-existence of alternatives for certain PPP uses.

5.3.4 Conclusion and recommendations

The essential use concept has the potential to cause a significant change in the way how chemical usage is governed in the EU. For pesticides, most elements of the essential use concept are already present in the PPP Regulation. However, the essential use concept is still in its infancy in EU policy. It will take a significant effort and time before it is operationalized in EU policy. The current version of the concept is not very precise, nor is it clear how it will be implemented in Regulations.
The case studies in which the essentiality of fluopyram for strawberries and lambda-cyhalotrin for potatoes was assessed based on a theoretical approach, show that a broad range of interpretations of the concept is possible. With that, the outcome of such an assessment can therefore also be very different and final conclusions about the effect of implementing and operationalizing essential use in EU chemicals legislation cannot be drawn yet. The following recommendations were drawn:

Redefine which substances are applicable for assessment under the essential use concept. Hazard criteria that prevent authorisation of a PPP ingredient (active substance, safener or synergist) are those which indicate a most harmful substance whose (essential) uses can be evaluated. For example, if an ingredient is a class 1A carcinogen, it cannot be authorised for use in a PPP. However, if it does not have any of the listed hazardous properties, it is not considered a most harmful substance. Therefore, it will not be evaluated under the essentiality criteria. The group of chemicals listed as most harmful substance under the essential use concept should be future-proof and in line with the vision expressed in the Safe and Sustainable by Design framework.

Reassess the practical implications of the essential use concept. The criteria are (still) ambiguous and broad, which can lead to unexpected or undesirable interpretations and effects. More specific terminology should be used instead of the current wording of ‘significantly safer’ and ‘similar level of performance’ and ideally it should be quantifiable. This will aid in testing, comparison and approval of alternatives.

Harmonize essential use concept directives with current PPP regulations. The current form of the essentiality concept only has marginal differences to Regulation No 1107/2009 concerning identification of harmful substances. While this allows for an easier transition to a harmonized set of rules regarding chemical substances, it still presents some pitfalls. For instance, similarities in the regulations could lead to unnecessary ‘double rulings’ where substances are covered under multiple legislations. These double rulings create uncertainty surrounding the application of policies and allow for loopholes in regulations.

Develop a streamlined method and platform for identifying and assessing alternatives for candidates for substitution. This can serve as the framework used in identifying replacements for non-essential uses cases of PFAS in PPPs. A platform, such as the ‘marketplace’ from ChemSec or equivalent, would serve to expedite and ease the process of identifying and assessing the alternatives.

Ensure continued availability of emergency authorizations of PPP containing PFAS and PPP in general. Based on interviews with experts, the students conclude that if the PFAS ban and essentiality criteria are accepted and written into EU law, care must be taken that specific temporary emergency use options of “harmful substances” stay available to allow for resistant or invasive pests to be dealt with when preventative measures and biological control have failed or are not effective at further controlling the outbreak. A similar emergency authorization is already present in Reg. No 1107/2009 under article 53 and could function as a starting point for further discussion.

5.4 PFAS and the Safe and Sustainable by Design framework

5.4.1 Short overview of the SSbD framework

The SSbD framework is a voluntary framework meant to support the design and development of safe and sustainable chemicals. Two key elements, as the name suggests, are safety and sustainability; their definitions are shown in Figure 9. The Safe and Sustainable by Design framework operationalizes an important aspect of the Chemicals Strategy for Sustainability: how to ensure that both safety and sustainability are taken into account throughout the full research and development process of a new product.

5.4.2 Steps in a typical SSbD assessment

To better understand if and how SSbD will affect the environmental impact, we here take PPPs as a category of products that are used in agriculture of which some contain PFAS. First, we sketch the line of thinking behind SSbD. In any future R&D trajectory aiming to develop a new chemical or material, product design and SSbD assessment should occur simultaneously. While the Technological Readiness Level (TRL) of the product under development increases over time, more and more information will become available. When it becomes clear what the constituents of the product are and what the ratios between these are, one can evaluate safety and sustainability in more detail than in the beginning of the R&D trajectory. However, it would not be good to wait too long to assess these aspects for the new products: when it becomes clear that the new product does not fulfil certain safety or sustainability aspects early in the project, less resources are wasted on developments that will never reach the market. A product development project following the SSbD approach should consist of the following two components.

1. Design of new product

SSbD principles need to be taken into from the start of the process to create a new chemical or material. These principles include material efficiency, minimizing the use of hazardous chemicals and materials, design for energy efficiency, using renewable resources, preventing and avoiding hazardous emissions, reducing exposure to hazardous substances, design for end-of-life, and consider the whole lifecycle. A full list of principles, indicators, and assessment methods can be found in Annex 2 of the report "Safe and sustainable by design chemicals and materials – Framework for the definition of criteria and evaluation procedure for chemicals and materials" (Caldeira et al., 2022). The SSbD framework is still under development, therefore this list of principles can also still change over time

2. 'Safe and Sustainable' Assessment

In this phase, the safety, environmental, and socio-economic aspects of the chemical or material are assessed in five steps. For a more detailed account of these five steps in relation to PPPs, see Annex 2.

a. Hazard assessment of the chemical or material in line with the EU Chemicals Strategy (CSS).
b. Human health and safety assessment related to production and processing, including recycling and EoL.
c. Human health and environmental aspects in the final application phase, concerning the assessment of risks for end users.
d. Environmental sustainability assessment to assess the environmental sustainability of a material or product or chemical throughout its lifecycle.
e. Social and economic sustainability assessment.

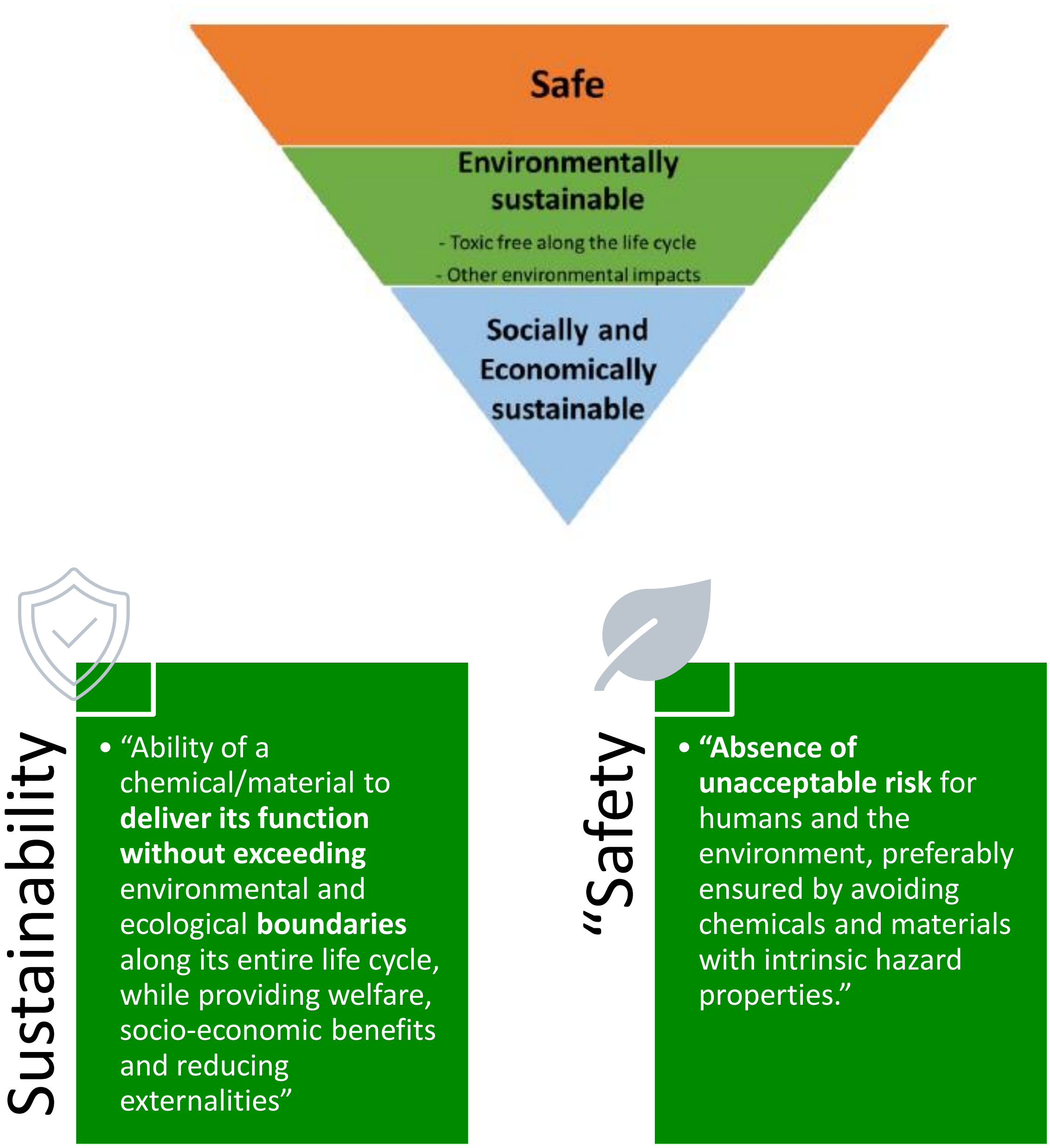

Figure 9 Hierarchical approach of the SSbD framework, adapted from Caldeira et al, 2022.

5.4.3 Comparison of hazard assessment following PPPR and following SSbD approach

Hazards of active ingredients, safeners and synergists to be used in plant protection products (PPPs) are assessed by notified bodies (such as Ctgb); the assessments are currently based on the EU Plant Protection Product Regulation (PPPR), EC 1107/2009, and amendments. Here, we perform a thought exercise to understand how an assessment following SSbD guidelines could turn out.

Table 12, which can be found in Annex 3, gives an overview of how hazards are grouped under PPPR and SSbD and what the consequences could be when a PPP ingredient falls under a certain category. Note that additional conditions and exemptions apply for hazards evaluation under PPPR, for example concerning the possibility to use a material in a safe way.

Substances of Very High Concern (SVHC) are defined in the REACH Regulation(Regulation (EC) No 1907/2006: The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), 2006)). The definition of ‘most harmful substances’ has been published more recently than that of SVHC and that of the SSbD list of aspects (Table 3 in JRC report). We therefore assume that the classification laid out in the CSS is leading.

Altogether, there are multiple elements in the SSbD framework that, when applied properly, will likely lead to lower levels of PFAS emissions and lower human health risks compared to the current situation:

- SSbD places the responsibility for understanding the potential emissions throughout the value chain at the chemical product developer by taking this along in the design phase. Knowing these potential emissions, the chemical producer could advice on safe and sustainable use in well-contained environments (if possible at all).
- Hazards of co-formulants are assessed in the same process as hazards of active ingredients under the PPPR, but the requirements in terms of providing data for hazard assessments are significantly less strict. When following SSbD guidelines, this would not be the case.
- SSbD is significantly stricter for PPP ingredients than the current EU legislation. SSbD-based legislation might infer additional rules on controlling the emissions, tracking chemicals throughout the lifecycle, and demanding substitution by safer alternatives.
- SSbD takes additional elements into account compared to the current set of regulations for PPPs. For example, by executing an LCA, effects that can be associated with the lifecycle of a PPP ingredient such as eutrophication or water use are taken into account in a risk assessment (the 'Safe and Sustainable' Assessment).
- PPPs are almost always mixtures of an active ingredient, co-formulant(s), safener(s), and synergist(s). Co-formulants in PPPs are used to enhance the effectivity of an active ingredient, but can also lead to a strong increase of toxicity to human cells (PAN Europe, 2025). The approach to hazard assessments is to evaluate individual chemicals. Under SSbD, hazard assessments should focus on the 'intrinsic properties of chemicals and materials', thus implying that mixtures should be evaluated in addition to individual chemicals. Evaluating the hazards of mixtures is still very challenging for various reasons (Cassee et al., 2024), it can thus be expected that it will take time before hazard assessments can really follow this approach.

Next to these, there are also multiple elements in the SSbD framework that are not taken into account in the current approval process. The most important element is likely the incorporation of socio-economic effects as a separate step in an approval process following SSbD guidelines. This is an important additional dimension that is currently not taken into account. An assessment based on Essential Use would however also include this dimension, if executed properly.

6 Conclusions and recommendations

In this chapter the overall conclusions are given in section 6.1, followed by more detailed answers to the specific research questions in section 6.2. Section 6.3 provides recommendations for the commissioner and for further research.

6.1 Overall conclusion

In this project we explored the potential of two novel chemicals governance frameworks - the *Safe and Sustainable by Design* (SSbD) framework and the *Essential Use* Concept (EUC) – in the context of reducing PFAS uses in the agricultural sector. Assessments of new products following the SSbD approach are much more elaborate than current assessments. Additional elements include assessing the environmental sustainability in a lifecycle analysis (LCA), assessing potential hazards and emissions throughout the full value chain, and assessing socio-economic aspects. The results from these assessments shall be gathered right from the start of a product design process, thereby making it more attractive to focus on developing materials and products that are likely to show favourable results in these assessments. An approach for pesticide approval based on the EUC is also more elaborate than in current legislation, but less so than SSbD. The main difference with the current situation is the strong focus on the societal debate around essentiality. As the current legislation also sets very specific limits to use volumes and emissions of pesticides, and requires re-evaluation of the safety aspects when new relevant information becomes available, many aspects remain the same when following the EUC approach.

We conclude that both concepts offer promising tools for taking socio-economic, environmental and human health aspects more serious when compared with the current regulations governing authorisation and use of pesticides. Both approaches nevertheless contain a large degree of ambiguity and are therefore not in themselves sufficient for ensuring a rapid transformation to green chemistry. Both approaches also require a much wider scope of assessments than the current legislation. Current lead times for pesticide approval are already long. Some mechanisms are built into both approaches that should lead to a lower workload, mainly by excluding many uses from the start (EUC) or by starting with the assessment from the beginning of a product development process (SSbD). Based on the insights from and results of all subprojects, we conclude that in order for these new concepts to be efficient and effective, the following drivers for green chemistry need to be addressed:

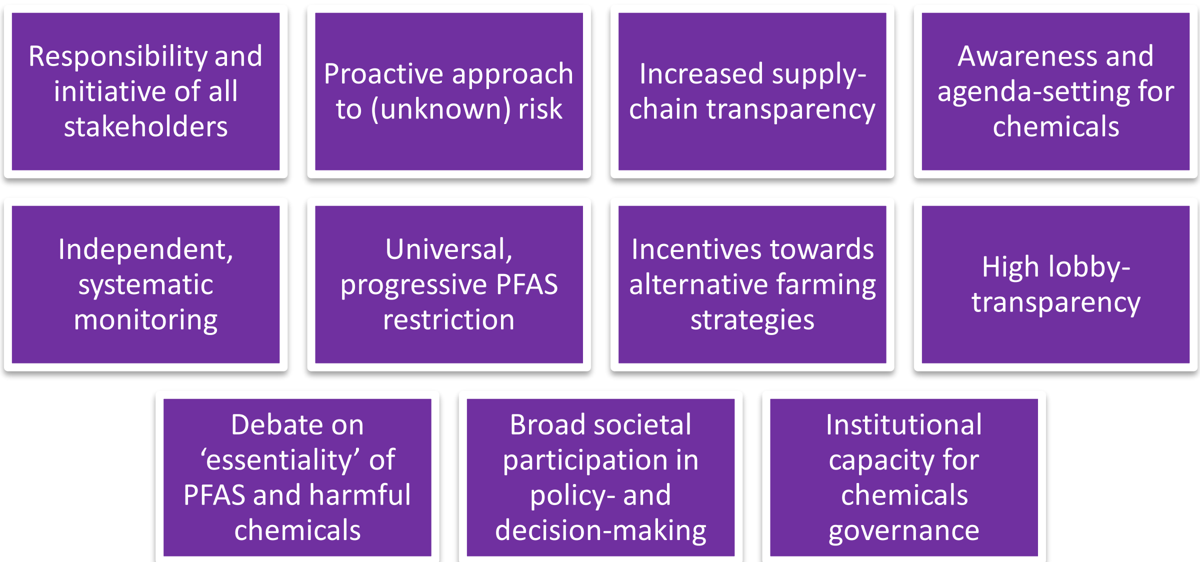

Figure 9 Drivers for a transformation to green chemistry, based on SSbD and EUC in agricultural applications

6.2 Answer to research questions

Below we summarise the main findings for each of the research questions.

1. **What are the sectors/stakeholders that make use of PFAS chemicals in significant quantities and that fall out of the scope of the PFAS restriction proposal under REACH?**

This project focused specifically on agriculture. Like in most sectors, within the agricultural sector PFAS are used in a large number of products – some uses are specific to the sector (e.g. active substances in plant protection products (PPPs)), others are general (e.g. fluoropolymers in bearings, gaskets, and seals). Whereas chemicals used in other sectors are fully governed by REACH, chemicals in most parts of PPPs are governed by specific legislation, thus leaving these out of scope of the PFAS restriction proposal under REACH. The same is true for active pharmaceutical ingredients in veterinary medicines, which are covered in Regulation (EC) No 726/2004.

2. **For agricultural applications: What is the sector/stakeholder's 'stake' and known position in the PFAS restriction debates?**

PFAS are currently an important ingredient of some PPPs, which can be necessary for conventional farmers to get a profitable harvest. Strawberry farmers were somewhat aware whether the PPPs they use contain PFAS, but have no access to detailed information as PPP labels do not provide that**.** In most cases only the active compound is mentioned, while the co-formulants or additives are undetermined due to limited research and trade secrets. Without access to factual information, it is impossible to voice a well-argumented opinion for most individual farmers. In contrast to other sectors and as far as we are aware, organizations in the agricultural sector did not publish whitepapers to express their opinion on the PFAS restriction proposal under REACH.

3. **To what extent can PFAS residues found on fruits and vegetables be traced back to the various PFAS applications in their production?**

In one of the projects executed by students, it was envisioned to shine light on this question using data from scientific literature. It turned out that currently, too few sources for such data are available in literature. To answer this question with original data from measurements, one would need access to specific measurement infrastructure, mature analysis methods, and experienced users thereof. Within the context of short projects executed by transdisciplinary groups of students, this could not be achieved.

4. **Should agricultural application of PFAS be considered an 'essential use' for societal benefit?**

Essentiality can only be judged for a use case of a substance, that is, a combination of PPP formulation, crop type and geographical area where the cultivation takes place, and pest to be countered by using the PPP. There is therefore no way to state that agricultural application of PFAS in PPPs can be considered an 'essential use'.

5. **What are the strengths and weaknesses of PFAS-free alternatives, seen from the perspective of society, farmers and the environment?**

One group of students listed PPPs that could serve as alternatives for fluopyram in strawberry cultivation and lambda cyhalotrin in potato cultivation, and compared various aspects with the PFAS-containing PPP. As explained in more detail in 5.3.2, fluopyram is not a 'most harmful substance', but it is very persistent. Alternatives with varying effectiveness, both synthetic and biological, are available to prevent or reduce grey mould due to the presence of *Botrytis* fungi. Listing and comparing the effects of these alternatives on health and environment was already such a large task that other aspects could not be evaluated within the timeframe of the project. This indicates that such elaborate evaluations, especially when a SSbD approach would be followed, will take significant amounts of time. A risk is that the approval procedures will take so much time that resistance of pests agains PPPs builds up faster than new treatments can be introduced. Another risk is that when insufficient safe and sustainable alternatives are available, emergency uses of otherwise banned PPPs will have to be issued more often, thus potentially decreasing the positive impact of finding safe and sustainable alternatives following an extensive procedure.

6. What are the main limitations and strengths of applying the SSbD framework to pesticides?
Both new and renewed approval of a PPP would require a significantly broader set of aspects to be considered in a process following SSbD than in the current process. This will ensure that, among others, environmental aspects will be taken into account and that they will have a more significant influence on the outcome of the evaluation process. An LCA forms the core of the environmental analysis and should, for example, show the eutrophication potential related to the use of a PPP. Socio-economic effects will also have to be evaluated in a PPP approval process that follows SSbD, although it is not yet clear in what way this will be incorporated. A major potential challenge is the additional and more elaborate evaluation compared to current regulation, which will require additional workforce and will likely lead to (even) longer approval processes. Long lead times at notified bodies may be the result. This could lead to a low level of innovation in this field (no or few new applications get accepted), which may result in continued use of existing products for which no approved alternatives exist in the market.

6.3 Recommendations

For the Home Earth Foundation (stichting Huize Aarde) we recommend the following:

- In the pursuit of green chemistry, the *Safe and Sustainable by Design* (SSbD) framework and the *Essential Use concept* (EUC) are promising developments that align with the values of the NGO. Huize Aarde is advised to actively seek cooperation around these topics with other NGOs that share the same values and goals to support the EU transition to a safer use of chemicals, considering the large amount of regulations that deal with this topic. To increase its impact, Huize Aarde could mobilise their network and the public to engage in these complex yet urgent societal discussions on chemicals governance.
- As an established NGO, Huize Aarde can have an important role in contributing to the societal debates on essential use (what is 'essential') and for SSbD (defining social and economic sustainability). Huize Aarde is advised to leverage its expertise and knowledge in pharmacy and environmental chemistry to firmly engage in these debates.

For future research we recommend the following:
As green chemistry is a complex future vision with trade-offs across stakeholder groups, one recommendation for future research is to do scenario analysis. In contrast with predictive or exploratory scenarios, normative scenarios depict a preferred, 'good' future vision, and allow one to work back to show how this might be achieved in a process sometimes referred to as normative future visioning. The process aims to devise trajectories to move between past, present and future, and vice versa, to achieve collective goals (Comelli et al., 2024). Scenario analysis could show the wide range of transformative action and change that needs to happen in order to change course from the PFAS crisis and broader chemicals governance crisis.

For policy we recommend the following:
Due to the range and diversity of economic sectors involved in chemicals governance, the policy frameworks discussed in this project should be tested to understand real-life implications of new procedures. Such tests should help to find an effective and efficient balance between extensive evaluation of all details and a workable process.

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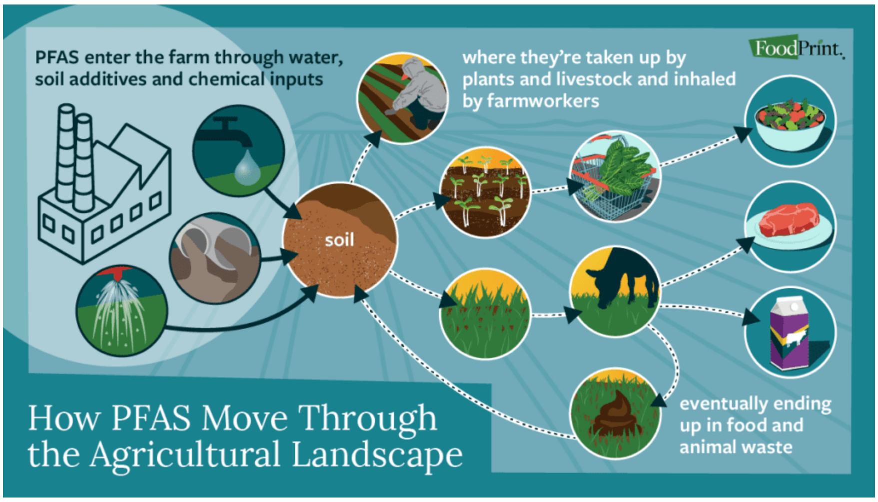
Annex 1 Calls for ACT projects

ID	3.294
Title	Detoxing EU agriculture- the case of ‘forever chemicals’ PFAS in pesticides
Case owner	Wageningen University **Science Shop project**, coordinated by Astrid Hendriksen (ENP)
Description of the assignment	**General introduction of the problem:** Per- and Polyfluoroalkyl Substances (PFAS) are a group of very persistent, often very toxic chemicals used in a very wide range of products. They pollute water resources and accumulate in soils, food crops and living organisms, including humans. Besides the famous PFAS uses in non-stick pans or in waterproof clothing, PFAS are also used in agriculture, for example in plant protection products (PPP) and biocides; in short: pesticides. In such applications, PFAS are very likely to leak into the environment. Due to growing awareness of the scale of the problem, the EU is proposing a ban on PFAS production and use. However, pesticides are not covered by this upcoming ban and as such risks escaping timely regulation, with severe consequences for human and environmental health. There is a need to get a clearer picture of the PFAS volume used in pesticides, which uses are ‘essential’ in the short term, and how the transition towards alternatives could be sped up. This requires an interdisciplinary approach of understanding the technical/chemical aspects and translating this into implications for policy. **Students are asked to:** **1. Map out** the main PFAS pathways in agricultural applications, for the Netherlands and an EU country of choice. 2. **Advise** how national policymakers can encourage the transition away from non-essential PFAS usage in pesticides. **The following questions form a starting point:** • Where are PFAS being used in agriculture? How and in what quantity are these chemicals applied? • What are consequences for humans and environment of the used PFAS pesticide in agriculture? • Can PFAS residues found on fruits and vegetables be traced back to PFAS uses in agriculture? • How can leakage into the environment be prevented when using PFAS in PPP and biocides? • What would be the consequences of moving away from PFAS in pesticides? Which uses are most ‘essential’?
Background	The case owner is the coordinating team of this Wageningen University **Science Shop project**, consisting of Astrid Hendriksen (ENP) and Freddy van Hulst (ENP). This ACT assignment contributes towards this project, which was started following a request by the Dutch NGO ‘Stichting Huize Aarde’. Huize Aarde works towards sustainable development through innovation and sharing of knowledge. As ACT group you will liaise with both the Project coordinators (WUR), and the problem owner (Huize Aarde).
Literature	• Pesticide Action Network, 2024. European citizens face increasing exposure to PFAS pesticides through fruit and vegetables. Link • Farmers’ use of PFAS pesticides can be a ticking time bomb: Feb 9, 2023. Link • EU PFAS restriction proposal. 2023. Annex XV • Cousins et al, 2019. The concept of essential use for determining when uses of PFASs can be phased out. Link • Yin and Qin, 2023. Long-Chain Molecules with Agro-Bioactivities and Their Applications. Link • Guida et al., 2023. Confirming sulfluramid (EtFOSA) application as a precursor of perfluorooctanesulfonic acid (PFOS) in Brazilian agricultural soils. Link • M. Wilcox, 2022. Pesticides Are Spreading Toxic ‘Forever Chemicals,’ Scientists Warn. Link

Confidential	**NO**
Relevant expertise & keywords	Relevant keywords are: • Pesticides • Plant Protection Products • Biocidal products • Pesticide regulation • Environmental policy Suggested master programs: MPB MML MES MBI MPS MUE MEE
Case owner	Wageningen University and Research Dr. Astrid Hendriksen, Environmental Policy Group Droevendaalsesteeg 2, (Leeuwenborch) 6708PB WAGENINGEN T: ENP secretariat: +31317488509 E: astrid.hendriksen@wur.nl mailto:r.vos@nordwincollege.nl

Title	**PFAS from farm to fork- conceptual mapping of PFAS pathways with agricultural uses**
Case owner	Wageningen Science Shop project, coordinated by Freddy van Hulst (ENP)
Description of the assignment	General introduction of the problem: Per- and Polyfluoroalkyl Substances (PFAS) are a group of very persistent, often toxic chemicals used in a wide range of products. Their presence in the environment poses a significant threat to water resources, soils, food crops, and human health. While commonly associated with non-stick cookware and waterproof textiles, PFAS are also used in agriculture, particularly in plant protection products (PPP) and biocides. These applications create a high risk of PFAS contamination in the environment.  Source: The FoodPrint of PFAS - FoodPrint Raising public awareness of this complex and largely invisible issue requires a clear understanding and visual representation of the pathways through which PFAS enter agricultural sites—such as through groundwater, air, pesticides, and veterinary medicines—and ultimately end up in food products. Given the scarcity of measured data, this project will focus on conceptual mapping and modeling, integrating knowledge from policy, food systems, environmental sciences, and communication design. The ACT team is asked to develop an interactive environment that illustrates the movement of PFAS through the environment and into the food system. This includes identifying key exposure pathways, tracing contamination sources, incorporating relevant EU policy developments, and presenting this information in an accessible and engaging way for different stakeholders. **The following questions form a starting point:** • What is the most effective interactive format (e.g., a story map) for intuitively engaging a broad audience with complex PFAS-related information? • How do PFAS residues accumulate in fruits, vegetables, livestock, and aquatic food sources? • What are the primary food and drink-related exposure pathways for humans? • How and when have PFAS been introduced into agricultural practices, and how do they transfer into food products? • How could the interactive environment be used as a tool for discussion and awareness among different stakeholder groups?
Background	The case owner is dr. Freddy van Hulst (ENP), who is the coordinator of a Wageningen Science Shop project. This ACT assignment contributes towards this project, which was started following a request by the Dutch NGO 'Stichting Huize Aarde'. Huize Aarde works towards sustainable development through innovation and sharing of knowledge. As ACT group you will liaise with both the case owner and Stichting Huize Aarde.

	The Science Shop WUR supports research projects for organizations that do not have the financial means to turn to professional consultancy bureaus. The goal of the Science Shop is to generate direct social impact by carrying out bottom-up research and creating new bridges between science and society. Students and researchers of WUR conduct research for the Science Shop. Freddy Van Hulst is the project leader of this Science Shop research project
Literature	• https://foodprint.org/reports/the-foodprint-of-pfas/ • Pesticide Action Network, 2024. European citizens face increasing exposure to PFAS pesticides through fruit and vegetables. Link • Farmers' use of PFAS pesticides can be a ticking time bomb: Feb 9, 2023. Link • EU PFAS restriction proposal. 2023. Annex XV • Cousins et al, 2019. The concept of essential use for determining when uses of PFASs can be phased out. Link • Yin and Qin, 2023. Long-Chain Molecules with Agro-Bioactivities and Their Applications. Link • Guida et al., 2023. Confirming sulfluramid (EtFOSA) application as a precursor of perfluorooctanesulfonic acid (PFOS) in Brazilian agricultural soils. Link • M. Wilcox, 2022. Pesticides Are Spreading Toxic 'Forever Chemicals,' Scientists Warn. Link
Confidential	**NO**
Relevant expertise & keywords	Relevant keywords are: • Pesticides (regulation) • Farm to fork pathways • Environmental systems analysis • Environmental policy Suggested master programs: MPS, MBI, MES, MAS, MNH, MBE, MAM
Case owner	Wageningen University and Research Dr. Freddy van Hulst, Environmental Policy Group Droevendaalsesteeg 2, Leeuwenborch 6708 PB WAGENINGEN T: ENP secretariaat: +31317488509 E: freddy.vanhulst@wur.nl

Annex 2 'Safe and sustainable' assessment for PPPs

This Annex describes how the PPP approval process could look like when following the currently available descriptions of a 'Safe and sustainable' assessment. The steps are taken from the framework as published by the EU (). Based on the authors' knowledge of the current approval process, interpretations were added to shown what a SSbD assessment would look like for PPPs.

1. **Hazard assessment** of the chemical or material in line with the EU Chemicals Strategy (CSS).
Chemicals are divided into the following groups:

- Group H1 (Most Harmful Substances according to CSS(Guiding Criteria and Principles for the Essential Use Concept in EU Legislation Dealing with Chemicals, 2024)).
- Group H2 (Substances of Concern according to CSS).
- Group H3 (Chemicals with hazard classes that are not covered in Group H1 or H2).

Hazards are assessed in a multistep approach, whenever new information becomes available, the assessment has to be reviewed. There are significant differences in hazard assessments when following the SSbD approach compared to when following the approach in the PPPR. The differences are discussed in more detail in Section 5.4.3.

2. **Human health and safety aspects** related to production and processing, including recycling and EoL.
This aspect concerns occupational health throughout the value chain. Related policy arrangements include national laws concerning occupational health (NL: Arbowet), Regulation (EC) No 1107/2009 on Plant Protection Products, a set of 5 Directives concerning indicative occupational exposure limit values, and likely several more.

In this phase, the product use is placed centrally. This assessment should identify the possible emissions throughout the value chain, considering both the chemical itself and its potential degradation products. Moreover, it possible or likely human exposure routes are identified and the related hazards estimated.

The most important difference with the current situation is in assessing 'throughout the value chain'. In the design phase of a PPP, the product developer needs to take into account which emissions are likely to occur when the product is used as intended. This requires deeper knowledge of how chemicals are used in end products, a feedback loop providing this information needs to be installed that is currently not in place.

3. **Human health and environmental** aspects in the final application phase.
This step concerns the assessment of risks for end users. Assessing safety upon application and exposure in the environment are currently also part of a risk assessment of PPPs. Current SSbD guidelines are insufficiently clear to conclude whether this evaluation would change significantly or not.

4. Environmental sustainability assessment
LCA (more specifically: environmental footprint impact assessment) is used to assess the environmental sustainability of a material or product or chemical throughout its lifecycle. If a substance or material has multiple uses, for example as an ingredient of multiple PPP mixtures for use on different crops, an LCA study has to be conducted for each combination of substance, use, and end-of-life. Like it is challenging to assess the hazards associated with a substance or product that is still at a low level of development, the same is true for assessing environmental sustainability through LCA when insufficient reliable data is available. The ex-ante LCA and prospective LCA approaches can be used to uses estimated values and scenarios to obtain a more accurate result for a product in development. The impact of the new product is compared to the to-be-replaced product in terms of the impact categories listed in the guidelines for SSbD (Caldeira et al., 2022). In a system that is yet to be developed, the performance on all indicators is combined into a single 'level'. Since this concept is still to be worked out in detail, we cannot yet analyse the potential effects of this step in SSbD on the use patterns of PPPs and the ingredients thereof. By using an LCA and developing a set of rules and guidance on how to use the LCA tool for specific product categories, it can be expected that environmental

aspects will be significantly more important than in the current situation when assessing the potential approval of PPPs and ingredients thereof.

5. Social and economic sustainability assessment

The socio-economic sustainability assessment is the last step in an SSbD analysis. This step should only take aspects into account that are not covered by any of the previous steps. The SSbD framework mentions that Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) are methods that could be used to perform the SSbD socio-economic assessment. Both are less mature than the well-known standard LCA that focuses on environmental aspects. Other methods that can form the basis for socio-economic sustainability assessment exist as well, but not a single method is advanced enough to be adopted in the SSbD framework. In currently used procedures for approval of PPPs or ingredients thereof, socio-economic effects are not at all taken into account.

Annex 3 Comparison of SSbD with current PPP regulation

Table 12 Overview of potential assessment results for co-formulants under PPPR and under SSbD

PPPR			**SSbD**			
Hazard	Active substances, safeners and synergists	Co-formulants	Hazard group	Hazard (blue: covered in PPPR)	Active substances, safeners and synergists	Co-formulants
Human health: CMR Cat 1A+1B, ED HH Cat 1	Not allowed	Not allowed	H1: Most harmful substances (CSS)	*Human health*: CMR Cat 1A+1B, STOT-RE cat 1, ED HH Cat 1, respiratory sensitation cat 1	Level 0: stop assessment, not allowed	Level 0: stop assessment, not allowed
Environment: PBT, vPvB, ED ENV cat 1, POP				*Environment*: PBT/vPvB, PMT/vPvM, ED ENV cat 1		
Human health: Carcinogenic, mutagenic, toxic to reproduction, sensitising, very toxic or toxic, explosive, corrosive.	assess in risk assessment	assess in risk assessment	H2: Substances of concern	*Human health:* Skin sensitation cat I, CMR cat 2, STOT-RE Cat 2, STOT-SE Cat 1, ED HH cat 2	Continue assessment, choose alternative if available	Continue assessment, choose alternative if available
Environment: Persistent, bioaccumulative, endocrine disrupter, neurotoxic or immunotoxic effects.				*Environment:* Hazardous for ozone layer, chronic aquatic toxicity, ED ENV cat 2		
				Reuse: negatively affects re-use and recycling of materials		
Hazards not mentioned above	Evaluation in risk assessment not mandatory	Evaluation in risk assessment not mandatory	All other chemicals = H3	*Human health*: Acute toxicity, skin corrosion, skin irritation, serious eye damage, serious eye irritation, aspiration hazard Cat 1, STOT-RE Cat 3 *Environment*: Acute aquatic toxicity	Continue assessment, ensure safety along the life cycle until less hazardous alternatives are available	Continue assessment, ensure safety along the life cycle until less hazardous alternatives are available

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