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GOVERNING POLLUTANTS: THE POLITICS OF REDUCING AGRICULTURAL PESTICIDE USE

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Abstract

Governance attempts at various levels have failed to adequately address the interconnected environmental crises of climate change, biodiversity loss, and chemical pollution. Within this context, this thesis focuses on the governance of agricultural pesticide use and explores three main research questions: How does the rise of private actors in environmental governance affect policymaking? What is the (political) role of new forms of scientific knowledge in guiding transitions toward sustainability? What role do different types of policy instruments play in governing transitions toward sustainability, taking into account the interconnected nature of sustainability problems?

The four chapters examine the effectiveness of attempted policy change in different realms of pesticide governance and politics. Using the case of private agricultural standards and the listing of hazardous substances under the Rotterdam Convention, the first chapter examines interactions between public and private actors and their consequences for environmental governance. The case shows that private actors may inadvertently affect treaty-based decision-making processes, even when public and private actors share broadly aligned goals. The second chapter explores how the production and use of policy-relevant expertise affects political outcomes, based on France's process for developing new regulations on glyphosate, the most widely used pesticide worldwide. It finds that state actors restricted the political "solution space" by steering the production of expertise. This limited the framing of glyphosate alternatives to practices considered to be economically and practically feasible by selected experts and excluded more systemic alternatives from policy debate and instrumentation. The third chapter examines the role of phase-out policies within transitions to sustainability, comparing glyphosate governance in France and Germany. By situating glyphosate within a larger pesticide-intensive sociotechnical regime, it shows the need to switch from command-and-control towards a mix of management-based policy instruments to ensure the long-term effectiveness of a glyphosate phase-out. The fourth chapter addresses the link between pesticides and biodiversity loss, examining whether and how biodiversity is integrated into agricultural policies globally. It finds little biodiversity policy integration in national policies in either developing or developed countries, and identifies leverage points for integrating biodiversity considerations into existing sectoral policies, arguing that political will is required to drive this change.

The main contribution of this thesis is to show how the rise of private actors, the production and use of new forms of scientific knowledge, and the mobilization of different kinds of policy instruments shape environmental governance in an era of transitions toward sustainability. First, indirect interactions between public and private governance mechanisms can have unexpected counteractive feedback effects. Second, the production and use of specific forms of scientific knowledge for policymaking affect the division of political responsibilities and allocations of power among actors and institutions, with the potential to either open up or close down options for sustainability transitions. Third, command-and-control instruments alone cannot enable the phase-out of problematic technologies and the systemic change required. Effective environmental governance requires policy mixes that reconcile long-term and short-term goals across multiple interconnected sustainability problems and policy areas.

Zusammenfassung

Bisherige Governance-Versuche auf verschiedenen Ebenen verfehlen, die miteinander verknüpften Umweltkrisen Klimawandel, Verlust der biologischen Vielfalt und chemische Verschmutzung angemessen anzugehen. In diesem Zusammenhang konzentriert sich diese Arbeit auf die Governance des Einsatzes von Pestiziden in der Landwirtschaft und untersucht drei Hauptforschungsfragen: Wie wirkt sich der Aufstieg privater Akteure in der Umweltpolitik auf die politische Entscheidungsfindung aus? Welche (politische) Rolle spielen neue Formen wissenschaftlicher Erkenntnisse bei der Steuerung von Übergängen zur Nachhaltigkeit? Welche Rolle spielen verschiedene Arten von Politikinstrumenten bei der Steuerung des Übergangs zur Nachhaltigkeit in Anbetracht der eng miteinander verflochtenen Nachhaltigkeitsprobleme?

In den vier Kapiteln wird die Wirksamkeit des versuchten politischen Wandels in verschiedenen Bereichen der Pestizidverwaltung und -politik untersucht. Anhand des Fallbeispiels privater landwirtschaftlicher Standards und der Auflistung gefährlicher Stoffe im Rahmen des Rotterdamer Übereinkommens werden im ersten Kapitel die Interaktionen zwischen öffentlichen und privaten Akteuren und ihre Folgen für die Umweltpolitik untersucht. Dieser Fall zeigt, dass private Akteure ungewollt vertragsbasierte Entscheidungsprozesse beeinflussen können, selbst wenn öffentliche und private Akteure weitgehend übereinstimmende Ziele verfolgen. Im zweiten Kapitel wird am Beispiel des französischen Prozesses zur Entwicklung neuer Vorschriften für Glyphosat, dem weltweit am häufigsten verwendeten Pestizid, untersucht, wie sich die Produktion und Nutzung von politikrelevantem Fachwissen auf die politischen Ergebnisse auswirkt. Es wird festgestellt, dass staatliche Akteure den politischen „Lösungsraum“ für die durch Glyphosat verursachten Probleme einschränkten. Dadurch wurde die Entwicklung von Glyphosat-Alternativen auf Praktiken beschränkt, die von ausgewählten Experten als wirtschaftlich und praktisch durchführbar angesehen wurden, und systemischere Alternativen wurden von der politischen Debatte und Instrumentalisierung ausgeschlossen. Das dritte Kapitel untersucht die Rolle der Ausstiegspolitik im Rahmen des Übergangs zur Nachhaltigkeit und vergleicht die Glyphosat-Governance in Frankreich und Deutschland. Durch die Einordnung von Glyphosat in ein größeres, pestizidintensives soziotechnisches System wird die Notwendigkeit aufgezeigt, von der Anordnungs- und Kontrollpolitik zu einem Mix aus managementbasierten Politikinstrumenten überzugehen, um die langfristige Wirksamkeit eines Glyphosatausstiegs zu gewährleisten. Das vierte Kapitel befasst sich mit dem Zusammenhang zwischen Pestiziden und dem Verlust der biologischen Vielfalt, wobei untersucht wird, ob und wie die biologische Vielfalt weltweit in die Agrarpolitik integriert wird. Es wird festgestellt, dass die Biodiversitätspolitik sowohl in den Entwicklungsländern als auch in den Industrieländern nur in geringem Maße in die nationalen Politiken integriert ist. Außerdem werden Hebelpunkte für die Integration von Biodiversitätsaspekten in die bestehenden sektoralen Politiken identifiziert, wobei argumentiert wird, dass es eines politischen Willens bedarf, um diesen Wandel voranzutreiben.

Der wesentliche Beitrag dieser Arbeit besteht darin zu zeigen, wie der Aufstieg privater Akteure, die Produktion und Nutzung neuer Formen wissenschaftlicher Erkenntnisse und die Mobilisierung verschiedener Arten von politischen Instrumenten die Umweltpolitik in einer Zeit des Übergangs zur Nachhaltigkeit prägen. Erstens können indirekte Interaktionen zwischen öffentlichen und privaten Governance-Mechanismen unerwartete gegenläufige Rückkopplungseffekte haben. Zweitens wirken sich die Produktion und Nutzung spezifischer

Formen wissenschaftlicher Erkenntnisse für die Politikgestaltung auf die Aufteilung politischer Zuständigkeiten und die Machtverteilung zwischen Akteuren und Institutionen aus, was das Potenzial hat, Optionen für den Übergang zur Nachhaltigkeit entweder zu eröffnen oder zu verhindern. Drittens können Anordnungs- und Kontrollinstrumente allein nicht den Ausstieg aus problematischen Technologien und den systemischen Wandel ermöglichen, der für einen erfolgreichen Übergang zur Nachhaltigkeit erforderlich ist. Eine wirksame Umweltpolitik erfordert einen Policy-Mix, der langfristige und kurzfristige Ziele über mehrere miteinander verbundene Nachhaltigkeitsprobleme und Politikbereiche hinweg miteinander in Einklang bringt.

Résumé

Les initiatives de gouvernance prises à différents niveaux ont jusqu'ici échoué à répondre de manière adéquate aux crises environnementales du changement climatique, de la perte de biodiversité et de la pollution chimique, qui sont étroitement liées. Dans ce contexte, cette thèse se concentre sur la gouvernance de l'utilisation des pesticides dans l'agriculture et explore trois questions de recherche principales : la façon dont la montée en puissance des acteurs privés dans la gouvernance environnementale affecte l'élaboration des politiques publiques; le rôle des nouvelles formes de connaissances scientifiques dans l'orientation des transitions écologiques ; et enfin le rôle des différents types d'instruments politiques dans la gestion des transitions écologiques, en tenant compte de la nature interconnectée des problèmes environnementaux.

Divisée en quatre chapitres principaux, cette thèse examine l'efficacité des tentatives de changement de politique dans différents domaines de la gouvernance et de la gestion des pesticides. À partir du cas des normes agricoles privées et de l'inscription des substances dangereuses sur la liste de la Convention de Rotterdam, le premier chapitre examine les interactions entre les acteurs publics et privés et leurs conséquences pour la gouvernance environnementale. Il montre que les acteurs privés peuvent, par inadvertance, influer sur les processus décisionnels fondés sur des traités, même lorsque les acteurs publics et privés partagent des objectifs largement alignés. Le deuxième chapitre étudie la manière dont la production et l'utilisation de l'expertise scientifique influencent l'adoption de nouveaux instruments de politiques publiques, en se basant sur le processus français d'élaboration de nouvelles règlementations sur le glyphosate, le pesticide le plus utilisé dans le monde. Il montre que les acteurs gouvernementaux ont limité l'« espace de solution » politique en orientant l'élaboration de l'expertise apportée par certains experts vers des pratiques considérées comme économiquement et pratiquement réalisables qui excluent des alternatives plus systémiques du débat politique et de l'instrumentation. Le troisième chapitre examine le rôle des politiques d'élimination progressive dans les transitions écologiques en comparant la gouvernance du glyphosate en France et en Allemagne. En situant le glyphosate dans un régime sociotechnique plus large à forte intensité de pesticides, il montre la nécessité de passer d'un système d'instruments fondés sur la contrainte à une combinaison d'instruments différents, de façon à garantir l'efficacité à long terme d'une élimination progressive du glyphosate. Le quatrième chapitre se penche sur le lien entre les pesticides et la perte de biodiversité, en examinant si la biodiversité est intégrée dans les politiques agricoles au niveau mondial, et de quelle façon. Il constate une faible intégration de la biodiversité dans les politiques nationales, autant dans les pays en développement que dans les pays développés. Il identifie des leviers permettant d'intégrer les considérations relatives à la biodiversité dans les politiques sectorielles existantes, en faisant valoir qu'une volonté politique est nécessaire pour impulser ce changement.

La principale contribution de cette thèse est de montrer comment la montée en puissance des acteurs privés ainsi que la production et l'utilisation de nouvelles formes de connaissances scientifiques et la mobilisation de différents types d'instruments politiques façonnent la gouvernance environnementale à l'heure de la transition écologique. En premier lieu, les interactions indirectes entre les mécanismes de gouvernance publics et privés peuvent avoir des effets contraires inattendus. En deuxième lieu, la production et l'utilisation de formes spécifiques de connaissances scientifiques pour l'élaboration des politiques publiques affectent la division des responsabilités politiques et la répartition du pouvoir entre différents acteurs et

institutions, risquant de supprimer certaines options pour les transitions écologiques. En troisième lieu, les instruments fondés sur la contrainte ne peuvent à eux seuls rendre possible l'abandon des technologies problématiques et déclencher les changements systémiques nécessaires à la réussite des transitions vers la durabilité. Une gouvernance environnementale efficace nécessite un éventail de politiques publiques qui concilient les objectifs à court et à long terme en considérant de multiples problèmes de durabilité et de domaines politiques.

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List of acronyms

ATI	Agricultural Technical Institute
BRS	Basel, Rotterdam and Stockholm Conventions
BPI	Biodiversity Policy Integration
CRC	Chemical Review Committee
CAP	Common Agricultural Policy (EU)
COP	Conference of the Parties
CBD	Convention on Biological Diversity
DDT	Dichlorodiphenyltricholorethane
ESG	Earth System Governance
EPI	Environmental Policy Integration
EPA	Environmental Protection Agency (USA)
ECHA	European Chemical Agency
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GMO	Genetically Modified Organism
GBF	Global Biodiversity Framework
GCO	Global Chemicals Outlook
IPM	Integrated Pest Management
IPCC	Intergovernmental Panel on Climate Change
IPBES	Intergovernmental Science-Policy Panel on Biodiversity and Ecosystem Services
IARC	International Agency for Research on Cancer
MLG	Multi-level Governance
MLP	Multi-level Perspective
NAP	National Action Plan (for pesticides, EU member states)
NBSAP	National Biodiversity Strategy and Action Plan (parties to the CBD)
NGO	Non-governmental organization
POP	Persistent Organic Pollutant
PIC	Prior and Informed Consent
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
STS	Science and Technology Studies
SAICM	Strategic Approach to International Chemicals Management
SUD	Sustainable Use Directive
UN	United Nations
UNEP	United Nations Environment Programme
WHO	World Health Organization

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I. SYNOPSIS

1.1 Introduction

Globally, the use of chemicals, including pesticides, has accelerated rapidly since the 1950s. The value of the output of the global chemicals industry exceeded US$5 trillion in 2017 and is projected to double by 2030, a pace that is substantially larger than the growth of the human population (UNEP 2019). Pesticides are demonstrative of overall trends in the chemicals industry: worth over $50 billion globally, the pesticide industry is expected to continue to grow substantially (UNEP 2019). Increased chemical use and dependence in agriculture and beyond means that chemical pollutants — including, but also far beyond, synthetic pesticides — have become ubiquitous in the environment and in humans, causing myriad human health problems and driving biodiversity loss worldwide (UNEP 2019, 2022e). Governments, individually and collectively, have made a variety of efforts to mitigate some of the harmful impacts of chemicals, with pesticides as a notable example. Yet despite decades of governance interventions in Europe and globally, agriculture, like many other industries, has become more dependent on chemicals than ever before (Shattuck 2021).

This dissertation proceeds in five parts: the synopsis (Part I); list of publications (Part II); summary of publications (Part III); full publications (Part IV); and discussion and conclusion (Part V). Each is further divided into sections and subsections as outlined in the Table of Contents. Section 1.1 proceeds in four sub-sections. It first presents pesticides as a case study of environmental governance and politics (1.1.1) before introducing the scope, goals, and content of the dissertation (1.1.2). It then contextualizes the problem of pesticide use (1.1.3) and risks (1.1.4) before laying out the current state of pesticide governance and policies (1.1.5).

1.1.1 Pesticides as a case study of environmental governance and politics

Governance attempts have failed to adequately protect human health and the environment from chemical pollutants at the global level (UNEP 2019, 2021b). The presence of chemicals in air, surface and groundwater, soils, and biota around the world is, together with climate change and other global environmental disruptions, among the more measurable markers of humans' outsized influence on biophysical systems (UNEP 2019). Chemicals also permeate human bodies, leaving detectable traces of manufactured materials and their metabolites in human blood, urine, and breast milk, as well as in unborn children through the transfer of contaminants in the womb. These exposures lead to a wide range of adverse effects on human health, through both acute poisoning and chronic exposure (UNEP 2019). Documented health impacts, ranging from pulmonary and cardiovascular diseases to cancers and congenital abnormalities, impose a global disease burden which the World Health Organization (WHO) estimated to have caused 1.6 million preventable deaths in 2016 (UNEP 2019).

Environmental governance can be understood as "interventions aiming at changes in environment-related incentives, knowledge, institutions, decision-making, behaviors, and identities" channeled through institutional power (Lemos and Agrawal 2009, 71). It comprises a wide range of instruments deployed by different actors, from states to private actors to non-governmental organizations and international organizations, at different levels of governance (Biermann and Pattberg 2008; Delmas and Young 2009; Haas, Keohane, and Levy 1993; Lemos and Agrawal 2009; Pattberg and Widerberg 2015; H. Selin and VanDeveer 2015a; O. Young 1994). The governance of pesticides is one important area of environmental governance; yet, because pesticides cause multi-faceted problems, environmental concerns are only one dimension of pesticide governance. National and international pesticide policy agendas instead focus on reconciling three main — and potentially competing — goals: food production, environmental protection, and human health. Understanding and qualifying governance "failures" therefore depends upon the specific issues being assessed and the context and scope of the assessment, as well as interactions between and effects of governance on different goals. Moreover, although governance interventions have been successful in decreasing some impacts of pesticides at the local level, scientific assessments point to the detrimental *systemic* impacts of pesticides on human health and the environment which even the most stringent regulations in the world have failed to address (Helepciuc and Todor 2021; IPBES 2016, 2019; UNEP 2021b, 2022e).

Pesticides provide a useful case through which to examine environmental governance due to both their theoretical and empirical relevance. Their empirical relevance is underlined not only by the growing risks they pose to human health and the environment, but also considerable policy momentum on addressing these various risks at different levels of policymaking in recent years. At the international level, pesticides are specifically targeted in the post-2020 Global Biodiversity Framework's pollution reduction target under the Convention on Biological Diversity and in draft recommendations for chemicals governance beyond 2020 under the Strategic Approach to International Chemicals Management (SAICM) (UNEP 2023). At the same time, transnational private agricultural standards — which have become predominant drivers of contemporary agri-food systems globally — are increasingly adopting more stringent pesticide use restrictions (Henson and Reardon 2005). At the EU level, the Green Deal includes a goal of decreasing pesticide use and risks by 50 percent by 2030 (European Commission 2020c). France, an example of a country which has experimented with different instruments for governing pesticides since the early 2000s, has recently aimed to ban multiple widely used pesticides within a few years. These attempts to more stringently govern pesticides raise a wide number of theoretical and empirical questions.

Academic literature on the politics of pesticide use has broadly focused on three main areas: the roles of science, politics, and international cooperation in national and international policymaking (Allan, Downie, and Templeton 2018; Boardman 1986; Chasek, Downie, and Brown 2014; Hough 1998; Jouzel 2019; Karlsson 2000; Kohler 2019a; Kummer 1999; H. Selin 2010; Watson 2018); the impacts of the corporate power of the pesticide industry (Boardman 1986; Bosso 1987; Harrison 2011; Hough 1998; Watson 2018); and civil society action to address different impacts of pesticides and to promote alternatives (Ackerman-Leist 2017; Boardman 1986; Harrison 2011; Hough 1998). Social science theory on pesticide politics has focused on the roles of different actors, their interests, and their modes of exercising power (Boardman 1986; Bozzini 2017; Clapp 2021a; Hough 1998; Jouzel 2019; Watson 2018). Many of the "failures" of governance interventions have been attributed to the multiple channels of power of corporate actors in the agri-food sector. The pesticide industry in particular operates through different channels of power in order to defend its profit-maximizing interests and to maintain institutional structures which favor pesticide-dependent agricultural production systems (Clapp 2021c; Clapp and Fuchs 2009; Cohen 2019; Glenna and Bruce 2021; Sosa et al. 2019; Watson 2018). Pesticide companies' strategies to defend their products have involved tactics not only to defend a specific *model* of industrial agriculture but also to delegitimize alternative approaches that decrease chemical dependence (McIntyre et al. 2009; Watson 2018). These strategies include participating more directly in policymaking processes, for example through lobbying, as well as shaping scientific knowledge production. In response to these tactics, civil society actors representing public interests related to human health and the environment have organized various forms of resistance, both exposing the risks of pesticides and supporting the development and transitions towards other forms of agriculture (Ackerman-Leist 2017; Cohen 2019; Harrison 2011).

Interventions to reduce agricultural pesticide use have focused predominantly on farmers and have tended to be regulatory in nature (Coderoni et al. 2021; A. Hall 1998). With a growing number of actors now influencing pesticide use, approaches to pesticide governance need to be expanded to embrace a broader perspective on agri-food systems — one that encompasses a wider range of actors, instruments, types of knowledge, and levels of governance than those targeted now.

1.1.2 Scope, goals and content of this thesis

This thesis expands knowledge about environmental governance by adopting an actor-focused, multi-level approach to analyze the politics of reducing pesticide use. Its overall aim is twofold. First, it empirically investigates and analytically examines pesticide governance in the agricultural sector in different contexts and at different levels of policymaking. Second, drawing on this analysis, it explores issues in environmental governance related to actors and institutions, processes and instruments, and the role of environmental knowledge in decision-making. In doing so, it addresses ongoing policy debates on decreasing the use and risks of pesticides in line with recent scientific knowledge on pesticide risks and pesticide alternatives. It addresses the following three research questions: How does the rise of private actors in environmental governance affect policymaking? What is the (political) role of new forms of scientific knowledge in guiding transitions toward sustainability? What role do different types of policy instruments play in governing transitions toward sustainability, taking into account the interconnected nature of sustainability problems? These research questions are discussed in more detail in section 1.3.

The main contribution of this thesis is to show how the rise of private actors, the construction and use of new forms of scientific knowledge, and the mobilization of different kinds of policy instruments shape environmental governance in an era of transitions toward sustainability. It also contributes new empirical data and advances knowledge to a growing body of social science research on strengthening global, EU, and national pesticide governance. It does so across four substantive chapters by drawing on and contributing to debates from three primary literatures: environmental governance, Science and Technology Studies (STS), and sustainability transitions. Based on primarily qualitative methods (participant observation, semi-structured interviews, and document analysis), each chapter examines a different facet of pesticide governance and politics to narrow in on specific components and levels of governance across cases of attempted policy change.

Theoretically, the different chapters of this thesis contribute to debates in environmental governance on the roles of public and private actors in environmental governance, the role of phase-out policies within sustainability transitions, and the role of knowledge production in shaping the scope of policy options to advance sustainability transitions. Empirically, they contribute to international, EU-level, and national debates on different aspects of governing pesticides, with the aim of decreasing pesticide use and risks in line with differing norms and objectives in these various contexts. Overall, the thesis is explicitly oriented to inform action on pesticides, similarly to sustainability research in other domains (H. Selin and Selin 2020).

Though pesticides are employed for a wide range of purposes in a variety of sectors, the focus of this thesis is on pesticide use in the agricultural sector. This focus is justified on several grounds. First, the agricultural sector has been the subject of many calls for transformations to sustainability (Caron et al. 2018; IPBES 2019; Jørgensen et al. 2022; McIntyre et al. 2009) due to its strong relationship to a variety of sustainability challenges, including climate change (IPCC 2022), biodiversity loss (IPBES 2016, 2019), and diverse social problems linked to agricultural intensification and changes in supply chain structures (Rasmussen et al. 2018). Second, agriculture is the main sectoral driver of pesticide use globally by volume and area of application, therefore providing the greatest opportunity for mitigating the impacts of pesticide use on the environment (Shattuck 2021; Stoate et al. 2009; UNEP 2022e). Third, examining pesticide use in agriculture provides a sector-based entry point into understanding governance dynamics. Sectors are both key targets of governance and sites of socio-economic organization; as such, they are critical analytical entities for understanding how policies are made (Mermet 2011; Reber et al. 2022). A sectoral approach recognizes that sectors comprise an ensemble of actors with specific interests who are both the subject and the target of public policies governed by specific institutions (Jacquot and Halpern 2015; Muller 2019). It also emphasizes that sectors are the fora within which the definitions of problems, as well as goals for the future, are defined, impacting which governance interventions are considered legitimate (Meadowcroft 2009).

Each chapter of this dissertation addresses politics at a different level of governance, including the ways in which multi-level governance dynamics may impact sustainability outcomes. The first two chapters examine recent policy processes to narrow in on the role of specific actors and the incorporation of scientific knowledge in policies aiming to strengthen pesticide governance — or lack thereof. The second two chapters are forward-looking, taking an evaluative-descriptive approach to current policies to examine possible leverage points for future change. The chapters span different geographical scopes: the first and fourth focus on pesticide and agricultural policies from an international perspective; the second and third address the case of glyphosate in the EU, thereby honing in on the governance of a specific legacy pesticide at the regional and national levels. France and Germany are given particular attention due to their proposals for national bans on the substance.

The first chapter (**Paper I**) examines the interactions between public and private actors in international pesticide governance and the consequences of these interactions for governance outcomes, focusing on private agricultural standards and the listing of substances under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade.

The second chapter (**Paper II**) focuses on the recent development of new restrictions on glyphosate use in France, examining how the production of specific forms of knowledge for policymaking and the translation of this knowledge into new regulations affect the division of political responsibilities and allocations of power among different actors and institutions.

The third chapter (**Paper III**) focuses on the governance of glyphosate in France and Germany, using the concepts of sociotechnical lock-in and the governance of discontinuation to analyze the role of phase-out policies within sectoral sustainability transitions.

Finally, **Book Chapter I** provides a link between pesticides and biodiversity loss, reviewing the structural changes in agricultural practices which drive pesticide use. It examines whether and how biodiversity is integrated into agricultural policies globally and includes suggestions for transformative biodiversity governance in the agricultural sector.

1.1.3 Pesticides and their use

Pest control practices have been used since the beginning of agricultural cultivation to protect crops and to increase agricultural productivity (Hough 1998; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; UNEP 2022e; Watson 2018). Early methods included manual weeding and removing insect larvae from plants (Hough 1998; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). The earliest records of the application of inorganic compounds (such as arsenic, fluorine, lead, and mercury) to control insects date back to at least 2500 BC in Mesopotamia (Watson 2018). However, early pest protection primarily focused on the systematization of practices to remove pest habitats and prevent their proliferation, such as by installing crop rotations and removing crop residues after harvesting (Hough 1998). Although chemical (or synthetic) pest protection began to proliferate in the late 19^{th} century, the intensive use of chemical pesticides did not begin until the Second World War.

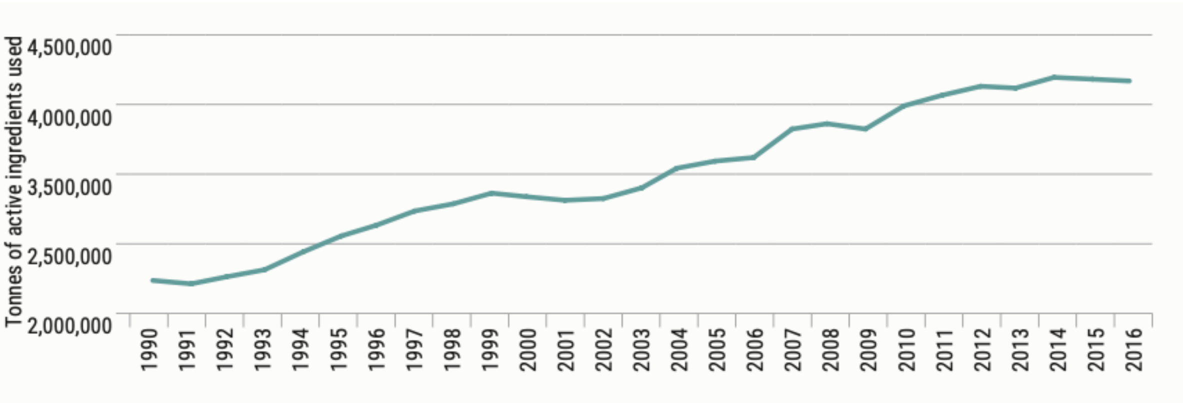
The term "pesticide" refers to any substances used for protection from harmful or undesirable entities, or "pests", as designated by humans (Boardman 1986; Hough 1998). It includes chemical substances and biological agents, the latter of which ("biopesticides") include substances extracted from plants and/or other (micro-)organisms to control pests (Watson 2018). This thesis uses the term 'pesticides' more restrictively to refer to chemical products used for plant protection, since the term is used extensively worldwide and in a variety of policy settings. Pesticides used for plant protection can be broadly divided into three categories: herbicides (targeting weeds), fungicides (targeting fungi), and insecticides (targeting insects) (Hough 1998).

Chemical pesticides consist of a combination of substances, including an "active substance" or "active ingredient" responsible for pest control (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). These are accompanied by co-formulants or adjuvants that dilute or help disseminate the active substances (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). "Pesticide formulations" (i.e. pesticide products) therefore refer to the mix of active substances and co-formulants. Pesticide companies develop multiple products for a given market based on a single active substance. Currently, pesticide companies offer thousands of formulations containing about 600 different active substances, a six-fold increase compared to 1960 (Phillips McDougall 2018).

Chemical pesticides can be divided into a variety of sub-categories according to different criteria, such as their chemical composition (e.g. organochlorines, organophosphates, phenoxyacetic acids, carbamates, synthetic pyrethroids), the risks they pose to human health and the environment, or their modes of use (Hough 1998; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Herbicides, for example, can be applied to a given crop to remove weeds between cultivated species (such as in vineyards), but can also be used as a desiccant to help dry crops (such as in the case of oilseeds) (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Similarly, insecticides can be applied on plants above the soil, but also to treat soils or to coat seeds, imbuing the resulting plant with insecticidal properties. Farmers typically combine a mix of different herbicides, insecticides, and fungicides on a single cultivated crop.

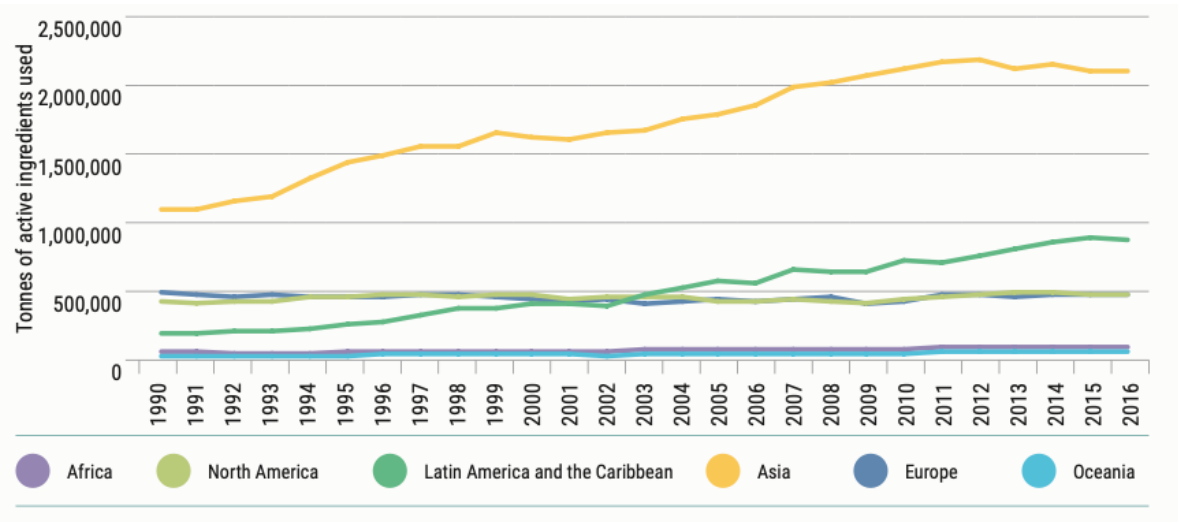
Globally, the sales volume of active substances exceeds 4 million tonnes and is expected to grow significantly, particularly in the Global South (UNEP 2019) (Figure 1). Pesticide use trends vary among regions, with Asia and Latin America experiencing substantial growth (Figure 2). Although pesticide use intensity per hectare tends to level off as countries become wealthier, wealthier countries still use more pesticides per unit of production (UNEP 2022f). A comparison of international pesticide data shows no clear reduction in total pesticide use intensity over time, since decreases in insecticide use are often offset by increases in herbicide and fungicide use (Schreinemachers and Tipraqsa 2012). Recent assessments suggest a slight decreasing trend in pesticide use intensity per area of cropland in high-income countries, possibly due to specific policies or the adoption of more efficient pesticides (UNEP 2022b). However, overall pesticide use per unit of crop output increases with wealth, despite policies enacted in wealthy countries (UNEP 2022b). The exact reasons for sustained high pesticide use in wealthier countries are not fully understood and may be influenced by agronomic, climatic, economic, and regulatory factors (Faraldo et al. 2021; UNEP 2022b). In summary, pesticide use intensity in high-income countries does not decrease as expected, despite significant policy efforts.

Figure 1: Global use of pesticide active substances by volume since 1990 (tonnes of active substance).



Source: UNEP (2022).

Figure 2: Pesticide use in agriculture by region (tonnes of active substance).



Source: UNEP (2022).

1.1.4 Growing risks from pesticide use

Rachel Carson is well-known as the initial and most influential scientist who brought attention to the varied and widespread detrimental impacts of pesticides on ecosystems and public health (Carson 1962). Her landmark work, *Silent Spring*, raised public awareness about pesticides and directly influenced the development of environmental regulations around the world (Clark 2017; Jas 2007; Lensing 2020; Rome 2003). This section examines the growing risks posed by the impacts of pesticides on human health and ecosystems.

Pesticides have a range of impacts on human health through various paths of exposure (Charbonnier et al. 2015; Inserm 2021; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; Seneff 2021; UNEP 2021a; Watson 2018). The effects of toxicity can be acute (i.e. through direct/short-term exposure) or chronic (through continued low dose exposure over long periods) (Boardman 1986). Chronic farmworker exposure to pesticides has been strongly linked to non-Hodgkin's lymphoma, multiple myeloma, prostate cancer, Parkinson's disease, cognitive disorders, and certain respiratory disorders (Inserm 2021; Starks et al. 2012). A survey found that over 40 percent of farm workers worldwide suffer from unintended acute pesticide poisoning after a single exposure (Boedeker et al. 2020). Personal protective equipment and educational programs for farmers have been the main intervention for reducing the health risks of pesticides, but research shows that the effectiveness of such equipment is likely overestimated (Garrigou et al. 2020; Watterson 2001). Because pesticide vapors enter the atmosphere through spraying, drifting in the wind, and evaporating from plants (Aubertot et al. 2005; Hough 1998), residents in agricultural areas are also exposed to pesticide air pollution (Ackerman-Leist 2017; Dereumeaux et al. 2020; Harrison 2011; Inserm 2021). The associated risks require continued investigation because health impacts are multi-factorial and chronic cases are difficult to identify.

People are also exposed to pesticides through consumption of contaminated food or drinking water (Hough 1998; UNEP 2021a). In contrast to the localized health problems described above, pesticide residues impact the health of consumers far from production. The mechanisms, as well as the extent and magnitude, of these health impacts are subjects of continued dispute and studies are rare due to the long-term nature of the impacts of exposure. One study found that reducing dietary intake of pesticide residues in fruit and vegetable consumption decreases mortality, while consumption of high-pesticide-residue products can "cancel out" the beneficial health impacts of consuming fruits and vegetables (Sandoval-Insausti et al. 2022). In the EU, analyses of pesticide residues on food conducted by NGOs show high levels of contamination of fruits and vegetables, while analyses by food safety authorities indicate that almost all pesticide residues (95 percent) fall below the legal limits aiming to ensure safe consumption (Carrasco Cabrera and Medina Pastor 2022; Pesticide Action Network Europe 2022). Safe levels of consumption remain a highly debated topic.

Similarly to other chemicals, pesticide exposure and impacts are strongly related to equity and justice considerations (Arcury and Quandt 2009; Donley et al. 2022; Ezeonu 2021; Harrison 2011, 2014; Williams 2018). Women and children are disproportionately vulnerable to the impacts of pesticides: pesticides can impact women's fertility and the development of children in the womb, and children can be more strongly affected than adults by pesticide exposure (Inserm 2021; Jacobs and Dinham 2003). Inequalities in exposure to chemicals also occur between countries in the Global North and Global South, with people in many Global South countries routinely exposed to higher concentrations of pollutants (UNEP 2019). This is often due to weaker regulations, as well as the dumping of pollutants and waste by the Global North countries in the Global South (IISD 2017). Within countries which have strong chemical regulations, chemical pollution still disproportionately affects poor and marginalized communities, due to the locating of industrial sites in disadvantaged neighborhoods combined with more deeply rooted historical legacies of institutionalized discrimination (see, for example, Cushing et al. 2022; Liboiron 2021). In the case of pesticides, many formerly colonized territories suffer from widespread health impacts resulting from the indiscriminate use of pesticides to support monocultural production of key export crops such as sugar, bananas, or tobacco, which in many cases continues to this day (Brisbois, Spiegel, and Harris 2019; Ezeonu 2021; Ferdinand, Malcom 2021; Williams 2018). These impacts often remain under-documented due to structural power imbalances and a lack of resources to investigate exposure. Pesticide residues also travel long distances across territorial borders through environmental transport and affect people and ecosystems beyond the jurisdiction of countries in which they are produced and/or used (UNEP 2022c).

Pesticides also pose myriad risks to the environment (Carson 1962; Hough 1998; IPBES 2016, 2019; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; Stoate et al. 2009; UNEP 2021a). The overuse of synthetic chemicals in agriculture is polluting soil, water, and air (IPBES 2019; Jørgensen et al. 2022; UNEP 2019, 2022c). Pesticides and their metabolites are among the main sources of chemical pollution worldwide (UNEP 2019). Soil contamination has become an increasing concern since pesticides can persist for decades, impacting non-target species and soil structure, with the potential to be transported offsite (IPBES 2018). In the EU, a majority of agricultural soils contain pesticide residues, including pesticides which have been banned for decades, such as DDT (Silva et al. 2019). Pesticides also contaminate surface and groundwaters worldwide; as in soils, many pesticides currently detected in water samples have been banned for years, if not decades (Hough 1998; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; Van Maanen et al. 2001; Mas et al. 2020; Schreiner et al. 2016; UNEP 2021a). Drinking water around the world is often contaminated above regulatory safety thresholds (Syafrudin et al. 2021). In the EU, 6.5 and 7.3 percent of groundwater and surface water, respectively, have failed to achieve "good chemical status" (i.e., exceeded the maximum concentrations of pollutants permitted to meet environmental quality standards) due to high concentrations of pesticides (European Commission 2020b). Another study suggests that this may be an underestimate: half of the streams analysed in 10 countries across Europe contained at least one pesticide above permitted levels, with herbicides as the main pollutant across samples (Casado et al. 2019).

The largest negative environmental impact of widespread pesticide contamination is the loss of terrestrial and marine biodiversity (IPBES 2019; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Chemical pollutants have been ranked as one of the five direct drivers of global biodiversity loss (IPBES 2019; Jørgensen et al. 2022; UNEP 2019). Because biodiversity loss is driven by multiple factors, the exact contribution of pesticides is not always well-understood, but it is likely that the extent of chemicals' influence as drivers of biodiversity loss has been underestimated (Alliot et al. 2022; Groh et al. 2022).

Recent scientific assessments have enhanced understandings of the magnitude and precise mechanisms of biodiversity loss driven by pesticides (Carson 1962; IPBES 2016, 2019). The high levels of pesticide contamination in streams is a key driver of reduced aquatic biodiversity (Beketov et al. 2013). Pesticides also negatively affect the abundance, species richness, and community structure of soil biodiversity, notably coupled with other common practices in intensive agriculture, such as intensive rotations (Orgiazzi et al. 2016; Tsiafouli et al. 2015) Across marine and terrestrial environments, the main organisms directly affected by pesticides are insects, whose declining populations affect entire ecological food chains. Several recent studies have demonstrated drastic declines in insect populations at the local and global levels (Hallmann et al. 2017; Sánchez-Bayo and Wyckhuys 2019; Seibold et al. 2019; Wagner 2020). Designed to kill insects, insecticides in particular have been shown to be a major direct contributor to insect decline, and in particular to the loss of pollinators, on which three-quarters of global food production depend (IPBES 2016, 2019). Globally, pesticides, along with land cover change, are the most important drivers of pollinator decline, affecting both population sizes and the overall diversity of pollinators (Dicks et al. 2021). Scientific studies have demonstrated both the direct and indirect adverse impacts of a new class of pesticides, "neonicotinoids" (or "neonics"), with the majority of studies focusing on bees. Neonicotinoids are used to treat seeds are characterized by a systemic mode of action: from the seed, they are absorbed by the plant's vascular system and expressed in the plant's leaves, pollen, and nectar, achieving their desired effects by attacking insects' nervous system. They remain in the plant tissue at consistently low doses, precluding the need for frequent plant spraying. Studies show that these products impair bees' immune systems, rendering them more susceptible to infections (Ellis 2022; Foucart 2019; Sánchez-Bayo and Wyckhuys 2019; Wood and Goulson 2017).

Aside from the organisms they are directly toxic to, pesticides also *indirectly* decrease biodiversity (IPBES 2016, 2019; UNEP 2022c). Because insects are an important part of the diets of birds, insecticides such as neonicotinoids are a major indirect driver of declines in bird populations and other species which depend on them (Hallmann et al. 2014; van der Sluijs et al. 2015). Herbicides, although not directly toxic to insects, reduce the density and diversity of plants upon which insects depend for food and habitats (IPBES 2016; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Therefore, even herbicides with no acute toxic effects on certain insects and birds can drive their population decline through habitat loss (Brühl and Zaller 2019). Finally, the use of multiple pesticides at the same time often has interactive effects, such as when the use of certain fungicides enhances the toxicity of insecticides (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022).

The overuse use of pesticides has also led to widespread pest resistance to pesticides, leading to a "treadmill" of pesticide use in which farmers are forced to constantly adapt their pest management strategies, usually increasing their pesticide use over time (Cowan and Gunby 1996; UNEP 2021a). This often leads to higher costs for farmers and can put the feasibility of their operation at stake.

Lastly, pesticides contribute to climate change through their production and use. The manufacturing, packaging, transportation and disposal of pesticides produce greenhouse gas emissions, the exact magnitude of which is not currently known due to a lack of information and methodologies for their estimation (Pesticide Action Network North America 2022; Tubiello et al. 2022). However, the production of pesticides is known to be energy intensive, emitting more greenhouse gases than fertilizer production (Rosa and Gabrielli 2023). In the EU, the chemical industry as a whole is the third emitter of carbon dioxide emissions behind the cement and iron and steel industries (European Commission 2023). Chemical pesticides are synthesized from fossil fuels and some are themselves powerful greenhouse gases; others emit greenhouse gases after their application; in yet other cases, their use can significantly increase the release of powerful greenhouse gases such as nitrous oxide and ozone (Das et al. 2022; Spokas 2003).

Overall, the numerous risks posed by pesticides result in significant societal costs (Alliot et al. 2022; CGEDD, IGAS, and CGAAER 2017; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; UNHCR 2017). Growing understanding of these risks — particularly to biodiversity — has increased attention to pesticides in various policy spheres.

1.1.5 Pesticide governance and policies

In order to better situate contemporary debates on pesticide governance, this section provides a brief overview and examples of a few key pesticide governance instruments and mechanisms at different levels of governance. A comprehensive review of the regulatory and policy environment for pesticide management was recently published by the United Nations Environment Programme (UNEP) (see UNEP (2022b)). Rather than discussing this landscape in detail, this section focuses on recent policy developments regarding pesticides at the international level, in the EU, and in France, which has been particularly active in pesticide policymaking since the early 2000s. The theoretical debates relevant to this governance landscape are then discussed in section 1.3.2.

International level

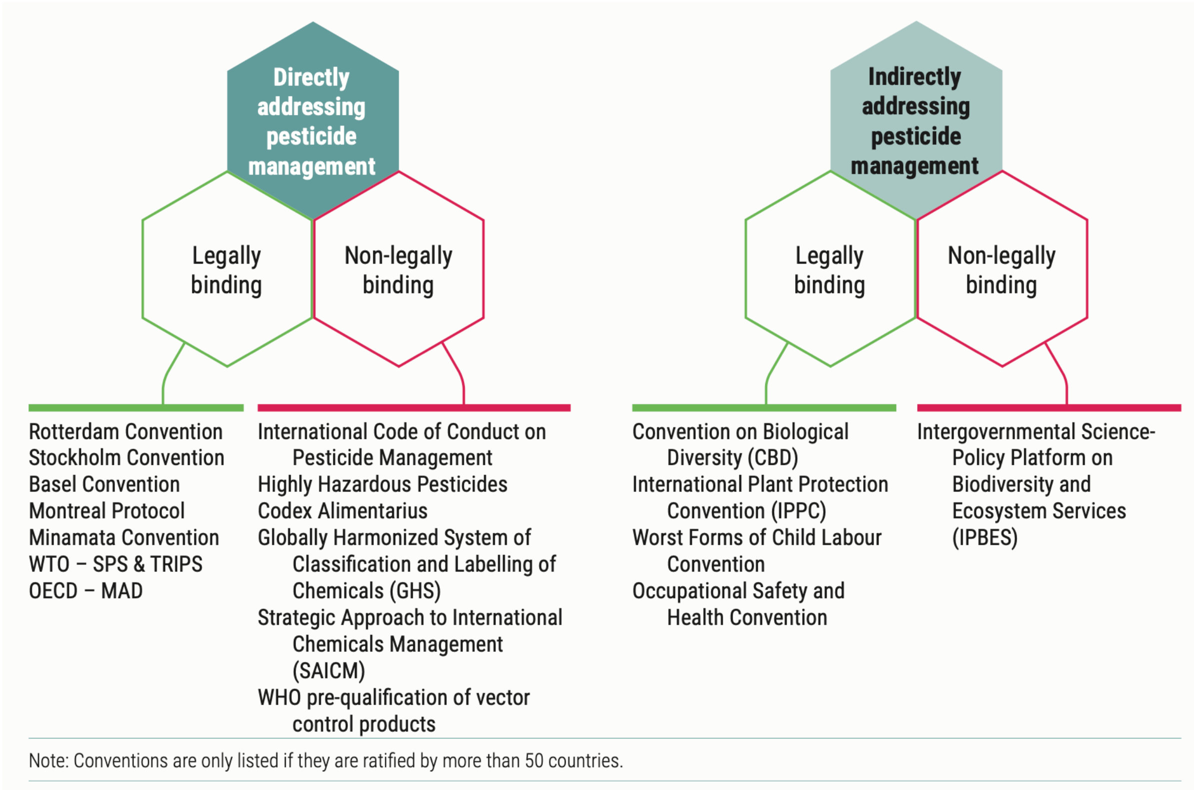
At the international level, pesticides are addressed directly and indirectly by both legally binding and non-binding instruments (Figure 3). Three main treaties form the core of the "chemicals regime:" the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the Stockholm Convention on Persistent Organic Pollutants (referred to jointly as the BRS Conventions) (H. Selin 2010). The BRS Conventions are central instruments in the international governance of chemical substances which address different stages of the production, use, and trade of chemicals and waste through different mechanisms (H. Selin 2010). Among these chemicals, a select list of pesticides is subject to specific control mechanisms (Kinniburgh et al. 2023). Since 2008, the BRS conventions have held joint meetings to enhance synergies between the treaties' overlapping objectives (Allan, Downie, and Templeton 2018).

Overall, the BRS conventions remain the main treaties which cover pesticides in continued use today. In addition, the Montreal Protocol, which requires the phase-out of ozone-depleting substances, covers only one pesticide, methyl bromide, but has had significant impacts: between 1999 and 2018, the volume of methyl bromide used decreased 99.6 percent[1] (UNEP 2022b). The fifth treaty directly addressing pesticides is the Minamata Convention, in which pesticides containing mercury must be phased out (UNEP 2022e). Although mercury compounds were widely used as pesticides in the past, they are no longer a significant source of mercury emissions. The other main legally binding instruments affecting pesticide use aside from these five treaties are agreements under the World Trade Agreement. Designed to ensure

[1] This excludes uses of methyl bromide exempted from the Protocol, notably to control pests and pathogens in quarantine and pre-shipment. These uses are closely monitored and have remained stable for the past two decades (UNEP 2022e).

that food traded internationally is safe, the WTO established a regime of "maximum residue limits" (MRLs) — or maximum legally tolerated doses of pesticide traces in food or feed — which is operationalized through the Codex Alimentarius of the Food and Agriculture Organization (UNEP 2022b). A variety of voluntary initiatives, including the FAO International Code of Conduct on Pesticide Management and SAICM, address different parts of the pesticide life cycle not covered by these treaties. Both lend particular attention to "highly hazardous pesticides" (HHPs), defined by the International Code of Conduct as "pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment according to internationally accepted classification systems" (UNEP 2022b, 22). While strictly regulated in some countries, HHPs remain in widespread use in many countries.

Figure 3: Key international instruments and mechanisms which address pesticide management and use.



Source: UNEP (2022).

International organizations, scientists, and NGOs have criticized the chemicals treaties for their weakness in governing pesticides effectively and have called for stronger implementation of existing instruments and/or the establishment of new instruments to strengthen global chemicals governance (Honkonen and Khan 2017; Jansen and Dubois 2014; Steinhäuser et al. 2022; UNEP 2022d; UNHCR 2017). Highlighting their weak performance to date, UNEP has emphasized the potential for strengthened implementation of existing international chemical conventions to substantially reduce the adverse impacts of chemicals and waste (UNEP 2021b). Echoing proposals from NGOs such as Pesticide Action Network, the 2017 UN Special Rapporteur on the Right to Food has pointed to the "critical gap" in current global chemicals governance and urged the international community to "work on a comprehensive, binding treaty to regulate hazardous pesticides throughout their life cycle" (UNHCR 2017, 22). Scholars have called for a global legally binding framework for the sustainable management of chemicals throughout their lifecycles, highlighting interactions between chemicals, climate change, and biodiversity loss (Steinhäuser et al. 2022). The case for strengthening chemicals governance is bolstered at the international level by a UN General Assembly decision in 2022 to enshrine a “clean, healthy and sustainable environment” as a human right (United Nations General Assembly 2022). Addressing the systematic risks posed by the overuse of pesticides is therefore now recognized as a part of multiple human rights: the right to a clean environment, the right to food, and the right to health.

In recent years, attention to pesticides has grown in international policymaking. Though delayed by the Covid-19 pandemic, discussions on the post-2020 agenda for global governance of both biodiversity and chemicals were ongoing during the writing of this thesis. Adopted in December 2022, the post-2020 Global Biodiversity Framework (GBF) under the Convention on Biological Diversity (CBD) includes pollution reduction as one of its 23 global targets for urgent action by 2030. Target 7 of the 2022 Kunming-Montreal GBF reads as follows:

> Reduce pollution risks and the negative impact of pollution from all sources, by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: reducing excess nutrients lost to the environment by at least half including through more efficient nutrient cycling and use; *reducing the overall risk from pesticides and highly hazardous chemicals by at least half* including through integrated pest management, based on science, taking into account food security and livelihoods (UNEP 2022f, 9)

A series of meetings on international chemicals management, initially scheduled for 2020, will now take place in September 2023: the fourth session of the Intersessional Process for Considering the Strategic Approach to International Chemicals Management (SAICM), the Sound Management of Chemicals and Waste Beyond 2020 (IP4.3), and the fifth meeting of the International Conference on Chemicals Management (ICCM5). During these meetings, stakeholders will consider the draft recommendations for SAICM beyond 2020 (UNEP 2023). The proposed targets include the elimination of the use of Highly Hazardous Pesticides in agriculture by 2030 and the implementation of government policies and programs to increase support for non-chemical alternatives including agroecology (UNEP 2023). International discussions have also been initiated to establish a global Science-Policy Panel on chemicals and waste, in the context of more general calls for strengthening science-policy interfaces for chemicals and waste through multiple different mechanisms, at different levels (Brack et al. 2022; UNEP 2020; Wang et al. 2019, 2021).

In addition to state-led initiatives governing pesticides, transnational private initiatives aiming to reduce pesticide use have grown rapidly in recent years, notably environmental certification schemes and private standards. The proliferation of environmental certification and private standards — widely documented across specific sectors, from telecommunications to education to agriculture — has been a key marker of the shift in transnational governance towards privatization (see Loconto and Busch (2010) for an overview). Part of the broader trend of private standardization, private agricultural standards have become predominant drivers of contemporary agri-food systems globally, beginning in the 1990s (Henson 2008). Many standards require pesticide use monitoring and/or the implementation of integrated pest management (IPM) and/or the prohibition of specific pesticides, among other requirements (UNEP 2022e). However, no assessments of the impacts of such standards on pesticide use or risks have been conducted so far (UNEP 2022e). Beyond the effectiveness of such standards, the implications of the rise of private standards for different governance processes and the interaction between various actors and institutions has been little examined.

EU level

The multi-faceted EU Green Deal is a political program to transform Europe into a climate-neutral continent by 2050 while simultaneously addressing a range of other sustainability issues. The EU is a global leader in chemicals governance, an area currently undergoing reforms as part of this broader agenda of transformations to sustainability. It includes the 2030 Climate Target Plan, the Farm to Fork Strategy and Organic Action Plan, the Biodiversity Strategy for 2030, the Chemicals Strategy for Sustainability, the Zero Pollution Action Plan, and the Circular Economy Action Plan, as well as other strategies which address sustainability (such as the European Industrial Strategy). The Farm to Fork Strategy includes a goal of decreasing pesticide use and risks by 50 percent by 2030 (European Commission 2020c) and the Zero Pollution Action plan aims for a toxic-free environment by 2050, enabled by a shift towards a sustainable chemicals industry and a circular economy where chemicals are intended to be "sustainable by design" (European Commission 2021b).

In the EU, pesticides are regulated under the 2009 "Pesticide Package" and under the general framework regulation for all chemicals, Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). The authorization process for any chemicals produced or imported into the EU is governed by REACH, adopted in 2006, which also established the European Chemical Agency (ECHA). Pesticides have become a particular focus of EU policy due to growing public concerns and growing knowledge of risks demonstrated by recent scientific assessments (European Commission 2022d). Public concern about pesticide risks has been reflected directly in two citizens' initiatives: "Ban glyphosate and protect people and the environment from toxic pesticides" and "Save bees and farmers! Towards a bee-friendly agriculture for a healthy environment". These initiatives called on the European Commission to set mandatory reduction targets for pesticide use, to restore biodiversity, and to support farmers in transitions to more sustainable practices (European Union 2017, 2019).

The EU's Pesticide Package included the adoption of *Directive 2009/128/EC of the European Parliament and of the Council of Oct 21 2009 establishing a framework for Community action to achieve the sustainable use of pesticides* (Sustainable Use Directive, hereafter SUD), which marked the beginning of an EU policy agenda aiming to promote a shift towards IPM practices and the use of low-risk pesticides. The SUD required each member state to develop a National Action Plan (NAP) detailing how it will fulfill the Directive's objectives. Despite this multi-level governance architecture, an evaluation of the SUD by the European Court of Auditors found "limited progress in measuring and reducing the risks" of pesticide use in 2020 due to weaknesses in the current EU framework (European Court of Auditors 2020). The European Commission has acknowledged that "the current rules of the [SUD] have proven to be too weak and have been unevenly implemented. Also, insufficient progress has been made in the use of Integrated Pest Management as well as other alternative approaches" (European Commission 2022c). As a result, the European Commission proposes to transform the existing SUD into a regulation (European Commission 2022d). In contrast with a directive, which outlines results that must be achieved but leaves implementation and legal transposition in the hands of member states, a regulation would be legally binding for every member state. At the time of writing, this proposal remains contentious and is under continued discussion.

Overall, the failure of the past decade of pesticide governance in the EU to decrease pesticide use in a majority of its member states suggests that current governance approaches are not effective and that significant reforms are necessary to reach EU objectives (Helepciuc and Todor 2021; Möhring, Ingold, et al. 2020). Given its influence on environmental politics and policymaking in its periphery and globally, the EU's pesticide governance and on-going reforms warrant further attention (H. Selin and VanDeveer 2015b).

National level: France as a pertinent example
At the national level, France has experimented with different instruments for governing pesticides since the early 2000s. Among EU member states, France is the largest user of pesticides by volume after Spain and the ninth largest per hectare; it is also among the biggest users of pesticides in the world (Faraldo et al. 2021). Agriculture accounts for 98.5 percent of the country's pesticide use by volume (CGEDD, IGAS, and CGAAER 2017). France adopted pesticide action plans before member states were required to do so under the SUD, in light of scientific evidence of the detrimental national impacts of pesticide use in the early 2000s (Maxim 2022). Launched in 2008, France's "Ecophyto" strategy set the goal of reducing pesticide use by 50 percent within 10 years (French Ministry of Agriculture 2008). After failing to meet this overall goal and instead seeing pesticide use increase, the government has progressively made its goals less ambitious (Faraldo et al. 2021). In 2018, the government pushed the deadline for its initial goal back to 2025. Nevertheless, France remains the only country in Europe with an overall pesticide reduction target of 50 percent, the EU's goal under its Farm to Fork Strategy. As of 2023, however, France appears unlikely to be able to meet this goal and is preparing the third iteration of its Ecophyto strategy. This is expected not to include a quantified reduction target (Girard 2023; Guichard et al. 2017).

France's failure to decrease total pesticide use is also reflected in its experience with specific pesticides. In 2015, glyphosate — the most widely used pesticide in the world — attracted global media coverage when the United Nations International Agency for Research on Cancer (IARC) judged it to be "probably carcinogenic," therefore endangering the health of farmworkers and consumers worldwide (Bozzini 2020). The same year, the European Food Safety Agency (EFSA) and the United States Environmental Protection Agency (EPA) released scientific assessments contradicting IARC's findings, instead stating that glyphosate is unlikely to pose a carcinogenic threat to humans (Paskalev 2020). Around the same time, citizens' and policymakers' concerns about the environmental impacts of the widespread use of pesticides intensified due to growing number of scientific studies linking neonicotinoids to massive insect loss (Foucart 2019; van der Sluijs et al. 2015).

Subsequently, in 2017, President Emmanuel Macron vowed to ban both glyphosate and neonicotinoids within a few years (Grimonprez and Bouchema 2021; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Neither ambition has been fulfilled. For glyphosate, a full ban has been replaced with partial regulations (Kinniburgh 2023). In the case of three neonicotinoids banned at the EU level in 2018, France has been repeatedly granted emergency use authorizations, especially for sugar beets (Alliot et al. 2022). Following a ruling from the Court of Justice of the European Union in January 2023 that "Member States may not offer exemptions from the bans," France will be obliged to fully enact the ban (Foucart and Mandard 2023). The failure to govern pesticide use reduction and to fully enact existing bans has not only increased the health and environmental risks of pesticide use, but has also been costly for the government and for farmers, whose pesticide spending continues to increase as greater quantities of pesticides are needed due to pest resistance (Cour des Comptes 2019; Faraldo et al. 2021).

1.2 Theory

This thesis in political science draws on and contributes to debates from three primary literatures: environmental governance, Science and Technology Studies (STS), and sustainability transitions. It also integrates insights from policy analysis, sociology (notably the sociology of science and the sociology of expertise), international relations, and political economy. It develops analytical frameworks which are adapted to the specific case at hand in each publication. Grasping the complexities of pesticide governance (a subset of chemicals governance) also requires integrating knowledge from the natural sciences, economics, and law, while focusing on pesticide use in the agricultural sector requires delving into agricultural sciences and the study of agri-food systems; literature from these disciplines also appears throughout the thesis.

This thesis is guided by a reflexive approach to research in which the underlying assumptions of various theories and methods are considered critically. While acknowledging the contributions of different approaches to a holistic perspective on governance, a reflexive approach draws attention to the relationship between knowledge production and the context of its production (Darnhofer, Gibbon, and Dedieu 2012). By drawing on these different disciplines in a reflexive way, this thesis contributes to bringing siloed theoretical and empirical debates together.

This section presents the concepts and theoretical debates central to environmental governance, focusing on pesticides as an empirical case. It does so in two parts. First, it examines key debates in environmental governance, organized into five thematic clusters:

1) Multi-level governance dynamics;
2) The role of private actors in environmental governance;
3) The politics of environmental knowledge and decision-making;
4) Governing sustainability transitions and technological discontinuation; and
5) Environmental policy integration and policy instrumentation.

It then provides an overview of key debates which differentiate pesticide governance from other areas of environmental governance. These are further organized into four thematic clusters:

1) The politics of risk management;
2) Debated strategies for reducing the use of pesticides;
3) Linking pesticides and agricultural paradigms; and
4) Transforming agri-food systems.

These theoretical discussions draw both from literatures on pesticides and from literature on environmental governance more broadly, notably since literature on pesticides and chemicals governance is scarce relative to literature on the governance of climate change and biodiversity loss.

1.2.1 Environmental governance

This sub-section explores concepts and theoretical debates central to environmental governance relevant to a broad range of environmental issues including and beyond pesticides.

1.2.1.1 Multi-level governance dynamics

Pesticides have been governed through a wide variety of mechanisms and instruments by various actors and institutions at different levels of policymaking since the 1960s, as discussed in section 1.1.5 (Boardman 1986; UNEP 2022e; Watson 2018). States have played a leading role in governing pesticides at the national level and at the global level through intergovernmental institutions. Yet developments in pesticide governance have occurred against a backdrop of a rapidly changing landscape of actors and institutions in which private actors have come to play an increasingly important role. This thesis examines both public policies and private governance, aligning with the analytical shift in political science literature from analyzing "government" to "governance" and recognizing the growing importance and power of non-state actors in guiding decision-making at every level (Hale 2020; R. B. Hall and Biersteker 2002). Throughout the thesis, I use "public" governance to refer to state-centric governance in both domestic and international policy-making, while "private" governance refers to authority exercised by actors other than the state, which are "not state-based and do not rely exclusively on the actions or support of states in the international arena" (R. B. Hall and Biersteker 2002). In this section, I first narrow in on theoretical questions addressed in literature on the public pesticide governance landscape; private governance is examined in sub-section 1.2.1.2.

At the international level, literature on global environmental governance has long debated fragmented versus integrated approaches to a wide variety of environmental issues, with a strong focus on the effectiveness of the overall regime in achieving its intended goals (Biermann et al. 2009; Pattberg and Widerberg 2015; O. Young 1996; O. R. Young 2001; Zelli and van Asselt 2013). Literature on regime complexes and institutional theory has shown that regime separation and integration are the effects of political choices and can facilitate strategic state behavior in different arenas (Johnson and Urpelainen 2012; Morin and Orsini 2014). However, despite these potentially strategic aspects, regime complexes also offer distinct benefits, including being more flexible and adaptive over time than more tightly coupled governance systems (O. Young 2011). At the same time, treaty linkages can both facilitate problem-solving and diffuse political disagreements across forums in ways that slow down decision-making (Allan, Downie, and Templeton 2018; H. Selin 2010). The joint meetings of the BRS Conventions represent an unprecedented experiment in the governance of international environmental agreements and have intensified the institutional complexity of the global chemicals regime, with mixed consequences for the politics, procedures, and policies emerging from the negotiations (Allan, Downie, and Templeton 2018).

Despite calls from policymakers for stronger coordination among different treaties and environmental regimes (Nordic Council of Ministers 2022; UNEP 2021b), there is little social science literature examining coordination between the chemicals clusters and other treaties, notably the CBD. Hough (1998) brought attention to the regulatory gap for pesticides at the international level, which leaves many of the environmental impacts caused by pesticide use entirely unaddressed. Over 20 years later, UNEP's recent assessment of pesticide governance (while noting the difficulty of assessing the impacts of the plethora of instruments affecting pesticide governance), emphasizes that the treaties addressing pesticides (the BRS and

Minamata Conventions and the Montreal Protocol) only cover a limited number of pesticides (UNEP 2022b). These instruments and mechanisms also lack enforcement power at the national level (Boardman 1986; UNEP 2022b).

Boardman (1986) is the main scholar who brought attention to multi-level linkages in pesticide regulation, examining how national regulations interact with the politics of international regulatory efforts and the international economy. In the case of pesticide authorization, the links between national and international pesticide regulations are bidirectional: national regulations affect trans- and international politics and vice versa. Bans or use restrictions in one country can become a justification for a ban in another country, or specific national regulatory schemes can become models adopted in other countries. National measures, such as export rules, can also directly impact other countries through restrictions on international trade (Boardman 1986). At the same time, states are impacted by political economy dynamics which shape pesticide and agricultural markets, as well as by the requirements of international pesticide regulations (Boardman 1986; A. Hall 1998; Hough 1998; Watson 2018).

The multi-level governance concept which has been developed since the 1990s draws attention to shared decision-making by a variety of actors at different levels, including but not limited to states (Bache, Bartle, and Flinders 2022). Prior to the development of the multi-level governance concept, Putnam (1988) argued in his theory of "two-level games" that decision-makers aim to reconcile domestic and international imperatives simultaneously, while recognizing that institutional arrangements strengthening decision-makers at one level may simultaneously weaken bargaining positions at another level. Recognizing that states no longer monopolize decision-making, the concept of multi-level governance emphasizes the existence of overlapping competencies amongst varied actors and institutions at multiple levels of governance and the interactions between them (Papa 2014). The concept originates within analyses of the EU, where supranational institutions (the European Commission, the European Parliament, the Council of Ministers, and the European Court) influence policymaking independently from their role as representatives of member states (Hooghe and Marks 2001; H. Selin and VanDeveer 2015a). It has also been applied to other regions and to describe the interactions among other levels of governance, namely international, national, and subnational policymaking.

Literature on multi-level governance shows that interactions between levels may limit actors' decision-making capabilities, and require careful attention to the timing of governance choices and connections to decision-making at other levels (Bache, Bartle, and Flinders 2022). A number of analytical debates focus on the appropriate scale for the governance of a given task. Jordan (2000), for example, argues that tasks should be governed at the lowest level unless displacement to a higher level would ensure greater comparative effectiveness (Papa 2014). For environmental governance, the characteristics of the biogeophysical systems that are being targeted for interventions are considered critical to determining an appropriate level of governance (O. Young 2002). However, in practice, the continual contestation of environmental issues and the way they are defined leads to varied multi-level governance arrangements (J. Gupta 2013). On the one hand, multi-level interactions can limit state-centric governance, potentially exacerbating environmental problems due to the difficulties of decision-making among a growing number of interlinked actors and institutions. On the other hand, linkages between different levels of policymaking can also lead to reinforcement dynamics which ultimately strengthen environmental governance (Schreurs and Tiberghien 2010). Since

Boardman's (1986) landmark analysis, these multi-level dynamics have been little explored with respect to pesticides compared to other fields of environmental policymaking, as a majority of pesticide literature focuses principally on a single level of governance.

1.2.1.2 The role of private actors in environmental governance

Governance literature is marked by a shift in analytical foci away from state-centric perspectives in recognition of the growing importance of non-state actors. The rise of private governance not only in the domestic realm but in international policy is closely tied to the rapid economic globalization of the late 20th century, which accelerated during the 1990s (Clapp 1998; Falkner 2003; Schleifer 2023). Non-state actors, ranging from private companies to non-governmental organizations, have come to perform "functions traditionally associated with national governments and inter-governmental organizations—rule-setting, dispute resolution, and public good provision" (Cashore et al. 2021, 4). Private governance emerges when interactions between firms or between firms, NGOs, and state actors give rise to institutional arrangements directing actors' behavior in specific issue areas to achieve objectives mutually beneficial to these actors (Falkner 2003). Such governance is long-term in nature, incentivizing actors to adjust their behavior out of recognition of the legitimacy of these arrangements.

Like many other sectors, agri-food systems have come to be increasingly privatized, globalized, and globally integrated, with a few powerful transnational corporations playing a central role in the production and international trade of food and agricultural products, as well as agricultural inputs, such as pesticides and fertilizers (Clapp and Fuchs 2009). Transnational corporations, including pesticide companies, have adapted strategies to the evolution of food systems according to different paradigms (which I will return to in section 1.2.2.3), demonstrating an "inherent capacity to resist change despite overwhelming pressures for [the pesticide industry] to do so" (Watson 2018, 123). This has led to increasing entanglement between the production of pesticides and that of other agricultural inputs, namely seeds and fertilizers. When the pesticide industry began to be systematically regulated in the 1970s, first in the Global North, the pesticide industry developed new, less hazardous pesticides and biotechnologies which are designed to be paired with specific pesticides (for example, RoundUp Ready Genetically Modified Organisms (GMOs), which are used with RoundUp, a glyphosate-containing herbicide). Increasing regulatory costs played a role in driving horizontal concentration among pesticide companies and vertical concentration among pesticide, seed, and biotechnology companies (Clapp 2021b; Ollinger and Fernandez-Cornejo 1998; Shattuck 2021; Watson 2018). Industry lobbies promoted institutional contexts which favored pesticides and the development of biotechnologies, leading to significant growth in industry profits and power in the 1980s and 1990s (Watson 2018). At the same time, the industrialization of farming systems in the Global South, where regulations developed much more slowly, allowed pesticide companies to develop strong economies of scale at the global level and to consolidate their power and market share (Watson 2018). Pesticides banned and/or strictly regulated in the Global North were — and continue to be — sold in the Global South.

Power consolidation in the agri-food system gives concentrated firms the ability to shape policy and governance frameworks along with markets, technology, and innovation agendas (Clapp 2021c; Clapp and Fuchs 2009). It also creates imbalances of power between farmers and their suppliers and buyers, creating pressure for farmers to produce at lower costs, without the gains from these lower costs necessarily being passed on to consumers (iPES Food 2017). In 2014, four transnational corporations controlled 84 percent of the global pesticides market: ChemChina/Syngenta, Bayer/Monsanto, BASF, and Corteva Agriscience (Folke et al. 2019). This reflects broader trends of strong corporate power and the concentration of ownership in the agri-food sector at all levels of the supply chain (UNEP 2021b). The same companies are involved in the development of seeds and biotechnology crops, which leads to a concentration in marketing, research and development (UNEP 2021b). The agri-food sector has been described as having an "hourglass"-shaped distribution in which a large number of farmers is supplied by a small number of upstream input suppliers (companies producing chemical pesticides and fertilizers, as well as agricultural machinery) who sell to a small number of downstream processors and retailers. These downstream actors in turn supply a large consumer base (iPES Food 2017).

The strong concentration of power among a handful of actors in agri-food systems often leads to analyses in which interest groups are at the center of theories of policy change — or lack thereof (for example, Clapp 2021a, 2021b; Clapp and Fuchs 2009). The role of interest groups in political systems in relation to state institutions is a subject of ongoing debate in political science and a challenging field of study, notably due to difficulties in access to transparent data (Malhotra, Monin, and Tomz 2019). Deliberate attempts by transnational agri-food companies to influence lawmakers through lobbying — the most visible expression of corporate power — has been documented in the US and Europe (Béné et al. 2019; Clapp and Fuchs 2009; iPES Food 2017). Such industrial lobbying affects the framing of specific issues for policymaking (Clapp and Fuchs 2009), as well as influencing the content and adoption of specific policy proposals (iPES Food 2017). By affecting the content of policies, lobbying and other less visible forms of corporate resistance are also likely to have self-reinforcing effects on politics by enhancing the power of the incumbent interest groups, as has been shown for the energy sector in the US (Stokes 2020). In the EU, in 2019, Bayer, BASF, Syngenta, and Corteva spent over 5.5 million euros combined in lobbying policymakers in the lead up to the expiration of glyphosate's authorization renewal in 2022 (Clapp 2021c). To date, the specific mechanisms and impacts of lobbying dynamics in European agri-food systems remain relatively little studied by academics, likely due to difficulties in information access. NGO analyses would suggest, however, that lobbying is pervasive (Corporate Europe Observatory 2022). Political economy literature also draws attention to how corporate power is expressed structurally through self-reinforcing cycles which leads to a dominance of transnational corporations in agri-food governance and to self-reinforcing feedback mechanisms which lead to the systematic and excessive use of pesticides (Béné et al. 2019; Clapp 2021b, 2021c; De Schutter 2017; Shattuck 2021).

While the role of transnational pesticide companies has featured prominently in agri-food system literature, a much smaller literature has been concerned with transnational private initiatives aiming to reduce pesticide use, notably environmental certification schemes and private standards. Beyond a direct empirical focus on pesticides, scholars have examined interactions between public and private actors, including in the realm of voluntary sustainability standards (Eberlein et al. 2014; Falkner 2003; Hale 2020; Lambin and Thorlakson 2018) and agri-food standards in particular (Busch 2011; Djama, Fouilleux, and Vagneron 2011; Fulponi 2007; Henson and Reardon 2005).

Despite the increasingly important governance role played by private standards, their effects on state-led policymaking remain understudied. A dominant question in the literature is the extent to which private governance competes with or complements "traditional" forms of state authority (Marsden et al. 2010). The first possibility presumes that firms may adopt private standards as a strategy to pre-empt or avoid public regulation, for example through "greenwashing" (Eberlein et al. 2014; Falkner 2003). This would produce an interruptive effect, through private standards competing with and (intentionally) undermining public governance, leading to weaker regulations. Since different types of standards have different production costs for companies, companies may pre-emptively set private quality standards to avoid the adoption of more stringent and costly public standards or regulations, thereby minimizing their production costs (McCluskey 2007). While there is some empirical evidence of the use of company standards leading to worse environmental outcomes (Khanna & Brouhle, 2009), there is currently little research which demonstrates such displacement of public regulation in the context of sustainability standards (Lambin & Thorlakson, 2018). Instead, interactions between private standards and public governance are more often considered to produce a synergistic effect leading to an enhanced outcome relative to what could be achieved through public governance alone, for example due to the increased resources the private sector may provide for implementation and monitoring (ibid). The idea that private standards can complement regulations is the underlying logic behind the adoption of a growing number of "hybrid" governance schemes and public-private partnerships, including in agricultural standard-setting (Andonova 2010; Verbruggen and Havinga 2017a).

However, research on relationships between public and private authority (Cashore et al. 2021; Eberlein et al. 2014) and the ways in which private standards help solve, or exacerbate, sustainability issues (Lambin and Thorlakson 2018) is relatively new. It has mainly focused on the forestry and fisheries sectors, often examining interactions between transnational private actors and national governments (Grabs, Auld, and Cashore 2021; J. F. Green and Auld 2017; Hale 2020). Regarding pesticides, the role of private standards in reducing the risks of pesticides in agricultural production and their relationship to other governance instruments remains understudied. From a governance perspective, better understanding interactions between public and private actors and their effects is critical to advancing environmental governance theory and to weighing in on policy debates on the role and expansion of private standards.

1.2.1.3 The politics of environmental knowledge and decision-making

Despite a wealth of knowledge about environmental problems, including pesticides, there continues to be a large gap between scientific knowledge and policymaking. In the context of growing calls to strengthen science-policy interfaces about chemicals and waste (Honkonen and Khan 2017; Nordic Council of Ministers 2022; H. Selin et al. 2018; UNEP 2019, 2022e; Wang et al. 2021), understanding the so-called knowledge-action "gap" is critical to contributing productively to debates on pesticide governance.

Debates about the gap between science and politics tend to be polarized around two opposing perspectives. On the one hand, many scholars and policymakers call for more and "better" scientific knowledge to support sustainability transitions, notably on chemicals and waste (UNEP 2021b; Wang et al. 2019). From this perspective, the lack of uptake of scientific knowledge may result from a lack of "usable" knowledge for policymaking; the solution therefore lies in the better "translation" of scientific knowledge for its intended use (for example, Glavan et al. 2019). This perspective is reflected in the widespread call for evidence-based policymaking, based on the premise that the use of evidence in policymaking is inherently helpful (Béné 2022). Evidence-based policy discourse often reflects a "linear model" of expertise, wherein credible and salient scientific knowledge is expected to be used as an input for policymaking in a relatively automatic and apolitical process (Beck 2011). This model assumes a clear analytical division — or boundary — between science and politics. From this perspective, experts are considered as (neutral) mediators of knowledge between these two (supposedly separate) worlds in the context of informing public policies; their legitimacy is founded upon the authority of science (Spruijt et al. 2014).

In contrast, scholars of STS and critical policy studies argue that both scientific and political actors continually shape and negotiate the boundaries between science and politics, leading both realms to be mutually shaped by one another (Beck et al. 2016; Beck and Mahony 2018). STS underlines that different scientific communities adhere to different practices and standards; the selection of experts is therefore more important to policy outcomes than the fact of involving scientific experts in decision-making or not, since experts weigh evidence differently (Oreskes 2004). Environmental controversies tend to exist due to conflicts over values and interests, and special interests can use evidence (or the lack of it) to advance their own agendas (Béné 2022; Sarewitz 2004). In the case of pesticides, scholars have enumerated many instances of decision-making where evidence "does not matter" and the adaptation of knowledge to its intended use does not influence the extent to which it is taken into account (Donadelli 2020; Hofmann et al. 2023; Knudsen 2018). While the direct political influence of interest groups (discussed in section 1.2.1.2) partially explains these dynamics, industry influence in political arenas alone does not sufficiently account for the lack of uptake of scientific findings or the permeation of specific framings and instruments which dominate pesticide governance and chemicals governance more broadly. The politics of knowledge are a related, but distinct factor which play a critical role in shaping policy outcomes. I use the term "politics of knowledge" to refer both to the production of scientific knowledge about pesticides and the use of diverse forms of knowledge to inform decision-making. Scientists are engaged in producing scientific knowledge (about pesticide risks and pesticide alternatives) which may be intended or designed to be used in decision-making processes, or may not. It is therefore critical to turn to which types of knowledge are produced and how these are taken into account in decision-making through the mediation of different institutions.

Because chemical regulation is characterized by scientific uncertainty and an approach focused on risk, scholars of pesticide politics have shown how political battles over pesticide policies have consistently played out in "technical" as well as overtly political arenas (Dedieu 2022; J. L. Durant 2020; Foucart 2019; E. Henry et al. 2021; Jouzel 2019). These literatures have drawn attention to the "sub-politics" of knowledge production and the processes which impact the use of science in policymaking. Such perspectives broaden analyses of power from a focus on traditional political arenas to a focus on arenas where such "sub-politics" play out, such as regulatory agencies or technical bodies. Hajer defines sub-politics as "the structural displacement of important political decisions to other, *formally non-political*, realms" (Hajer 1995, 39, emphasis added). In examining environmental conflicts, Hajer creates an analytical bridge between environmental politics and STS:

> Politically important decisions are in fact often taken in places that are excluded from the definition of politics one would find in classical textbooks, such as the concealed worlds of laboratories, of scientific councils (e.g. in the definition of what constitutes

> state-of-the-art technology or with the definition of exposure limits of certain chemicals). (Hajer 1995, 39)

This concept aligns with the Foucauldian notion of governmentality, where power is the result of the combined effects of different modes of micro power and knowledge, rather than of state power per se, even though the state may play a prominent role in guiding the production of knowledge for governance (Foucault 1991).

The concept of "boundary work," initially used by Gieryn (1983) to show the demarcations made by scientists to distinguish their work from non-science, has been developed to examine policymaking and the ways actors continually shape and negotiate the boundaries between science and politics (Beck et al. 2016; Beck and Mahony 2018). Boundary work is critical in the design of regulatory science, defined as "a set of scientific evaluation activities that are involved in taking legal measures to control industrial activities and products (authorization, withdrawal, setting of presence or exposure thresholds, labeling of drugs, cosmetics, certain foods or chemical products, etc.)" (Borraz and Demortain 2015). Because regulatory science is devoted to producing knowledge which is necessary for regulatory purposes, it establishes its own set of specific rules and procedures which do not adhere to modes of knowledge validation that prevail in established scientific disciplines (Demortain 2017). Regulatory science thus "embodies a particular way of *knowing* things that legitimizes a way of *intervening* on these very things and associated markets" (Demortain 2017, 148). Analyses of cross-country differences in regulations of the same substance reveal how regulatory science is a process of co-production of scientific paradigms and policy frameworks dependent upon cultural and institutional norms and settings (Brickman, Jasanoff, and Ilgen 1985; Joly 2016; Suryanarayanan and Kleinman 2014).[2]

In the case of pesticides, all stages of knowledge production and its uptake can be influenced by industry in various ways. It is now well established that the chemical industry — and the pesticide industry in particular — use scientific evidence in strategic ways to advance particular agendas or ideologies (Béné 2022). In addition to selectively using scientific authority to support their practices (by, for example, cherry-picking evidence), the industry is also well-known for deliberate intervention in scientific knowledge production (see, for example, Glenna and Bruce 2021). Through a number of different tactics, chemical industry actors block the production of evidence on the hazards of specific substances or risks, as has been demonstrated previously for the tobacco industry, the asbestos industry, and the oil industry (Oreskes and Conway 2010; Proctor 2012). Examining the case of neonicotinoid pesticides in Europe, Foucart (2019) documents how the pesticide industry uses a range of similar tactics to prevent regulatory action. These include highlighting the multiple causalities at play in causing a specific problem (such as insect loss), distracting the public from the issue, and building alliances with scientific researchers and policymakers to support their agenda. The pesticide industry has also engaged in scientific malpractice through a variety of tactics from ghost writing to interfering in the scientific review process (Glenna and Bruce 2021; McHenry 2018). Industry influence extends to the overall agronomic research systems which have accompanied the development of pesticides and agricultural paradigms which require intensive pesticide use (Jas 2021; Prete, Jouzel, and Dedieu 2021).

[2] The STS idiom of "co-production" conceptualized by Jasanoff describes the mutually constitutive nature of science and politics (Jasanoff 2004). This understanding of co-production allows for a reading of the ways in which political dynamics are reflected in knowledge production and its material embodiments: technologies. (For other conceptualizations and uses of co-production in the context of sustainability, see Miller and Wyborn (2020)).

Other scholars have drawn attention to more subtle knowledge-related dynamics which favor the use of pesticides, notably how the institutionalization of risk management has shaped the norms underlying entire scientific disciplines (such as toxicology), thereby shaping regulatory science. This literature has been concerned with jointly explaining "how science *and law* fail to protect us from pesticides" which are known to be toxic (Cohen 2019; Wargo 1996, emphasis added). Because pesticides have predominantly been framed as a risk management issue, the crux of the scientific debate on pesticides has revolved around defining acceptable levels of risk and developing methodologies to enable risk-based regulation (Davis 2014; Jouzel 2019; Whitford 2002). Institutionalized practices which delimit the types of knowledge included in policymaking have been developed based on specific protocols and standards in order to settle disputes regarding acceptable levels of risk (Demortain 2011). Regulatory routines can produce an institutionalized non-knowledge or ignorance of certain risks, excluding certain types of scientific knowledge from regulatory consideration when they are not produced according to the norms of regulatory toxicology (Jouzel 2019). Pesticides risk assessments are conducted on individual active substances in specific lab and field conditions which are not representative of real-world conditions, thereby systematically excluding the possibility of capturing real-world risks to pollinators, for example, induced by the use of multiple pesticides by farmers (Foucart 2019; Sponsler et al. 2019). These institutionalized procedures fulfill the function of preserving the legitimacy of risk management systems and simultaneously protecting the legitimacy of current modes of agricultural production (Dedieu 2022).

While literature on pesticides from an STS perspective has shown many mechanisms of industry influence on knowledge production about the risks of pesticides and their regulation, less has been written about how processes of knowledge production can open up or constrain policy processes about sustainability transitions away from pesticides, particularly in the context of policy instruments "in the making." Closely examining modes of mobilizing expertise is particularly important for states such as France, which has a strong tradition of using institutionalized processes for integrating science into policymaking (Maxim 2022). Little attention has been paid to these spaces of active construction of new policy instruments for pesticides and how knowledge production can affect issue framing and policy instrumentation.

By shifting the focus "upstream" of the negotiation of policy solutions, examining how knowledge is used to inform and construct an initial problematization allows for a different understanding of the solutions which are proposed to resolve a given problem (Gusfield 1983; E. Henry 2021). The term "problematization" refers to the process of defining problems (Lövbrand, Stripple, and Wiman 2009; Sherwood and Paredes 2014). Latour (1987) in particular drew attention to how the problematization of issues defines the locus of governance actions taken to address a given problem. Problematization occurs as a result of specific methods, data, and framings chosen by actors involved in governance processes; from Latour's perspective, a governance analyst must trace actors and the instruments they deploy to shed light on both the technical and political processes resulting in institutional responses to a given problem (Loconto and Fouilleux 2014). Processes which enable problematization can be understood as a key part of "issue framing" as depicted in the policy literature, which plays a critical role in agenda-setting for policymaking (Baumgartner and Jones 1993; Kingdon 1984). In policy literature, however, issue framing is often conceptualized primarily as a discursive practice, undertaken by actors who aim to (re)define a political issue, for example through a media campaign or social movement, rather than as a process of producing knowledge to problematize the issue itself (e.g. Tosun and Varone 2020).

For pesticides, there is a need for enhanced understanding of how science is produced and mobilized to develop new policy instruments. From an STS perspective, the concept of boundary work can be used to understand different phases of knowledge production and its use for policymaking, bringing attention to political dynamics within these seemingly apolitical spaces. While scholars of STS have used the concept of boundary work to examine how governments mobilize experts to establish epistemic and political authority for various kinds of public policies, less attention has been paid to the ways in which boundary work affects the scope of policy options to advance sustainability transitions.

1.2.1.4 Governing sustainability transitions and technological discontinuation

Sustainability transitions is a field of research which has expanded rapidly within the past 15 years and whose primary aims are to enhance conceptual understandings of sociotechnical transitions and to inform policies aiming to guide transitions (Köhler et al. 2019). Transition scholars conceive of transitions as processes of transformation towards sustainability occurring across multiple levels of structuration in sociotechnical systems (Geels and Schot 2007; Turnheim et al. 2015). The concept of “sociotechnical systems” emphasizes that technologies are inextricably linked to the social, political, and economic systems within which they are embedded. In the multilevel perspective (MLP) (Geels 2002; Rip and Kemp 1998), analyses distinguish between three interacting levels.[3] At the smallest level, *niches* present opportunities for novel technologies and configurations to develop. By definition, however, these remain marginal relative to a dominant *regime* “of existing actors and interests that benefit from ongoing reliance on current sociotechnical configurations” (van Oers et al. 2021, 161). A broader *landscape* provides the context within which actors operate and can be the source of exogenous change which creates destabilizing pressures for a dominant regime and opportunities for change (Geels 2002; Turnheim and Geels 2013). Using this conceptual lens, various “transition pathways” have been described which combine different types of changes in the niche, regime, and landscape levels. One common transition pathway results from a combination of pressures from “below” — the emergence and consolidation of innovations at the niche level — and pressures from “above” — growing pressure from the landscape on the regime, such as societal pressure, which gives niche technologies the opportunity to break through to become more generalized. Sustainability transitions take time, since “systems are changed through interconnected changes within self-reinforcing domains of technology, the economy, institutions, behavior and cultural systems” (Savaget et al. 2019, 884).

Lock-in around specific technologies and substances results from path dependency occurring through combined interactions between technological systems and governing institutions, such as in the case of fossil fuels (Seto et al. 2016; Unruh 2002). Scholars have examined various mechanisms which lead to sociotechnical lock-in, such as lock-ins through technologies, infrastructure, institutions, investments (Fisch-Romito et al. 2021), and behaviors and norms

[3] The Multi-Level Perspective of transition studies is not to be confused with the multi-level governance concept explored in section 1.2.1.1, as these refer to distinct conceptualizations of relevant analytical units of analysis. As the MLP has been criticized for a blurry conceptualization of these analytical levels, this thesis mainly focuses on the multi-level governance concept from political science, drawing occasionally from the MLP to characterize sociotechnical systems (in Paper III). There have been some attempts to bring these together (e.g. Hoffmann, Weyer, and Longen 2017).

(Buschmann and Oels 2019; van Oers et al. 2021). Analyses of lock-in mechanisms and their consequences for governing transitions have thus far mainly focused on fossil fuels, notably coal (Seto et al. 2016; Unruh 2002). The concept of lock-in has recently gained traction within analyses of agri-food systems, with multiple publications appearing since the beginning of this thesis research, notably from non-governmental organizations (Frison 2021; Hüesker and Lepenies 2022; Magrini et al. 2018; Neumeister 2022). This relative lack of attention to agri-food systems points to the need for further analyses of their particularities relative to other sectors and systems, as has been called for by a growing group of scholars within the transitions community (Hebinck et al. 2021).

Although early research on sustainability transitions was criticized for a lack of attention to political dimensions of sociotechnical change (Meadowcroft 2009), literature on the governance and politics of transitions has proliferated in recent years (Avelino and Rotmans 2009; Köhler et al. 2019; Patterson et al. 2017). From a more politicized perspective, transitions are therefore understood as "political processes in which actors with varying degrees of access to sources of power vie with one another over the direction that processes of sociotechnical change should take, how to steer this and [...] who will end up as winners and losers" (Meadowcroft 2009; Yuana et al. 2020). Because transitions involve fundamental transformations of social and technical systems, it is well established that incumbent regime actors are likely to resist change through a variety of strategies (Geels 2014; van Oers et al. 2021). These manifestations of power and resistance can take various forms, including through material strategies (enabled by financial resources and technical capacities), discursive strategies, and organizational strategies (through the shaping of institutional contexts and political cultures and ideologies) (Buschmann and Oels 2019; Geels 2014; Kern 2011; Rosenbloom, Berton, and Meadowcroft 2016).

Due to the entrenched power of incumbent actors, scholars have suggested that active governance may be necessary to destabilize the conditions which give incumbent actors their *de facto* position of centrality in established sociotechnical configurations (Turnheim 2023). A small but growing literature is focused on explaining processes of destabilization and the "discontinuation" of specific technologies or substances, many of which are locked in (Kuokkanen et al. 2018; Stegmaier 2023; Turnheim 2023). More specifically, there is growing interest in whether and how technological discontinuation can be governed such that it can address the interconnected sociotechnical lock-in mechanisms which have been widely documented in different sectors (Stegmaier 2023). The notion of governing the decline of specific substances or technologies has been explored using various terminologies, including deliberate decline (Rosenbloom and Rinscheid 2020), deliberate destabilization (Turnheim 2023; Turnheim and Geels 2012), governance of discontinuation (Hoffmann, Weyer, and Longen 2017; Johnstone, Stirling, and Sovacool 2017; Stegmaier, Kuhlmann, and Visser 2014; Stegmaier, Visser, and Kuhlmann 2021), and creative destruction (Kivimaa and Kern 2016). This thesis focuses on the concept of discontinuation, which emphasizes the discontinuation of a specific technology or substance (such as pesticides), considering discontinuation as a subset of the broader destabilization of specific sociotechnical systems as a whole. Although the literature on destabilization governance has grown in the years since the beginning of this dissertation (Frank and Schanz 2022; Koretsky et al. 2023), there remains considerable ambiguity about whether and how existing institutions and instruments in specific sectors can be mobilized to enable discontinuation.

Transitions literature shows that past societal transitions have been extremely complex and rarely deliberately guided; rather, many past transitions have been driven primarily by market forces or technological change (Turnheim and Sovacool 2020). However, the pace and magnitude of change required to meet current challenges has led many scholars to argue that governments should play a role in guiding transitions (Johnstone and Newell 2018). The state is also a central player due to its role in structuring markets, creating the regime conditions within which actors operate, and in enabling coherence across policy areas and between different levels of governance (Johnstone and Newell 2018). Moreover, transitions are understood as goal-oriented and therefore normative, representing specific values and visions of what a good society looks like (Shove and Walker 2007). Transition scholars embrace this normative directionality, acknowledging that transitions require normative judgments about what transitions are seeking to achieve (Köhler et al. 2019). The state can therefore play a leading governance role by defining visions, pathways and targets to provide directionality for transitions (Johnstone and Newell 2018).

Government-led phase-out policies have gained attention in transition studies, notably due to a rapid expansion of fossil fuel phase-out policies. Yet phase-out policies have existed and documented by scientific communities, notably for hazardous chemicals, since at least the 1970s (Trencher et al. 2022). Because substance and technology phase-outs have been predominantly driven by state interventions (Stegmaier 2023), phase-outs are a useful entry point for examining public policies for transitions.

Though phase-outs have recently gained momentum to guide sustainability transitions, many proposed phase-out policies focus narrowly on the substitution of specific technologies or substances, neglecting the systemic nature of sustainability problems and underestimating the resistance of incumbents to such measures. There remains a disconnect between the concepts and lessons learned in existing phase-out literatures and ongoing debates about the conceptualization of governance processes in transitions studies (Trencher et al. 2022). In contrast with fossil fuels or plastics, both of which are also increasingly targeted by phase-out or reduction efforts, pesticides have received little attention (Brauers, Oei, and Walk 2020; Frank and Schanz 2022; Oei et al. 2020). Multi-level dynamics are also underrepresented in the transitions literature, reflected by the call for more research "that goes beyond the national level and embraces the multi-scalarity of transition dynamics, which could build, for example, on evolving theorizing about global regimes" (Hansmeier, Schiller, and Rogge 2021, 173). In order to prevent phase-out reversals or further lock-in dynamics, further research is needed on the potential role of phase-out policies in enabling systemic change (Rinscheid et al. 2021). It is therefore of theoretical and practical importance to examine how phase-out policies can be embedded within broader agendas of systemic change and to shed light on the context- and case-specific political challenges which arise in doing so.

1.2.1.5 Environmental policy integration and policy instrumentation

We turn now to theories related to processes and instruments through which environmental objectives can be operationalized, notably in public policies. Environmental Policy Integration (EPI) has been defined as "the incorporation of environmental objectives in non-environmental policy sectors, such as agriculture, energy and transport, with the aim to target the underlying driving forces, rather than merely symptoms, of environmental degradation" (Persson et al. 2018, 113). The concept of EPI has gained prominence as an analytical tool in recent years, notably as it gains stronger political backing (Persson et al. 2018). Policymakers and practitioners present EPI as a tool to promote policy alignment and coherence in the face of cross-sectoral environmental challenges which often suffer from policy fragmentation and incoherence (European Environment Agency 2019). The concept has notably been integrated into the Treaty of the European Union, which states that "environmental protection requirements must be integrated into the definition and implementation of the Community policies" (European Commission 2022a). EPI is concretely operationalized through policy outputs such as national environmental plans, sustainability development strategies, or sectoral policy strategies and programs (European Environment Agency 2019).

Several conceptual distinctions have been made in the EPI literature, which is characterized by a range of interpretations of the concept and different typologies for assessing integration (Jordan and Lenschow 2010; Persson et al. 2018). Horizontal integration refers to environmental co-ordination across (siloed) policy areas and sectors, while vertical integration refers to environmental co-ordination within a single sector (Alons 2017; Runhaar et al. 2020). A "weak" understanding of EPI suggests the need for environmental considerations to be taken into account alongside other policy objectives, even if final policy outcomes do not reflect environmental objectives. In contrast, a "strong" understanding of EPI implies that environmental objectives take priority in decision-making and that responsibility for environmental protection is shared by all policy sectors, at different levels (Persson et al. 2018; Runhaar et al. 2020). As Jordan and Lenschow (2010) write, a strong understanding of EPI has aims which are "nothing less than radical — to turn the policy status quo on its head, such that environmental protection involves a much more holistic, and, above all, proactive search early on in the policy process for opportunities to prevent environmental damage from occurring" (Jordan and Lenschow 2010, 156).

To distinguish between different understandings of EPI, Persson et al. distinguish EPI in terms of "*process* (how the policy process has been re-arranged to integrate environmental objectives), *output* (formal decisions, e.g. concrete plans or measures taken in non-environmental policy sectors that aim at some form of environmental protection) and where possible, *policy outcomes or impact* (estimated or observed changes in behavior and improvements of environmental conditions)" (2018, 114). While research on processes and policy outputs is growing, assessments of policy outcomes or impacts is scarce, in part due to the multi-factorial nature of sustainability outcomes. Focusing on EPI as a policy process, various studies have emphasized the complexity of pursuing EPI in a multi-level governance context (Runhaar et al. 2020).

A growing literature has examined EPI and related concepts at different levels of governance, in different policy sectors, and according to different environmental policy goals (Persson et al. 2018). "Mainstreaming" is another concept related to EPI which is more commonly used by policymakers, within and beyond the EU (Karlsson-Vinkhuyzen et al. 2018). Mainstreaming literature has expanded analyses of integration beyond public policy to include private governance (Karlsson-Vinkhuyzen et al. 2017). In terms of levels of governance, EPI and mainstreaming literatures have examined international, EU, national, and local levels, as well as the interlinkages between them (Persson et al. 2018). In terms of policy sector coverage, energy, transport, forestry, coastal and marine management, and agriculture have been examined through the lens of EPI (for example, Alons 2017; van Oosten, Uzamukunda, and Runhaar 2018; Sumrada et al. 2020). In terms of policy goals, climate change mitigation and adaptation have been a major focus of EPI literature and policy practice (De Roeck, Orbie, and Delputte 2018; Russel, den Uyl, and de Vito 2018).

In contrast, little literature has examined the integration of goals relating to reducing biodiversity loss, with the major exceptions of Karlsson-Vinkhuyzen et al. (2017, 2018) and Zinngrebe (2018), who propose different frameworks for assessing biodiversity mainstreaming, with the practical goal of identifying potential barriers and levers for enhancing policy action. Zinngrebe (2018) proposes a focus on "biodiversity policy integration" (BPI) as a subset of EPI to examine national-level integration of international biodiversity goals. Existing analyses suggest that biodiversity has been little incorporated into sectoral planning to date; however, further research is needed across different sectors (Karlsson-Vinkhuyzen et al. 2018; Whitehorn et al. 2019). In particular, although global assessments have elucidated the mechanisms by which biodiversity is impacted by the agricultural sector, little is known about attempts to incorporate biodiversity objectives into agricultural policies in different national policy environments.

At the national level, policy instruments are a critical component of policy integration (J. J. L. Candel and Biesbroek 2016). Policy processes shape the choice and content of policy instruments (i.e. "outputs"), thereby influencing policy outcomes (Kivimaa and Kern 2016; Lascoumes and Le Gales 2007). Policy instruments can therefore be an empirical starting point through which to understand approaches to public policymaking and their underlying logics. EPI literature focusing on policy outputs has shown that no single instrument can enable policy integration; instead, EPI requires a suite of complementary instruments and mechanisms (Persson et al. 2018; Runhaar et al. 2020). This literature connects with perspectives in the sustainability transitions literature focusing on "policy mixes," understood as a set of policy instruments to address identified problems (Kivimaa and Kern 2016). Given the complexity of sustainability problems, a focus on policy mixes reflects the understanding that "real world policy contexts involve several policy instruments in different policy domains and with different rationales, dispersed governance structures and many levels of administration" (Kivimaa and Kern 2016, 2016). In the EPI literature, closer attention to policy instrumentation is considered essential since EPI instruments follow different logics of intervention (Jordan and Lenschow 2010). This connects with other literatures examining policy instruments: a "sociology of instrumentation" has notably been developed in France as part of a broader literature on the sociology of public problems, originating in the early 2000s and partially drawing on insights from STS. This literature focuses on revealing how the specific policy instruments chosen to deal with an issue significantly impact how a problem is defined and how it is managed: in short, instruments materialize theories of change (Jacquot and Halpern 2015; Lascoumes and Le Gales 2007).

Literature assessing policies for reducing pesticide use has increased, notably since 2009 (Lee, den Uyl, and Runhaar 2019). In a review of policy instruments for pesticide use reduction, Lee et al. (2019) develop a categorization of policy instruments to evaluate their effectiveness. They identify five characteristics of policy instruments: 1) aim; 2) spatial orientation (i.e. scale); 3) which actors are involved, including who is targeted, who is leading the application of the instrument and what governance arrangement is used; 4) strategy; and 5) application (i.e. as an isolated instrument or in combination with others) (Lee, den Uyl, and Runhaar 2019). The "strategy" refers to the type of policy measure, which the authors divide into three main categories: regulatory (e.g. pesticide authorization, bans and use regulations), economic (e.g.

taxes, direct payments, or financial support for specific technologies), and informative (e.g. labelling or educational measures). Situational and contextual factors are particularly important for determining which instruments successfully contribute to pesticide use reduction; tailoring to the characteristics of different farms and production systems is particularly critical to contributing to effectiveness (Lee, den Uyl, and Runhaar 2019). Overall, this review, along with more recent literature (e.g. Möhring, Ingold, et al. 2020), argues that pesticide use reduction necessitates a mix of policy instruments applied at multiple scales and interacting levels. This literature highlights a need to further examine policy instrumentation in specific contexts and to enhance understandings of how different governance levels interact with one another to enhance EPI and to support more sustainable outcomes.

1.2.2 Pesticide governance

The next sub-section turns from outlining key concepts and debates central to environmental governance to those central to the governance of pesticides in agriculture specifically. It examines how the notion of risk has shaped pesticide politics and policy instruments and how different conceptualizations of the agricultural sector affect the problems pesticide governance seeks to address.

1.2.2.1 The politics of risk management

When governments began to address the problems posed by pesticides in the 1960s, pesticide governance became largely separated from a more fundamental consideration of the broader structural changes within the agricultural sector and their various implications: pesticide governance instead became framed primarily as a risk management issue. This is reflected in early pesticide governance literature and continues to be a primary framing in policy discourses today (Boardman 1986; Hough 1998; Wargo 1996; Whitford 2002). Pesticide governance — and chemicals governance more generally — has been built around a paradigm of reducing the risks posed by chemical substances by making those risks measurable and controllable, rather than limiting sources of pollution themselves (Borraz 2008). Thus, while pesticide governance varies around the world, the institutionalization of different modes of governing pesticides has generally embodied an acceptance of pollution as a "negative but inevitable by-product of industrial processes" (R. Durant, Fiorino, and O'Leary 2004, 428). The pesticide problem is thus frequently framed as a question of choosing the "desirable" level of risk, while also taking into account the fact that safety, health, and environmental regulations have high costs (Boardman 1986).

Significant pressure from civil society groups at the national and international levels following the release of *Silent Spring* (Carson 1962) led governments, individually and collectively, to segment pesticide management into distinct problems governed through different mechanisms by different actors and institutions. At the national level, France, Germany, the US, and the UK, the early adopters of the pesticide-intensive agriculture, developed a variety of regulatory instruments addressing localized pesticide risks to human health and the environment in the 1960s and 70s (Boardman 1986). In the 1970s and 80s, public awareness also increased about the global nature of the pesticide problem as the transboundary impacts of pesticides began to be exposed and environmental and consumer organizations such as PAN, Greenpeace and Friends of the Earth pressured governments to take action (Hough 1998). Countries in the Global South began to develop regulations, following their later adoption of chemical pesticides relative to Europe and the US. Civil society groups therefore brought attention to the fact that the international trade of pesticides across jurisdictions with vastly different legal systems made states lacking strong chemical regulations vulnerable to exports of hazardous pesticides banned in some countries yet still traded internationally (Hough 1998). The “circle of poison,” wherein pesticides banned in the Global North returned in the form of toxic residues on food imported from the Global South, accelerated international action on pesticides (Hough 1998). Pesticide governance was therefore segmented into four separate problems posed by pesticides: environmental pollution; risks to human health through pesticide use; risks to human health through food contamination; and the “circle of poison” caused by international trade of pesticides between countries with differing regulations (Hough 1998).

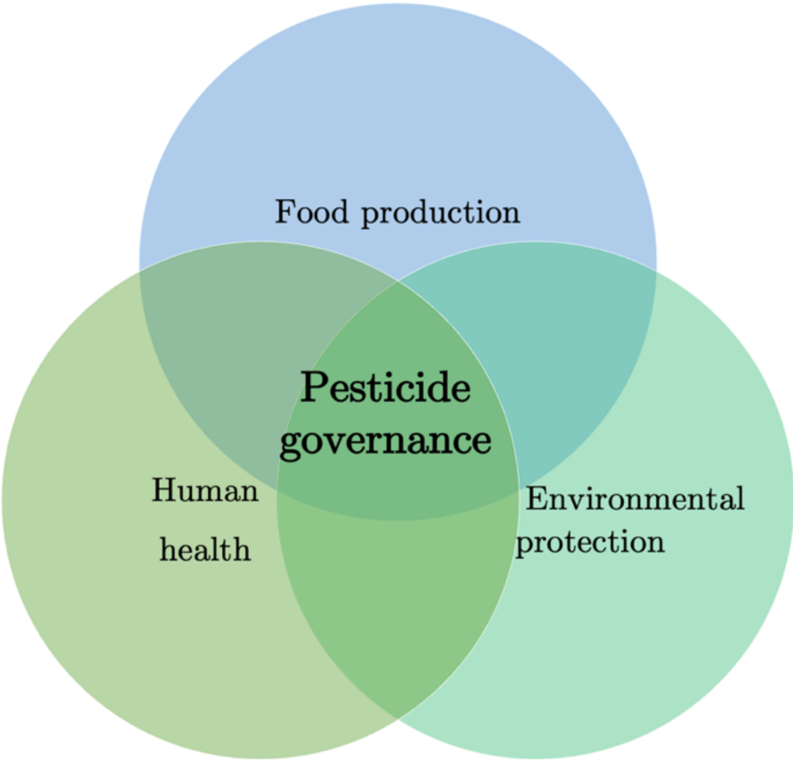
The regulatory regimes which developed at the national and international levels reflect institutional efforts to address these problems, balancing specific competing norms and values. Norms define the rules of conduct by which actors are expected to abide. Hough (1998, 10) summarizes seven main norms which emerged in the development of the international pesticide regime:

1. We should strive to attain optimal food yields
2. Disease and damage due to pests should be limited
3. The misuse of pesticides leading to human poisoning should be prevented
4. The international trade in pesticides should be regulated
5. Pesticides should not be overused
6. Environmental pollution by pesticides should be limited
7. The contamination of food by pesticides should be limited.

Based on these norms, Hough (1998) conceptualized pesticide politics as the result of struggles over the salience of different norms to different actors. Though different actors generally share these collective norms at the international level, they differ in their ranking of each norm’s relative importance. While industry actors tend to emphasize the need to maintain a steady food supply and reduce food loss due to pests, civil society groups emphasize the need to ensure food security while addressing the risks of pesticides, which may increase costs of production.

Based on these norms, national and international pesticide policy agendas focus on reconciling three main goals: food production, environmental protection, and human health (Figure 4) (Hough 1998; Möhring, Ingold, et al. 2020). Although these issues are generally interlinked, they are often addressed through different measures and have historically driven distinct political agendas carried by different actors (Hough 1998; Jouzel and Prete 2015). As a result, national pesticide regulations are highly heterogeneous in different countries. Comparative analyses of policy divergence reveal differences in national institutions, interest group politics, and government priorities relative to these and other competing goals (Boardman 1986; Brickman, Jasanoff, and Ilgen 1985; Hoberg 1990; Hough 1998). Similarly to risk regulation in other domains (e.g. Justo-Hanani and Dayan 2015, 2016; Vogel 2012), pesticide risk regulation is also strongly influenced by domestic policy styles, public concern, and differing approaches to risk.

Figure 4: Main goals of pesticide governance.



Source: Author.

Pesticide regulations cover various parts of the pesticide life cycle, from the research and development stage to pesticide recycling and disposal, as show in Figure 5. One of the most developed stages of pesticide regulation worldwide is pesticide authorization, which determines whether a pesticide can be sold on a given market (Storck, Karpouzas, and Martin-Laurent 2017). Substance-by-substance authorizations, given by national regulatory authorities, include specifications on the conditions of use of each chemical, including allowed doses, the timing of applications, and required minimal distances from certain ecological features (such as streams or rivers).

Figure 5: Parts of the pesticide life cycle and aspects which are often regulated.

Source: UNEP (2022).

Pesticide authorizations are based on risk assessment procedures, which are conducted according to two main approaches: a hazard-based approach and a risk-based approach (Bozzini 2017). Hazard refers to the intrinsic capacity of a substance to elicit adverse effects. Risk results from the combination of hazard and the probability of harm from a given hazard in specific circumstances. A common example for pesticides relates to the concept of "safe use": if workers apply a chemical substance which is hazardous (i.e. toxic to human health), the risk to that worker can be decreased through the use of protective equipment, which decreases the probability of harm. From a hazard-based perspective, a substance found to be intrinsically dangerous (e.g. carcinogenic) would be forbidden. In contrast, based on a risk-based approach, such a substance could be authorized for use if the assessed probability of harm in specific circumstances of use is deemed to be sufficiently low, or deemed economically worthwhile (Bozzini 2017). Chemical risk assessment is therefore "typically based on the assumption that human and environmental exposure to hazardous chemicals can be predicted and exposures to dangerous levels can be avoided" (Scholz et al. 2022, 2382). A central part of pesticide authorization therefore lies in defining appropriate thresholds for "safe" levels of risk of different exposed populations.

Considered a global leader in chemicals governance, the EU provides a useful case to examine the politics of risk management. The 2009 overhaul of EU pesticide regulations marked a shift from a risk-based approach to a hazard-based approach to pesticide authorization (Storck, Karpouzas, and Martin-Laurent 2017). Under regulation 1107/2009 of the Pesticide Package, an active substance cannot be authorized if it corresponds to any of seven hazards considered unacceptable: carcinogenic; mutagenic; toxic for reproduction; persistence, bioaccumulative and toxic for the environment; classified as a persistent organic pollutant (POP); very persistent and very bioaccumulative (vPvB) or an endocrine disruptor (Bozzini 2017).

Adopted in 2006, REACH is frequently noted for its incorporation of the precautionary principle, which refers to an approach based on taking preventative action in the face of uncertainty (Eckley and Selin 2004). The precautionary principle places the burden of proof on manufacturers rather than regulators; industry is therefore responsible for carrying out toxicological tests on active substances. As a result of incorporating precautionary language in laws on chemicals and adopting a hazard-based approach to risk assessment, the EU is now widely considered to have the most stringent pesticide governance in the world (Bozzini 2017). However, multiple problems persist. Gaps in regulatory processes allow for the continued production and use of hazardous chemicals. In particular, member states can ask for "exceptional authorizations" for banned pesticides under specific circumstances — a procedure which has been used by France more than any other member states (Storck, Karpouzas, and Martin-Laurent 2017). Scholars have questioned whether the EU approach can indeed be considered precautionary since many cases show that no preventative actions were taken even in the case of early warnings of risks (European Environment Agency 2013; Hansen, Carlsen, and Tickner 2007). Civil society, international organizations, and scientists alike have pointed to the deficits in risk assessment procedures for pesticides, notably a lack of regulatory procedures for taking into account the effects of human and environmental exposure to chemical mixtures which can provoke combined effects even at thresholds deemed safe for individual substances (Schäfer et al. 2019; Scholz et al. 2022; Stehle and Schulz 2015; UNEP 2022c). Despite excluding systematic risks both to humans and the environment, current risk assessment procedures follow similar logics worldwide. Risk management, rather than risk prevention, remains the central approach for pesticide governance.

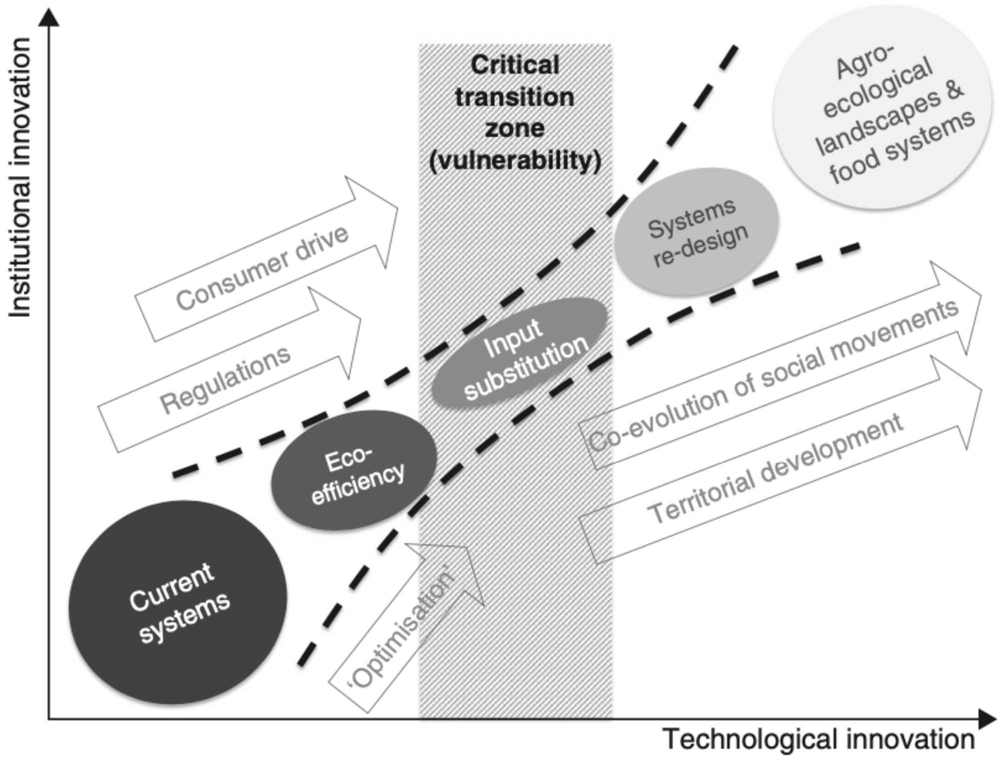
1.2.2.2 Strategies for reducing the use of pesticides

Pesticide use is highly context-specific: there is wide variability in use under different circumstances, including for the same crop and within similar geographical settings. It is influenced by factors ranging from physical determinants (such as weather and climatic conditions), to farm-level decisions (such as crop choices and risk tolerance of farmers), to economic and financial determinants (such as crop insurance and crop markets) (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; Möhring, Dalhaus, et al. 2020; Reboud et al. 2017). In order to understand possible interventions to govern pesticide use, this section outlines debates in agricultural science about the diversity of alternatives to pesticides and different ways to reduce their use, focusing on farm- and landscape-level considerations.

One of the major challenges for research on pesticide governance concerned with decreasing environmental impacts poses challenges of choosing the relevant analytical scale. When considering the environmental impacts of pesticide use, the local level is highly relevant, since pesticide use and risk are primarily influenced by production practices at the local level. However, as discussed elsewhere in this thesis, farm-level decision-making cannot be separated from the broader socioeconomic context — indeed, the two are mutually constitutive of one another. This thesis therefore draws on farm system research, which uses systems thinking and interdisciplinary methods to understand farming in a systemic way. In contrast with more traditional approaches to agricultural research in which different parts of the system are analyzed separately, farming system research emphasizes the interconnections between a system's elements, its dynamics, and its relation with the environment (Darnhofer, Gibbon, and Dedieu 2012). Farming systems research "investigates how spatial, technical and social relations are constructed, represented, materialized and contested by a broad range of societal actors" (Darnhofer, Gibbon, and Dedieu 2012, 7). Farming systems are therefore both sociotechnical and socioecological, embedding both farmers and their social environment as well as ecosystem dynamics at multiple scales. Defining the boundaries of what consists of a "farming system" is a critical part of systems research.

Understanding farm-level production practices and their relationship with pesticide use is a first step towards connecting environmental outcomes with pesticide governance interventions. The "*efficiency-substitution-redesign*" framework is a useful heuristic for differentiating between farming practices aiming to increase production sustainability (Hill and MacRae 1996). The three "stages" comprise non-linear components of transitions, based on different underlying principles. The concepts of efficiency, substitution, and redesign are relevant to reducing the impacts of pesticides as well as other farm inputs, such as fertilizers (Figure 6). In many cases, inputs are over-applied so volumes can be reduced simply by ensuring that only the necessary quantities are used (Pretty 2018). Increasing the *efficiency* of pesticide use can therefore be achieved through optimization techniques, such as precision farming based on sensors, soil mapping, weather data, etc. *Substitution* focuses on replacing technologies and practices with others deemed less harmful. For pesticides, toxic chemicals can be replaced with less toxic ones or by non-chemical alternatives, such as biocontrol agents or mechanical weed control (Aulagnier and Goulet 2017). The use of these farm-level techniques (efficiency and/or substitution) is compatible with maintaining existing cropping systems, understood as "the type and sequence of crops grown and practices used for growing them" (Blanco-Canqui and Lal 2010, 167).

Figure 6: "Stages" of transitions towards sustainable food systems.



Source: Tittonell (2014).

In contrast, the *redesign* of cropping and farming systems according to ecological principles involves *system-wide changes* going beyond the farm level and conceived over pluriannual time periods (Butault et al. 2010; Charbonnier et al. 2015; Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022; Pretty 2018). System redesign incorporates a prophylactic perspective, which recognizes that a key component of decreasing the use of pesticides is to decrease pest pressure (Jacquet, Jeuffroy, Jouan, Le Cadre, Malausa, et al. 2022). Intensive agricultural practices create conditions which encourage the proliferation of pests, therefore requiring the use of more pesticides to control them. Various practices, such as the adoption of pest-resistant plant varieties and practices such as diversification — both within crop rotations and at the landscape level — and longer crop rotations can help create a less hospitable environment for pests. Such practices are also key strategies for simultaneously reducing synthetic fertilizer use (Andert et al. 2016; Guyomard et al. 2020; Nemecek et al. 2015; UNEP 2022d). Crop diversification creates less favorable conditions for the growth of weeds and is therefore particularly important for reducing the use of chemical herbicides (Andert and Ziesemer 2022; Strehlow, de Mol, and Gerowitt 2020). The incorporation of legume crops into crop rotations is critical to enriching soil fertility, thereby decreasing the need for synthetic fertilizers since they are able to convert atmospheric nitrogen into a form usable by plants (Crews and Peoples 2004; Magrini et al. 2018). The concept of system redesign encompasses a broad range of agricultural models, including agroecology, organic agriculture, and diversified farm systems (Butault et al. 2010; Tittonell 2014). Agroecology in particular has been highlighted by the UN Special Rapporteur for Food as the main approach which should be promoted to decrease dependence on pesticides (UNHCR 2010, 2017).

Given the widespread use of the IPM concept in policymaking, how does it fit into agronomic discussions? Although IPM has emerged as the dominant concept to reduce pesticide use in pesticide management and policy, this thesis generally avoids the concept due to the wide variety of definitions and practices associated with IPM which render it largely unworkable. According to the FAO, IPM:

> means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM promotes the growth of a healthy crop with the least possible disruption to agro- ecosystems and encourages natural pest control mechanisms (FAO 2022b).

Examining the "quasi-infinite number of interpretations and definitions" of the concept within agronomic literature, Deguine et al. (2021) show how IPM has evolved in different contexts since its creation in the 1950s. The wide range of IPM-based practices can vary from "light" to "strong," and these practices often need to be applied in combination to optimize synergies (Jacquet, Jeuffroy, Jouan, Le Cadre, Litrico, et al. 2022). Agronomists who are critical of IPM highlight that the IPM focus in policy settings has not succeeded in catalyzing significant pesticide use reductions at the global level; in the majority of cases, chemical control remains the basis of plant health protection (Deguine et al. 2021; Jacquet, Jeuffroy, Jouan, Le Cadre, Litrico, et al. 2022). Such agronomists therefore recommend using more unambiguous concepts, such as "agroecological crop protection," which have more specific and applicable principles (Deguine et al. 2021).

Although there is debate within the agricultural science community about the efficacy of different approaches, there is growing recognition that a 50 percent reduction in pesticide use (the goal set out in EU policy objectives) requires ecological redesign and de-intensification of agricultural systems (Butault et al. 2010; Guyomard et al. 2020). Few studies aim to evaluate the contrasting strategies of efficiency, substitution, and redesign at scales which are meaningful for policymaking. Moreover, much of the literature on strategies to reduce pesticide use is francophone because pesticide reduction has been a focus of research in France since the early 2000s, and due to a high volume of research emerging from INRAE,[4] France's national agricultural research institute and a globally leading research institute on agriculture (for example, Aubertot et al. 2005; Butault et al. 2010; Charbonnier et al. 2015; Jacquet et al. 2022).

In 2010, a report by INRAE investigated strategies which would allow France to reach its goal of reducing pesticide use by 50 percent (Butault et al. 2010). This study, "Ecophyto R&D: what paths to reduce pesticide use?", demarcated the impacts of different approaches to reducing pesticide use. The research team developed different scenarios for the agricultural sector at the national level to evaluate the available techniques, the conditions necessary for deployment, and their costs. The different scenarios were ranked according to their "level of

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[4] The current institutional acronym INRAE is used throughout this thesis for consistency although references to "INRAE" prior to 2020 actually designate INRA. INRAE is the result of the merger between INRA and IRSTEA as of January 2020.

disruption" ("niveau de rupture"), or how different they were relative to the baseline at the time of the study, namely intensive agriculture practiced on most French farms. Each scenario encompassed a range of measures detailed in the report; the most "disruptive" scenario comprised a complete shift to organic agriculture (which excludes the use of any chemical pesticides).

Based on these scenarios, the report contrasted an efficiency- and substitution-based approach with a system redesign-based approach (Aulagnier and Goulet 2017). The efficiency- and substitution- approach was deemed capable of delivering a 30 percent reduction in overall pesticide use. The report concluded that a 50 percent reduction could only be achieved using a system redesign approach. This second finding was revealed by the study's national scale of analysis, which examined impacts beyond the farm level, enabling the evaluation of possible changes not only in farm practices (how crops are grown), but in cropping systems at the landscape (multi-farm) level which collectively help decrease pest pressures for all farms (Lamine 2011).

Although no similar national studies have been conducted since, this finding was corroborated in a report assessing strategies to reach the Green Deal objectives (Guyomard et al. 2020). This report concluded that simultaneously achieving policy goals on climate change and reducing biodiversity loss requires a policy mix favoring farming systems which rely less on chemical inputs and more on biological cycles, including an expansion of organic agriculture as well as mixed crop-livestock systems. Although not based on quantitative scenario analysis, a review paper published in *Science* evoked similar conclusions:

> Although both efficiency and substitution are important, they are not sufficient for maximizing coproduction of favorable agricultural and beneficial environmental outcomes without redesign. Whereas efficiency and substitution tend to be additive and incremental within current production systems, redesign should be the most transformative. (Pretty 2018, 362)

"Sustainable intensification" and agroecology are increasingly being proposed by scientists and policymakers as solutions to interconnected sustainability issues (MacLaren et al. 2022; McIntyre et al. 2009; Pretty 2018; UNHCR 2017). Similarly to IPM, "sustainability intensification" is interpreted in different ways by different actors, with no real agreement on common principles. Agronomists (for example, Therond et al. 2017) have proposed other typologies for farming systems which account for both biotechnical and socioeconomic factors. This thesis mainly refers to agroecology, which designates a more specific set of principles and practices than IPM or sustainable intensification.

Overall, approaches such as agroecology remain highly contested and politically charged, mainly on the grounds that system redesign approaches may lead to a reduction in crop yields (Jacquet, Jeuffroy, Jouan, Le Cadre, Litrico, et al. 2022). However, a growing number of studies show that such practices can compete with conventional production in the long term, providing potentially lower but more stable yields (Guyomard et al. 2020; MacLaren et al. 2022; Reboud et al. 2017). In this way, agroecological practices can provide increased resilience to climate change-related risks (Nicholls and Altieri 2018). As climate change threatens to endanger stable agricultural production around the world, resilience in the sector is key component to sustainable development (Linkov et al. 2014). However, new paradigms of research are needed to develop systemic innovations which deliver on multiple sustainability goals (Jacquet, Jeuffroy, Jouan, Le Cadre, Litrico, et al. 2022)

Beyond agricultural challenges, the redesign of agriculture and food systems present significant global political, social, and institutional challenges. While weighing on the debates regarding the effectiveness of different agronomic strategies is beyond the scope of this thesis, understanding them and their scalar implications is critical to conceptualizing appropriate levels of analysis and analyzing relevant levels of governance.

1.2.2.3 Linking pesticides and agricultural paradigms

This section enlarges the scope of analysis to link farm-level environmental impacts to broader scales which are more directly linked to national and international governance. The concept of agricultural paradigms links the farm level to these broader sociopolitical factors. The need to closely examine different sociopolitical factors beyond the farm level is bolstered by the observation that the increasing use of pesticides is due not only to the expansion of industrial modes of agriculture around the world (notably in the Global South) but also a trend towards higher pesticide intensity of agricultural production even among different modes of industrial agriculture. Growth in the use of pesticides has been significantly higher at the global level than increases in global crop acreage and in crop output per hectare (Schreinemachers and Tipraqsa 2012; Shattuck 2021). Understanding how agricultural production paradigms have shifted due to socioeconomic factors is critical to understanding this disproportionately large increase in pesticide use relative to overall productive output in agriculture.

After the Second World War, a turn towards pesticide-intensive agriculture occurred in many countries around the world as a result of profound structural changes in farming practices and agri-food systems (McIntyre et al. 2009; Watson 2018). During this period, the use of chemical pesticides, combined with synthetic fertilizers, mechanized production, and the improvement of plant varieties — commonly distinguished as the main characteristics of "agricultural modernization" — led to unprecedented increases in the production of food (Alliot et al. 2022; McIntyre et al. 2009). These changes were particularly rapid in Western Europe and the US, where governments adopted agricultural and industrial policies to support significant structural changes in the sector to address food security concerns (McIntyre et al. 2009; Watson 2018). These policies were bolstered by state-led agricultural research programs (Cornu, Valceschini, and Maeght-Bournay 2018). In the Global South, the significant use of chemical pesticides began a few decades later, in 1970s and 80s, when the ideas of the Green Revolution began to spread globally and chemical companies began to expand from Europe, the US, and Japan to global markets (Boardman 1986).

Structural changes to the agricultural sector such as those which occurred in the postwar period have been theorized as distinct agricultural paradigms characterized by different drivers which significantly shaped the use of pesticides and the development of the pesticide market (Watson 2018). These drivers include both external factors (such as increasing food demand, knowledge and information systems about agricultural production, economic markets, and state intervention) as well as the strategies of the pesticide industry itself, which has constantly evolved to adjust to different economic, social, and political contexts (Watson 2018).

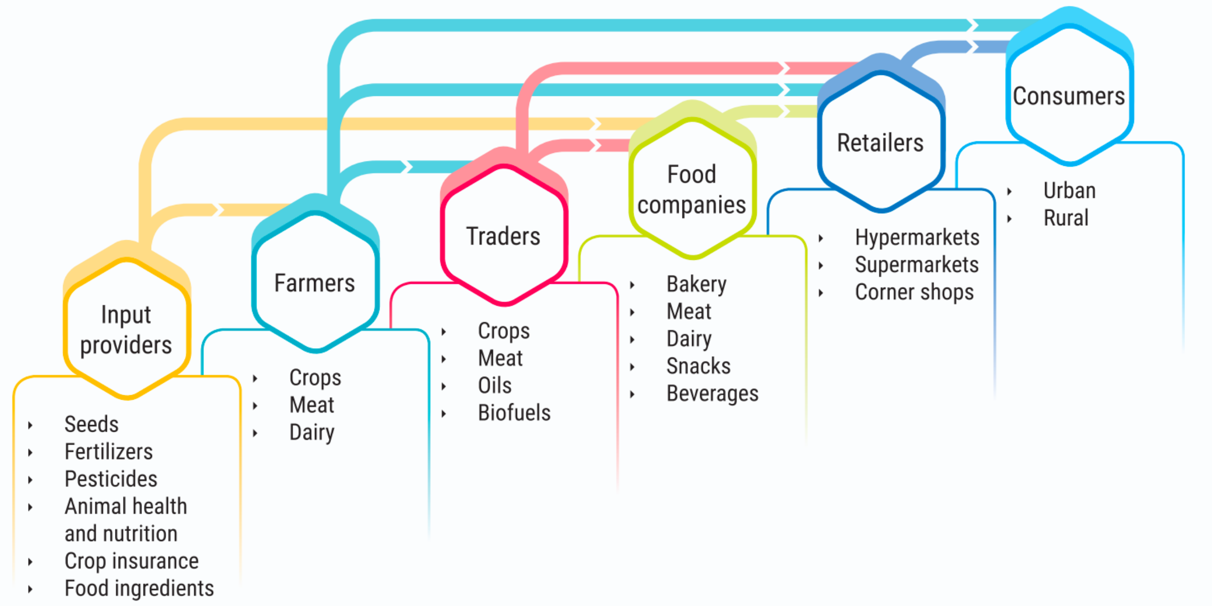
Since the beginning of recorded use of pesticides in 2500 BC, increasing agricultural yields has been a central societal preoccupation in light of increasing populations and the emergence of a global food market in the second half of the 19th Century (Watson 2018). Yet the productivist mode of agriculture only began to emerge in the 1930s, when Fordist models of mass production were adopted across various sectors to sustain a model of mass consumption of standardized goods (Watson 2018). Agricultural productivism can be considered as "a commitment to an intensive, industrially driven and expansionist agriculture with state support based primarily on output and increased productivity. The concern [of productivism] was for 'modernization' of the 'national farm', as seen through the lens of increased production" (Lowe et al. 1993, 221). Agricultural modernization has relied heavily on mechanization, genetic improvements, and the use of chemical inputs, which have all contributed to increasing productivity (Bosc and Bélières 2015). The main transformation during the turn towards productivism from pre-productivism was the commodification of agricultural production, in which farmers shifted from non-market (subsistence) to market forms of production (Watson 2018).

The large-scale shift towards productivism and commercial agriculture which accelerated in the second half of the 20th century led pest control to become a key form of risk reduction for farmers who began to make increasingly large investments for farm equipment (Watson 2018). The commercialization of agriculture was dependent on large investments by farmers, which required high incomes to pay back. Although farmers have always faced risks of crop losses due to pests, the need to maintain production to maintain financial stability changed farmers' attitudes towards risk (Watson 2018). Rather than being used curatively (i.e. when pest outbreaks occurred), pesticides began to be used systematically, as they decreased the probability of crop losses. From the 1930s to the 1960s, chemical pesticide production expanded rapidly to supply inputs for the expansion of productivist agriculture, which was boosted in the postwar period by the development of national agricultural policies to prevent food shortages and to support economic growth (Hough 1998; Watson 2018). These subsidies were generally tied directly to quantities of agricultural production, which incentivized intensification. In the postwar context, policy debates in the US and Europe on pesticide use were "almost exclusively in agricultural terms" within the agricultural community, which shared a commitment to pesticide use due to the benefits provided by their convenience, simplicity, and immediate applicability (Bosso 1987).

While the productivist paradigm persists to this day, several other agricultural paradigms began to emerge in the 1970s as the pesticide regulatory landscape began to take shape and globalization dynamics created new agricultural markets and geopolitical dynamics (Karlsson 2000; Watson 2018). Watson (2018) characterizes four paradigms which continue to coexist. Productivism, which is strongly driven by state policies and regulated farm wages, persists in many countries, including in Western Europe, where the robust resilience of key interest groups has maintained strong state support for productivist farming practices (Watson 2018). Productivism focuses on the mass production of standardized commodities, based on a narrow range of crop commodities. Due to increased integration of the agricultural sector of many countries into the global economy, a new form of productivism, "neo-productivism," has simultaneously emerged. While reliant on similar farm-level production strategies as productivism (notably high levels of off-farm inputs), neo-productivism is characterized by market (rather than state) regulation of wages and a turn towards the mass production of an even narrower range of crop species (notably wheat, corn, and soybeans) to produce cheaper, low-value commodities (Watson 2018). In contrast, the third paradigm, "post-productivism," moves away from the mass production of cheap commodities towards the production of differentiated, high value-added products targeting niche markets, such as specialized cheeses or wines. A fourth agricultural paradigm is the sustainability paradigm, in which environmental impacts of production are central concerns, driving a de-commodification of production and efforts to lower reliance on off-farm inputs (Watson 2018).

These changes in farm-level modes of production have occurred against a backdrop of increasingly complex agri-food systems. Pesticide use is affected by diverse actors within agri-food systems, often conceptualized as a "value chain" (Figure 7)(UNEP 2022a). Actors to the left of farmers in the figure (i.e. input providers) are considered "upstream" actors, while all actors to the right are "downstream." A small number of corporations currently control a majority of agri-food supply chains globally, from input providers to retailers. Actors in the entire agri-food system affect on-farm practices. The linkages between structural factors shaping agri-food systems and farm-level characteristics of different agricultural paradigms therefore form the critical context within which pesticide governance has evolved.

Figure 7: Actors in agri-food value chains.



Source: UNEP (2022).

1.2.2.4 Transformative change for agri-food systems

There is a growing understanding that environmental governance must grapple with addressing multiple interconnected environmental problems, challenging traditionally siloed approaches to addressing problems separately (Pattberg and Widerberg 2015). Global assessments, such as those published by the IPCC, IPBES, and UNEP, are unequivocal regarding the state of the environment and the pace and scale of change needed to address the joint environmental crises of climate change, biodiversity loss, and chemical pollution (IPBES 2019; IPCC 2022; UNEP 2021b). The IPCC's warnings on the severity of climate change and the ensuing global commitments to keep the global temperature rise below 2° Celsius above pre-industrial temperatures (as embodied in the Paris Agreement) clearly demonstrate that the decarbonization of human societies is the overarching agenda within which other environmental governance is inscribed. Addressing the climate crisis alone requires rapid action at all levels, yet the loss of biodiversity and chemical pollution around the world call for equally strong action to avert the degradation of nature which is threatening ecosystems and their ability to support human life and wellbeing (IPBES 2019).

As countries develop long-term climate strategies, it is becoming clear that the agricultural sector is critical to reaching net zero goals and to enabling effective climate adaptation (IPCC 2023; UNEP 2022g). Agriculture is a major source of greenhouse gas emissions and also contributes to biodiversity loss, not only through its use of chemicals but also through land use change for agricultural expansion and through management choices regarding agricultural practices (see section 1.1.4) (Ramankutty et al. 2018). It is also a sector expected to be most impacted by climate change, as already reflected in the slowdown in the growth in global agricultural productivity (Crippa et al. 2021; IPCC 2022; Ortiz-Bobea et al. 2021; Zurek, Hebinck, and Selomane 2022). Agriculture must therefore be at the forefront of the transformations that need to take place. Yet while it is also increasingly recognized that different decarbonization strategies have different socioeconomic impacts, as well as impacts on environmental issues other than climate change, these impacts are understudied in specific contexts relevant to policymaking (Aubert, Gardin, and Alliot 2021; Booth 2023).

Regarding the nature of the changes required, intergovernmental assessments clearly state the need for systemic, transformative change across all sectors which "is unprecedented in terms of scale" (IPCC 2023, 68). The 2019 IPBES *Global Assessment on Biodiversity and Ecosystem Services* stated that "goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond *may only be achieved through transformative changes* across economic, social, political and technological factors" (IPBES 2019, 14). Similarly, UNEP's second *Global Chemicals Outlook*, released in 2019, called for "*systemic and transformational changes* towards safer chemicals and innovations in chemistry that will contribute to sustainable development" (UNEP 2019, 7). For its part, UNEP's 2021 report, *Making Peace with Nature*, stated that collective efforts had failed to meet any of the environmental targets set by the international community since the Stockholm Conference in 1972 (UNEP 2021b). Linking different interconnected environmental problems addressed in separate assessments, UNEP echoed IPBES in its warning that: "*Only a system-wide transformation* will achieve well-being for all within the Earth's capacity to support life, provide resources and absorb waste. This transformation will involve a fundamental change in the technological, economic and social organization of society, including world views, norms, values and governance" (UNEP 2019, 15). Addressing the risks of pesticides — and chemical pollutants more generally — is therefore only one of many pillars of what these assessments have identified as a need for transformative societal change to fundamentally alter how humans impact the environment (UNEP 2021b).

There is growing recognition that addressing interconnected environmental problems requires integrated approaches and that public policies play a critical role in creating the structural conditions for other actors to initiate transformations at different levels (Secretariat of the Convention on Biological Diversity 2020; UNEP 2019, 2021b). Intergovernmental agencies such as UNEP highlight that "all actors" have a role to play in accelerating transitions, including the private sector and individuals, particularly in wealthier countries, who can contribute by modifying unsustainable consumption patterns (UNEP 2021b). Yet the urgency of addressing these challenges and the critical importance of reducing greenhouse gas emissions within this decade will require "intergovernmental cooperation, policies, and regulations that transform society and the economy" (UNEP 2019, 133). Given the scale and character of the problems to be addressed, a key role of public policies is to enable cross-sectoral planning and to design integrated policy mixes that "find synergies, address trade-offs, and manage the interactions between areas including water, food, energy, climate change and human health" (UNEP 2021b, 28). UNEP's *Global Chemicals Outlook* also acknowledges the politics of transformations, highlighting that opposition from vested interests "is to be expected but can be addressed," notably through political leadership and redirecting subsidies (UNEP 2019, 19). The language of transitions and transformations has increasingly been adopted by policy communities, notably in the EU, acknowledging the call for integrated approaches and explicit attention to political dynamics and opposition to transition measures, which can be partially addressed through better policy design (European Environment Agency 2019; UNEP 2021b).

Agriculture and food systems are examples of this interconnectivity between different environmental problems and the need for integration across sectors and policies. Due to the multiple linkages between food systems and the global sustainable development agenda (notably several Sustainable Development Goals), food systems are highlighted as a key sector in need of reform (Benton et al. 2021; Hebinck et al. 2021; IPBES 2019; IPCC 2022; McGreevy et al. 2022; UNEP 2021b, 2022e). These scientific assessments and policy discussions on food system transformations focus on the need to address climate change, biodiversity, land degradation and the social issues of growing poverty and inequality jointly. As highlighted by UNEP and many scientists, there may be tradeoffs between various sustainable development goals, including potentially between pesticide use and addressing climate change (Deprez, Vallejo, and Rankovic 2019; IPBES 2018; UNEP 2021b). At the same time, however, many actions which halt biodiversity loss can also mitigate climate change, showing the necessity to take these interlinkages into account (Shin et al. 2022).

Globally, public policies have played a critical role in guiding the development of agriculture in the past century. Looking ahead, it is critical to examine the potential role of public policies in shaping the future of not only agriculture, but the agri-food sector as a whole, and its linkages with different parts of the sustainable development agenda. The EU's Green Deal can be seen as a pioneering effort to devise an integrated approach to this century's inter-related global challenges. Its Farm to Fork Strategy outlines a vision for a systemic transformation of the EU's food system in a way that aligns with the EU's larger climate-neutrality and other sustainability goals. Despite outlining a normative agenda, the Green Deal leaves significant ambiguity in terms of how the adopted goals will be achieved. Political battles on food system reforms reflect different interpretations of "sustainability," of "transitions," and of "transformations" for different actors (Béné et al. 2019; Skrimizea et al. 2020; Weber et al. 2020). It is critical to unpack these politics and different modes of environmental governance in light of rapidly changing actor dynamics and global challenges. The remainder of this thesis endeavors to contribute to this task, focusing on pesticides.

1.2 Research questions

The concept of governance has been interpreted and adapted by scholars in a wide range of disciplines, ranging from political science to public administration, sociology, economics, and law. In this thesis, governance is understood as the process of deliberately and interactively steering society toward specific goals. Since the surge of interest in the concept of governance in the 1990s, governance theory has developed as an interdisciplinary endeavor in which a range of overlapping theoretical discussions and debates occur, often in distinct literatures

(Ansell and Torfing 2022). The concept of "governance" can therefore function as an interesting boundary object which "encourages theoretical cross-fertilization" (Ansell and Torfing 2022, 12).

Governance theories have different purposes. They may explain the roles played by different actors in governing processes at different levels; examine how actors, institutions and levels of governance interact; unveil how governance is designed, organized and orchestrated; help understand the impacts or effects of governance and its contribution to solving problems; or seek to explain governance failures and/or how to improve governance efforts (Ansell and Torfing 2022).

In rethinking environmental governance in an era of sustainability transitions, this thesis probes the governance of change in sociotechnical systems. The systems-focused analysis underlying all chapters of the thesis is based on the recognition of the complexity of relationships between societal activities and biophysical processes which shape the environment (H. Selin and Selin 2022). Systems-focused analyses aim to understand these relationships, emphasizing that systems are characterized by non-linearities, feedback loops, and time-delayed impacts (H. Selin and Selin 2022). Analyzing systems requires characterizing them, thereby deciding which system components to include or exclude and focusing on a limited number of critical components.

Building on prior research examining the governance of sociotechnical change (Borrás et al. 2014), this thesis focuses on three interrelated components of environmental governance across the four chapters: actors and their interests; institutions and policy instruments; and scientific knowledge. It lends special attention to the roles played by different actors in governing processes and examines how their interests shape policy instruments and the use of scientific knowledge in decision-making. Ultimately, it probes whether and how governance has contributed to solving — or exacerbating — sustainability problems.

Actors and their interests

Actors have agency and power, either over other actors or over specific outcomes, and are therefore central to understanding governance. Examining actors in the context of pesticide governance means both examining who is governing pesticide use and who are the subjects of governance. Actors governing pesticides may not be the primary agents of change affecting pesticide use, which may instead be driven by other forms of governance by other actors, or by external factors. From a multi-level governance perspective, understanding the (differentiated) roles of various actors in governing pesticides at different levels of governance is key. The proliferation of actors involved in environmental governance presents new challenges for analyzing whose agency matters in terms of affecting sustainability outcomes.

Scientific knowledge

In a policymaking paradigm which increasingly aims to be evidence-based, scientific knowledge often plays a critical role in decision-making. The co-constitutive nature of science and politics remain understudied within political science, notably in environmental governance. It is therefore critical to unpack how expertise is produced and used to understand environmental problems, to inform contested political decisions, and to justify action. In the case of pesticides, scientific knowledge is critical to problematization and to justifying governance interventions. Scientific knowledge also underpins understandings of the impacts of human activities — and, in particular, governance interventions — on sustainability outcomes, providing a critical link between understanding biophysical processes and societal activities.

Institutions and instruments

The question of how governance is enacted requires examining the institutions through which governance is mediated and the instruments used by different sets of actors to achieve specific goals. Examining these instruments in the context of pesticide governance means understanding existing instruments and analyzing the potential for alternative instruments to contribute to specific governance goals. From the perspective of enabling sustainability transitions in the agri-food system, there is a need to understand how existing governance instruments can contribute to overarching sustainability transition goals spanning multiple policy areas.

Based on these components of environmental governance, this thesis is guided by three overarching research questions:

1. How does the rise of private actors in environmental governance affect policymaking?

2. What is the (political) role of new forms of scientific knowledge in guiding transitions toward sustainability?

3. What role do different types of policy instruments play in governing transitions toward sustainability, taking into account the interconnected nature of sustainability problems?

Through different case studies, these three components of environmental governance are analyzed at three different levels: the international level, the supranational level (focusing on the EU), and the national level (focusing on France, Germany, and on tropical countries). The different chapters of this thesis examine different forms of governance, including regulatory, private, and state-led governance. In a forward-looking approach, two chapters draw on the concept of leverage points (Abson et al. 2017; Meadows 1999) to suggest interventions which aim to provoke sociotechnical change with the goal of societal transformations toward sustainability (H. Selin and Selin 2020). The specific research questions and theoretical gaps addressed by the different chapters of this thesis are summarized in section 1.5 and detailed in each individual publication in part IV of the thesis.

1.3 Research design

This section of Part I proceeds in four sub-sections. It outlines the research approach and context (1.4.1), explains the case selection (1.4.2), discusses the methodological approach (1.4.3), and describes research challenges encountered (1.4.4).

1.4.1 Research approach and context

The context of this research relates to the political climate leading up to the beginning of this thesis, in January 2019, when environmental concerns were becoming more widely acknowledged and expressed by civil society and policy actors in the wake of the adoption of the Paris Agreement in 2015 and the beginning of a vivid international youth climate movement, Fridays for Future, in late 2018. My decision to focus on pesticides as a pollutant and my approach to this research were also rooted in my personal and professional interests and trajectory, characterized by an interdisciplinary approach to sustainability issues. My undergraduate training in Columbia University's Sustainable Development program emphasized interdisciplinarity across the natural sciences and social sciences, while my Master's in Environmental Policy at Sciences Po exposed me to French schools of thought in the sociology of public action, controversy studies, and STS. Though initially perplexed by the relative lack of social science research on pesticides, I came to realize that this scarcity likely results, at least in part, from the technicality of the subject, which is often a deterrent to scholars trained more exclusively in the social sciences. My approach is therefore aligned with other literatures which emphasize how interdisciplinary perspectives can inform understanding and action on a variety of sustainability issues (H. Selin and Selin 2020).

In 2020, growing concerns over pesticide use were reflected in the adoption of an EU goal to decrease this use and the associated risks by 50 percent within a decade. EU policies for reducing pesticide use, including quantified goals, therefore provide an overall normative framing for the dissertation. The pesticide reduction target reflected in the Green Deal is a shared policy goal within the EU, but not globally: simultaneously with these developments, countries around the world are seeing the loosening of policies to control pesticide use, and, in many cases, the reauthorization of many chemicals previously banned (such as, notably, in Brazil and the United States (Alvarez Noli 2019; Bombardi and Changoe 2022; Ollinaho, Pedlowski, and Kröger 2022)). Due to growing recent literature demonstrating the detrimental direct and indirect effects of pesticides on biodiversity, addressing biodiversity loss is now a central part of the EU's policy goals, in addition to the longer-standing goal of reducing pesticides' impacts on human health. Transformations in the agri-food sector must also align with the EU's larger climate-neutrality goals. Thus, although the EU's normative agenda for transformations towards sustainability leaves significant ambiguity in terms of *how* the adopted goals will be achieved, it outlines several scientifically-informed goals which provide a strong normative framing for pesticide governance.

This thesis is based on a primarily qualitative approach, based on multiple case studies on pesticides grounded in novel empirical material in **Papers I, II** and **III** and a meta-analysis of policy integration between agricultural and biodiversity based on existing academic and grey literature in **Book Chapter I**. In the three papers, I adopt an interpretivist epistemological position, aiming to understand policymakers' and stakeholders' interpretations of their positions based on inductive reasoning often employed in sociology (Garcia and Hoeffler 2015). These qualitative methods were complemented by quantitative analysis to analyze trends of pesticide production, use, and trade and in agricultural production in cases where this was analytically useful to identify system dynamics. The selection of cases, methods for data production and analysis, and challenges posed by the study of contemporary pesticide governance are outlined in more detail in the next sections.

The book chapter is published in an edited volume, *Transforming Biodiversity Governance*, which resulted from a collaboration between researchers of the Rethinking Biodiversity Governance network, a network of social scientists and policy practitioners working on biodiversity governance. Its aim was to inform the development and implementation of the CBD Post-2020 GBF. The book is published with Cambridge University Press and is part of the Earth System Governance (ESG) book series. Our chapter on transformative biodiversity governance for agricultural landscapes is explicitly aimed at informing efforts to transform and enhance the implementation of the Post-2020 GBF goals relating to agriculture.

1.4.2 Case selection

Because this thesis takes the strongly multi-level nature of contemporary environmental governance as a conceptual starting point, the selected cases each examine different levels of policymaking and their interactions. Cases were selected based on a combination of their relevance, their coherence, the availability of data, and personal access to decision-making fora which would allow for close contact with decision-makers through participant observation and interviews. Recognizing the context-specificity of the cases and the problems of generalization associated with case studies, these finding are not intended to be representative, but rather to contribute conceptual insights to help guide environmental governance analyses and the development of effective, context-specific policies for reducing pesticide use.

The case study in **Paper I** was selected based on the growing importance of pesticide governance in international arenas. The governance of hazardous chemicals has taken on new importance in the context of efforts to advance sustainability. At the same time, due to IPBES' focus on pollutants as one of the major drivers of biodiversity loss worldwide, pollution became a focus of the Post-2020 Global Biodiversity Framework. Among all pollutants, pesticides and plastics have been singled out for policy action: both are among the proposed headline indicators for monitoring progress towards the pollution reduction goal. Increasing the scope and effectiveness of international pesticide governance has therefore increased in importance in its own right due to the growing risks posed by chemicals, as well as its interlinkages with related global sustainability issues.

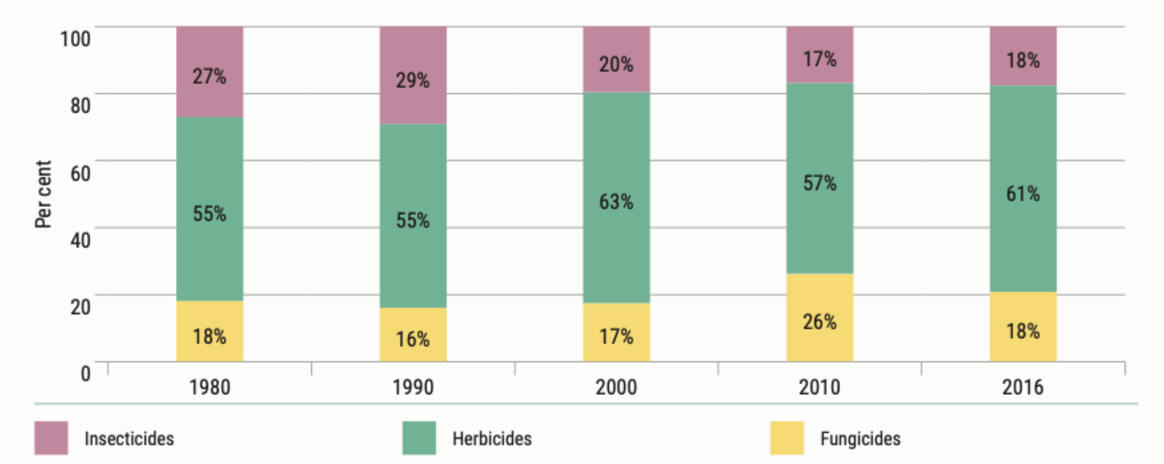
The Montreal Protocol, the Rotterdam Convention, and the Stockholm Convention are the three major global treaties that address select pesticides; each includes its own individual lists of pesticides which are subject to specific requirements, and a separate mechanism which allows these lists to be expanded over time. Among these, the Rotterdam Convention stands out due to its "governance by disclosure" approach, which institutionalizes a Prior and Informed Consent (PIC) procedure for hazardous chemicals covered by the treaty (Jansen and Dubois 2014). Since 2008, however, various parties to the Rotterdam Convention have begun blocking the addition of several chemicals approved for addition to the PIC list by the Chemical Review Committee. The growing political contention surrounding blocked pesticides since the late 2000s has led to a debate among Rotterdam Convention parties and other stakeholders around the effects of adding chemicals to the PIC list, and, in particular, why parties would block additions if the Rotterdam Convention primarily enables transparency. The simultaneous growth in private sustainability standards controlling the use of pesticides within certified supply chains provided fertile grounds to investigate whether and how the rise of private actors governing sustainability affects international treaty-making.

In addition, before the Covid pandemic delayed numerous international negotiation processes, two major issues were scheduled to be negotiated in 2020: the post-2020 agenda under the CBD and the "Strategic approach and sound management of chemical and waste beyond 2020" under the Strategic Approach to International Chemicals Management (SAICM). Though both were delayed (to 2022 and 2023, respectively), 2019 was a year of intense diplomatic preparation for these negotiations. In 2019, the BRS Conventions held a combined triple COP, a key arena where governments decide on procedures to control the production, use, disposal, and trade of certain substances, as well as define modalities for the exchange of information on chemical hazards and risks. My prior experience working on multilateral environmental agreements and attending negotiations, the possibility to attend negotiations as an observer, and the detailed documentation provided in United Nations documents were additional motivations for pursuing this case. In attending these negotiations, I discovered the growing importance of private voluntary agricultural standards and their linkages with the continuing implementation of the chemical treaties.

Papers II and **III** focus on the multi-level governance dynamics at play in the EU by narrowing in on the case of a single pesticide active substance, glyphosate. The EU is a unique supranational institution in that it comprises the most integrated form of international coordination in the world. It also has one of the most comprehensive and protective regulatory frameworks for chemicals and is a model for safety standards worldwide (European Commission 2020a). Its pesticide regulations exemplify many of the complexities of multi-level governance. For example, the SUD and the EU's new proposals for pesticide governance require national action to reduce pesticide "use and risks." However, the majority of EU member states have converged around an approach based on reducing environmental risk rather than decreasing pesticide use (and thus sales). Unlike the EU's hazard-based approach to the market authorization of pesticide active substances, once a substance is on the market, member states may take a risk-based approach to governing its use. Thus, use authorizations specify requirements for pesticide application by crop based on a risk assessment. Regulations for pesticide formulations therefore vary widely across EU member states depending on their approach to risk, despite the EU's integrated approach to regulating active substances.

Focusing on a single active substance — in this case, glyphosate — is useful to examine technical and social issues related to its specific attributes and how its use has developed in different contexts. Glyphosate is an herbicide and the most widely used pesticide in the world. Among different pesticide types, herbicides comprise the largest use of pesticides by volume globally and are also responsible for the majority of the increase in global pesticide use (Figure 8) (UNEP 2022e). Glyphosate in particular stands out: this active substance alone is responsible for the largest part of the growth in pesticide use in the last 15 years (Shattuck 2021). This is partially due to the widespread adoption of herbicide-resistant GMOs in major agricultural exporting countries such as Argentina and Brazil; over half of the glyphosate used in 2012 was sprayed on GMOs (Shattuck 2021). Glyphosate use has continued to increase due to the low cost of generic products, whose production rapidly expanded after the expiration of Monsanto's patent in 2000 (Werner, Berndt, and Mansfield 2022). Glyphosate, and herbicides more generally, are therefore emblematic of the dependence of agriculture on pesticides more generally.

Figure 8: Pesticide use in agriculture by region (tonnes of active substance).



Source: UNEP (2022).

Glyphosate became a subject of significant public concern and a rare pesticide whose risks were widely debated globally (Lock 2020). Corporations, political institutions, research institutes, civil society and activist groups, and media outlets all contributed to debates regarding a potential EU ban, providing rich sources of empirical material to draw upon (Lock 2020). Discussions of glyphosate bans were also taking place in numerous countries outside of the EU. Understanding the politics and decision-making processes regarding glyphosate is critical since policies in one country may set a precedent and be reproduced in other contexts. The case of glyphosate moreover raises a variety of questions of empirical and analytical value. The papers further break down the case of glyphosate in two different ways.

Paper II narrows in on France, in light of the theoretical precept that transitions can be accelerated with strong guidance from the state. France's history as a "dirigiste" state, which played a crucial role in guiding French postwar "modernization," "emphasizes the importance and coherence of the overarching ideas developed by elites influential within the French state" (P. Hall, Schmidt, and Thatcher 2015, 241). Its strong recourse to expertise as part of a broader technocratic approach provide an interesting case to investigate how expertise is mobilized and produced. President Emmanuel Macron's government has been particularly active in making political promises related to sustainability transitions across all sectors, particularly after France hosted the UNFCCC COP in Paris in 2015. France has also been actively experimenting with new modes of environmental governance since its 2007 "Grenelle de l'environnement," an open multi-party debate which brought together members of local and national governments and civil society (NGOs, industry organizations, trade unions) to develop a plan of action to tackle environmental issues.

In 2017, France was the first country to announce an intention to ban glyphosate within three years and the only country in Europe with an overall pesticide reduction target of 50 percent, equivalent to the EU's 2030 goal under the Farm to Fork Strategy (European Commission 2020c). The French government and research institutions have also been especially active on the issue of pesticides, displaying an ambitious approach unlike those displayed by other member states in their National Action Plans on pesticides. It is the only country which adopted a volume-based approach in its initial NAP (French Ministry of Agriculture 2018). The French experience of developing scientific expertise and a variety of new governance instruments aiming to enable this reduction are important for understanding the politics and instrumentation of pesticide governance more broadly. In lieu of a full ban, France developed a novel regulatory instrument which restricts the use of glyphosate based on the availability and costs of alternatives, rather than on health or environmental risks alone. This innovative policy instrument provided a fitting case to examine new modes of pesticide governance.

Given the critical role of the EU in determining pesticide and agricultural policies, **Paper III** examines glyphosate governance in France and Germany to disentangle multi-level governance dynamics and to shed light on the design and role of phase-out policies within a broader sustainability transitions agenda for agri-food systems. Because active substances are regulated at the EU level, the political promises made by France and Germany to ban glyphosate in the absence of an EU ban marked an unprecedented experiment in multi-level pesticide governance at that time.[5] In France and Germany, agricultural uses comprise 95 and 90 percent of all glyphosate sales, respectively, in line with the EU-wide average of 91 percent (Antier et al. 2020). Over the course of this thesis, an EU-wide glyphosate ban became less likely and both France and Germany only adopted partial bans. This example of policy retrenchment was useful for understanding the flipside of transitions and for examining why lock-ins persist despite attempts to govern change.

1.4.3 Methods

This thesis takes a primarily qualitative methodological approach, employing quantitative analysis in some instances to identify system dynamics and drivers of pesticide use. The different methodological approaches used are described below.

Participant observation

Paper I made strong use of information gathered through participant observation at two meetings of the BRS Conventions due to the opportunity to participate in multilateral environmental negotiations as an observer. The joint BRS COP meeting took place in Geneva from April 29th to May 10th 2019. Having identified the Rotterdam Convention as a particularly salient case to focus on based on participation at the COP, I attended the Rotterdam Convention Chemical Review Committee (CRC) meeting from October 8th to 11th 2019. I attended both as an academic researcher observer affiliated with the Technical University of Munich. In person participation at the BRS COP allowed for detailed ethnographic observation of plenary sessions with all parties to the three conventions and of side events hosted by NGOs, national governments, UN organizations, and the secretariats of the three conventions. All attendees are granted access to negotiation documents, and presentations from side events are also frequently shared. The documents and presentations shared during these meetings are particularly important resources as they are not always included in the resources made publicly available by UN bodies or the reports of the Earth Negotiations Bulletin. Interim decision-making documents can shed light on negotiation processes and capture specific actors' evolving positions and issue framings, which may become less visible in final decisions. My participation in the 2019 BRS COP and CRC meeting also enabled the identification of experts for interviews and for initial contact and trust-building.

[5] Subsequently, but before taking definitive action on glyphosate, France unilaterally banned all uses of neonicotinoid pesticides in 2018. This experience, in turn, affected its glyphosate policies, as explained in Paper III.

Interviews
I conducted semi-structured interviews with key actors in each case for **Papers I**, **II** and **III**. **Paper I** focused on country delegates, NGO representatives, past and present members of the Rotterdam Convention secretariat, and private sector actors, including from the pesticide industry and private agricultural standard-setting bodies. For **Papers II** and **III**, interviews were conducted with actors in the agricultural sector, non-governmental organizations, political spokespeople, and policymakers at national and subnational levels. Interviews were conducted between May 2018 and August 2022.

I used interviews mainly to understand actors' situated perspectives and to strengthen my understanding of the particularities of each case. Preparation for interviews first involved the identification of key actors, whom I found through participation in the negotiations (**Paper I**) and based on document analysis (described hereafter), through professional contacts, and through snowball sampling (**Papers II** and **III**). I contacted potential interviewees in person or via e-mail, specifying my overall area of research and remaining relatively vague as to not influence the interviewees' responses. Following ethical guidelines for research conduct in the EU (European Commission 2021a), interviewees were given consent forms to sign prior to the interview itself. In order to allow for maximum openness, interviewees were told at the beginning of the interview that all information would be anonymized. I specified that identification of their institutional affiliation would be helpful and was granted the permission to list different levels of detail in terms of affiliation depending on each interviewee. I prepared interview guides prior to each interview adapted to the interviewee's context within the case studies.

During the interview, I aimed to establish a certain level of rapport with interviewees, maintaining awareness of the need for balance between sufficient distance to maintain ambiguity on my personal aims and enough rapport to ensure sufficient connection for the disclosure of certain potentially sensitive information (McCracken 1988). I was also aware of potential power dynamics between myself as an interviewer and the interviewee (Ackerly and True 2010). Given that I conducted mainly expert interviews, the power generally lay with the interviewee, requiring me to establish legitimacy and rapport, generally by affirming my status as a researcher at TUM and prior experience as a researcher at IDDRI. Depending on the context, I would explain my own disciplinary background and understanding of the issues discussed in order to diminish the power differential with certain experts, notably academic researchers. In some cases, I was asked questions in return by the interviewee, indicating a change in the dynamic. In these cases, I would defer the interviewee's question until the end of the interview to ensure that my response would not affect the interviewee's responses. I opened each interview with a question regarding the interviewee's personal background, disciplinary training, and current role in order to situate the actor within a broader social network. Interviews ranged between 20 and 130 minutes.

Due to the Covid pandemic, the majority of the interviews were conducted virtually using the videoconference program Zoom. I asked all interviewees for permission to record audio content, to which the majority consented. Although notetaking during interviews is sometimes thought to create an "unnecessary and dangerous distraction" (McCracken 1988, 41), I took simultaneous notes on my computer for the majority of the interviews. During in-person interviews, taking notes without looking at the keyboard allowed for the maintenance of eye contact with interviewees and enabled a smooth interview. Interviews conducted on Zoom enabled more discreet note-taking. Interviews with French stakeholders were conducted in French; all other interviews were conducted in English. Language barriers were not particularly strong given the high level of English for the majority of experts. Interviews were fully transcribed based on the audio recordings after each interview. Due to the sensitive nature of the content discussed in many interviews, I asked for approval from interviewees for the use of any quotations. Interviews are listed in the appendices of each publication.

Document analysis

Document analysis was critical to all components of this thesis. **Paper I** draws on public information on different private agricultural standards from certification bodies' and retailers' websites and documents, as well as data from a survey of supermarkets in the UK conducted by Pesticide Action Network UK, which shared this unpublished data upon email request. For **Papers II** and **III**, a corpus of documents was assembled from policy and legal papers from the French and German governments, EU policymakers, and other prominent actors; press releases; peer-reviewed scientific literature; scientific expert reports; industry reports; NGO statements and reports; and media articles. Documents originally in German were translated using the software DeepL. Although automatically translated texts lose some subtlety, automated translation was sufficient for understanding general contexts and policies. In order to enable strongly actor-focused analyses, **Papers I, II** and **III** involved identifying and mapping actors based on documents and additional bibliographical information obtained through interviews and internet searches. This was critical to understanding actors' positionality and networks at a given point in time.

Integrating the different sources of data described above (interviews, participant observation, and document analysis), the qualitative analyses in **Papers I, II** and **III** are based on an interpretive and iterative approach. The diverse methods and data sources used in this thesis allowed for a triangulation among different data sources. For **Papers II** and **III**, I used the software MaxQDA to identify and code recurring themes in the interviews and document corpuses following a grounded theory approach to qualitative data, and to build my analytical frameworks (Charmaz 2006; Glaser and Strauss 1967). Interviews were then deductively coded a second time using codes and subcodes based on concepts from the theoretical frameworks defined in each paper. **Book Chapter I** consists of a meta-analysis of policy integration between agricultural and biodiversity based on existing academic and grey literature.

To supplement the qualitative analysis, descriptive statistical methods were used to analyze agricultural production and pesticide use data from selected national governments and research institutions. In the initial phases of research, I used pesticide use, production and trade data from the FAOSTAT and Comtrade databases. After gaining deeper knowledge regarding the limitations of pesticide data and difficulties in accessing useful and reliable statistics (discussed in section 1.4.4), I refrained from relying strongly on pesticide data related to volumes of use. I analyzed agricultural production, yield, and use trends from the 1960s to 2015 using national FAOSTAT data for different crop types to gain a perspective on the long-term structural trends within the agricultural sectors in France and Germany, as well as for Europe as a whole. These analyses informed the framing and content of **Paper III,** notably the characterization of the regime trends driving glyphosate use.

1.4.4 Research challenges

Investigating the social world is a messy process for which various disciplines have developed a range of analytical tools, each of which have strengths and limitations. Investigating contemporary environmental governance poses a number of challenges; pesticides add another layer of methodological obstacles, notably due to the lack of reliable and comparable use data across different contexts and levels of governance and strong industry influence in knowledge production and in policymaking.

The lack of recent information and quantitative analysis on pesticide use highlights the fact that public data on pesticides is sparse, difficult to obtain, and often unreliable or incomparable — the global pesticide market is "notoriously opaque" (Shattuck 2021, 235). The statistics on pesticide production and/or use published by international organizations (such as FAO and UNEP) and by national agencies are often provided by industry or based on national farm surveys (Shattuck 2021). Such publicly available data on pesticides have been criticized by scientists and policymakers alike on multiple grounds. In the case of farm survey data, the quality of data depends on the capacities of the institutions producing them and so is variable across countries (Shattuck 2021). Currently available data on pesticide quantities is for pesticides *sales* rather than pesticide *use*. Pesticide sales are often used as a proxy since data on use are inconsistent and scattered, but they may not reflect use accurately because, for example, farmers may store or circulate pesticides. Current sales data are also not disaggregated according to the crops they are used on. These factors limit the use of such data for research. The quality and granularity of publicly available data contrasts with data collected by the pesticide industry, which are categorized by crop group, volume, and area of application by country. However, industry actors are reluctant to disclose data which they contend to be proprietary. During the course of this research, I was able to access an industry data set on pesticide sales and use through personal contacts. As it was subject to a specific use agreement, I was not able to publish the data. The non-availability of data for policy analysis therefore does not reflect a lack of data per se, but rather lack of access to data collected by private actors. This lack of consistent and reliable data differentiates chemicals governance and research from research on climate change and biodiversity, where more data is publicly produced and publicly available (UNEP 2020).

A second and more fundamental issue with quantitative pesticide data is that, because different active substances have different levels of toxicity, indicators which measure pesticides by weight or volume do not provide information that is useful for policymaking or risk assessment (Möhring, Gaba, and Finger 2019). For example, at the global level, pesticide application rates per hectare are lower today than in the 1950s; however, this observable decrease is likely linked to the development of pesticides which are more toxic, therefore requiring smaller quantities to be effective (Phillips McDougall 2018; Shattuck 2021). Most notably, neonicotinoids' detrimental impacts on ecosystems (discussed in section 1.1.4) occur at doses measured in nanograms (Foucart 2019; M. Henry et al. 2012).

Deficiencies in pesticide data have been acknowledged and criticized by scholars and policymakers alike, who recognize that the most widely available, current indicators based on pesticide quantities may lead to adverse policy outcomes (European Commission and Eurostat 2019; Lewis et al. 2016; Möhring, Gaba, and Finger 2019). However, these are still the most widely used at the global level, as demonstrated by FAO statistics, which comprise the main database of international pesticide data. The FAO's principal indicator for pesticides is volume of pesticide active ingredients (in tonnes) (FAO 2022a). Despite ongoing efforts to address these problems, there continues to be a lack of transparent, reliable, and consistent data which can be used for policymaking. In light of these issues, this thesis generally presents data on single pesticides (to avoid comparability issues) and from specific analyses in which data was gathered through surveys or other non-standardized methods.

Given that pesticides cannot be analyzed in the same way as more classical policy or multi-level governance problems, a second major challenge in this research lies in linking different literatures across siloed policy spaces and linking different levels of analysis. Despite growing awareness of the methodological issues arising from linking micro and macro levels of analysis in transitions literature (Köhler et al. 2019), a wide variety of approaches to operationalizing these linkages exist in different literatures. This poses the challenge of conceptualizing appropriate levels of analysis across related but distinct frameworks.

Researching contemporary issues also presents several challenges. Many interviewees were concerned about revealing sensitive information, particularly regarding the case of glyphosate, which has been highly politicized. This likely contributed to a lack of response from many of the experts I contacted. For my research on international level pesticide governance, I mainly contacted experts I met in person during the BRS negotiations. For my research on glyphosate governance, 12 experts agreed to an interview in France and 6 in Germany. In the case of France, I attempted to interview high-level government officials in the prime minister's cabinet. Of the three cabinet members contacted, one replied asking for specific questions, after which I received no further reply. Two other interviewees (both government officials) initially refused the request for an interview, but eventually agreed upon my insistence of the pertinence of their specific expertise. All three French NGO actors as well as several agronomic researchers I contacted failed to reply to my email requests after multiple attempts. In some cases, I contacted experts via LinkedIn due to a lack of publicly available email addresses. In total, in France, 12 of 24 experts I contacted agreed to an interview. In Germany, 6 of 15 experts agreed to an interview. In general, actors from the pesticide and agricultural industries in both France and Germany, as well as at the BRS Convention meetings, tended to be the most willing to conduct interviews and the most generous with their time.

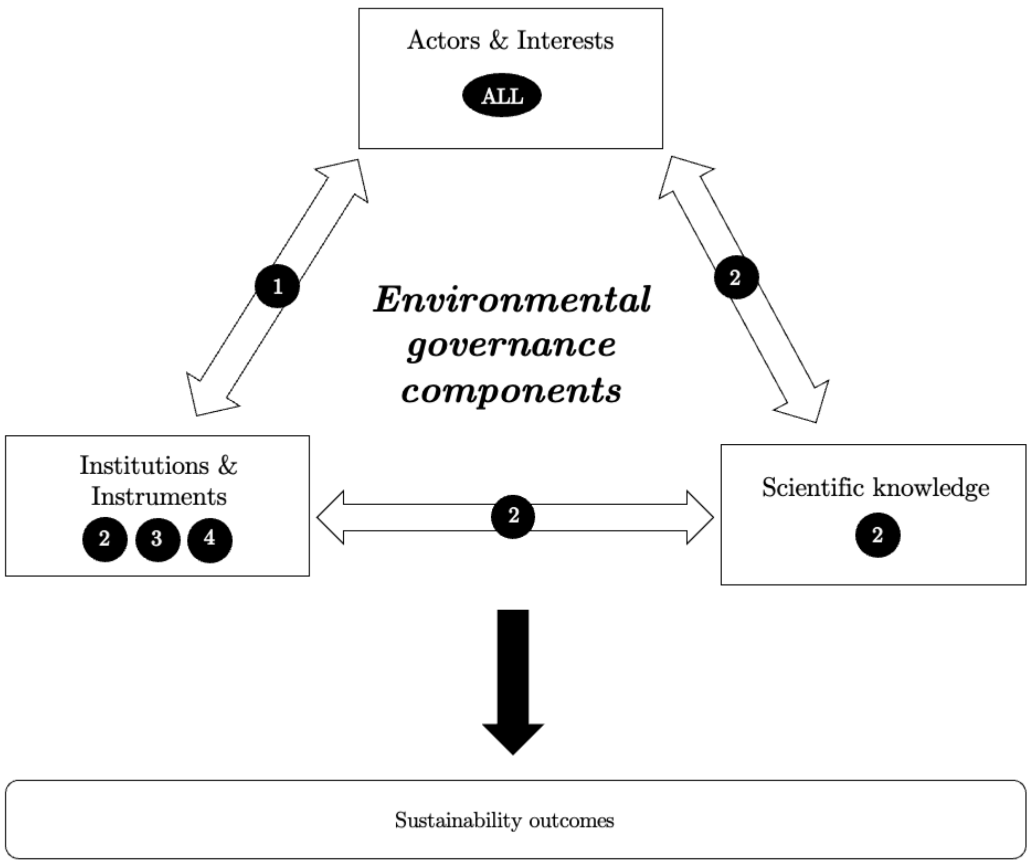
Some interviewees responded to interview requests indicating the reason for their refusal. In one case, an expert currently serving a three-year term on a committee for France's regulatory authority replied indicating that "the work of the committee cannot be communicated" and redirected me to the publicly available meeting minutes. Such a refusal also provides information regarding the functioning, procedures, and transparency within institutions. The sensitivity of the material also presents certain ethical dilemmas for researchers, who may be confronted with a situation in which the communication of certain information revealed in an interview could have direct consequences for an interviewee. Given the relatively small number of experts working on pesticides in the institutions investigated, the identity of some interviewees could potentially be inferred by actors from within these networks, despite intended anonymity. For this reason, the interviews in the three papers cannot be considered to consist of a representative sample, but rather serve to elucidate the perspectives of specific interviewees and details on policy processes not available publicly.

Lastly, as recognized by researchers around the world, special challenges arose due to the Covid-19 pandemic. The circumstances of the pandemic prevented in-person field work, limiting access to key sites for participant observation and making video conferences the default mode of operation for interviews. Although this presented certain advantages (notably, a higher level of comfort with video interviews among many interviewees), conducting interviews online prevents the interviewee from gathering ethnographic information about the interviewee and their context that in-person interviews allow.

1.4 Overview of dissertation

Across four publications, this thesis fills several theoretical and empirical gaps outlined throughout section 1.2. Theoretically, this dissertation contributes to debates in environmental governance on the roles of public and private actors (**Paper I**), the role of knowledge production in shaping the scope of policy options to advance sustainability transitions (**Paper II**), the role of phase-out policies within sustainability transitions (**Paper III**), and how to operationalize transformative biodiversity governance (**Book Chapter I**). Empirically, it contributes to international (**Paper I**), EU-level (**Papers II** and **III**), and national debates (**Papers II** and **III**) on different aspects of governing pesticides, with the aim of decreasing pesticide use and risks in line with differing norms and objectives in these various contexts. It also contributes to the assessment of biodiversity policy integration in agricultural policy worldwide, surveying both developed and developing countries (**Book Chapter I**). An overview of the different publications and their connections to these research gaps is outlined below. Figure 9 provides a schematic illustration of the three interacting components of environmental governance outlined in section 1.3 and shows how each publication relates to the different components. Linkages are emphasized to bring attention to the importance of understanding how different governance components interact, in addition to how different levels of governance interact. Across the four chapters, each of these three governance components is examined against the evaluative frame of how these individual governance components, levels of governance, and the linkages between them impact sustainability outcomes. Each chapter focuses more on some components of governance and/or interactions between components than others according to the specific case examined. All chapters focus on the role of actors and their interests.

Figure 9: Schematic illustration of relationships between components of environmental governance.



Publications

1 Paper I: "When private governance impedes multilateralism: The case of international pesticide governance"

2 Paper II: "The politics of expertise in France's assessment of alternatives to glyphosate"

3 Paper III: "From substitution to transformation: examining phase-out policies using the case of glyphosate in Europe

4 Book Chapter I: "Transformative biodiversity governance in agricultural landscapes: taking stock of biodiversity policy integration and looking forward"

⟺ Linkages between governance components

Source: Author.

***Paper I**: "When private governance impedes multilateralism: The case of international pesticide governance" (co-authored with Henrik Selin, Noelle Selin and Miranda Schreurs)*

The first paper aims to contribute to understandings of the interactions between private standard-setting bodies and public policy-making fora — including potential for negative feedback effects — and to draw lessons to inform academic and policy discussions on the (potential) role of private standards in advancing sustainability.

To do so, this paper examines how the operation of private agricultural standards influences international pesticide governance, focusing on the listing of substances under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, a treaty-based information-sharing mechanism that allows countries to refuse hazardous chemical imports. It does so based on participant observation at international negotiations, semi-structured interviews, and public information on different private agricultural standards from certification bodies' and retailers' websites and documents. We particularly focus on how actions and decisions taken by increasingly ambitious private standard-setting bodies influence multilateral decision-making under the Rotterdam Convention, and discuss the ways in which interactions between private standard-setting bodies and the Conference of the Parties (COP) to the Rotterdam Convention affect international pesticide governance more broadly. We address two interrelated research questions: First, how do private agricultural standard-setting bodies and parties involved in international treaty-based pesticide governance interact? Second, what are the effects of these interactions on pesticide governance?

***Paper II**: "The politics of expertise in assessing alternatives to glyphosate in France"*

Transitions to sustainability require not only structural policy reforms, but a rethinking of how policy-relevant expertise is produced. The role of expertise is particularly relevant to debates around potential policies to support the phase-out of technologies and substances such as fossil fuels and hazardous chemicals. Many technologies have become "locked in" at the system level, hindering the development and use of alternatives. Phase-outs therefore prompt questions around which alternatives are considered credible and by whom, and how policies can nurture the development of alternatives and support their deployment.

This article analyzes French pesticide regulation on alternatives to glyphosate in agriculture to reveal the governance implications of the construction of expertise. Glyphosate — the most widely used herbicide worldwide — can be seen as a bellwether for experimenting with policy options to reduce pesticide use given its ubiquitous use for a wide range of crops and applications worldwide. In 2017, France was the first country to announce an intention to ban glyphosate within three years and the only country in Europe with an overall pesticide reduction target of 50 percent, equivalent to the EU's 2030 goal under the Farm to Fork Strategy. Nevertheless, France has failed to reduce pesticide use. In 2020, instead of instituting a full ban on glyphosate, France announced new regulations which further restrict use authorizations for products containing glyphosate *based on the availability of alternatives*, rather than on glyphosate's inherent risks. I build on the concepts of co-production and boundary work to examine the development of regulations designed to address glyphosate use in the agricultural sector in France. Drawing on semi-structured interviews and document analysis, I address two interrelated questions: First, how do governments participate in the construction of expertise to inform policy choices on credible alternatives to dominant technologies for the governance of sustainability transitions? Second, what factors influence the boundary work undertaken by government actors and how do these impact policy outcomes?

***Paper III**: "From substitution to transformation: examining phase-out policies using the case of glyphosate in Europe"*

This article analyzes the role of phase-out policies within sectoral sustainability transitions, using the concepts of sociotechnical lock-in and the governance of discontinuation to examine France and Germany's policies to govern glyphosate, the most widely used pesticide in the world. Representing a third of herbicide use by volume in the EU, glyphosate is emblematic of the dependence of European agriculture on herbicides and pesticides more broadly. After initially announcing a plan to fully ban glyphosate by 2022 on the grounds of its risks to human health and the environment, both France and Germany subsequently adopted policies which allow for its continued use, notably in the agricultural sector. This example of policy retrenchment is useful for understanding the flipside of transitions and for examining why lock-ins persist despite attempts to govern change. The article examines state-led governance of discontinuation by characterizing the sociotechnical regime within which glyphosate is embedded and identifying key lock-in mechanisms, drawing on political economy and multi-level governance. I address three interrelated research questions: First, (how) can glyphosate be understood as part of a broader sociotechnical regime? Second, what are the lock-in mechanisms challenging the legitimacy of member state-led glyphosate phase-out in the absence of an EU-wide ban? Third, how does a broader understanding of sociotechnical regimes and lock-ins for specific substances or technologies inform choices about different governance approaches to phase-out?

***Book Chapter I**: "Transformative biodiversity governance in agricultural landscapes: taking stock of biodiversity policy integration and looking forward" (co-authored with Yves Zinngrebe, Marjanneke Vijge, Sabina Khan and Hens Runhaar)*

Current forms of agriculture are a major driver of biodiversity loss. Prevailing threats to biodiversity in agricultural landscapes are linked to management choices and habitat conversion. Biodiversity conservation in agricultural landscapes requires both setting aside valuable ecological areas (land-sparing), and radically changing agricultural practices (land-sharing). Yet while global assessments elucidate the mechanisms by which biodiversity is impacted by the agricultural sector, little is known about attempts to incorporate biodiversity objectives into agricultural policies.

Biodiversity Policy Integration (BPI) is an analytical tool derived from the broader literature of Environmental Policy Integration (EPI) (Zinngrebe, 2018). EPI can be defined as "the incorporation of environmental objectives in non-environmental policy sectors such as agriculture, energy and transport" and can be considered transformative because of its "aim to target the underlying driving forces, rather than merely symptoms, of environmental degradation" (Persson et al., 2018: 113). Governance elements and processes which support EPI have been widely studied, particularly in European and OECD countries. However, to date, empirical analyses of BPI and, in particular, policy integration between agriculture and biodiversity are scarce.

This book chapter employs the concept of BPI to assess to what extent biodiversity is integrated into agricultural governance in developed and developing countries. BPI analyzes the consideration of biodiversity in all sectors and levels of policymaking and implementation, providing a conceptual approach to identify leverage points for transformative change. Following Zinngrebe (2018), we analyze five dimensions of BPI: inclusion, operationalization, coherence, capacity, and weighting. We address two interrelated research questions: First, to what extent have biodiversity considerations been incorporated into agricultural policies? Second, what leverage points can enable transformative biodiversity governance for agricultural landscapes in the future?

Part II of this dissertation lists the four publications of this thesis and their publication details. Part III provides a brief summary of each publication. Part IV presents the four individual publications in their original publication format. Part V consists of an overarching discussion and conclusion across all publications.

I. LIST OF PUBLICATIONS

Paper I	**When private governance impedes multilateralism: The case of international pesticide governance** *Fiona Kinniburgh, Henrik Selin, Noelle Selin & Miranda Schreurs (2022), Regulation & Governance.*
Paper II	**The politics of expertise in assessing alternatives to glyphosate in France** *Fiona Kinniburgh (2023), Environmental Science & Policy.*
Paper III	**From substitution to transformation: examining pesticide phase-out policies using the case of glyphosate in Europe** *Fiona Kinniburgh (manuscript).*
Book Chapter	**Transformative biodiversity governance in agricultural landscapes: taking stock of biodiversity policy integration and looking forward** *Yves Zinngrebe, Fiona Kinniburgh, Marjanneke Vijge, Sabina Khan & Hens Runhaar (2022).* In I. Visseren-Hamakers & M. Kok (Eds.), *Transforming Biodiversity Governance* (pp. 264-292). Cambridge: Cambridge University Press.

II. SUMMARY OF PUBLICATIONS

Paper I: "When private governance impedes multilateralism: The case of international pesticide governance"

Publication details
Kinniburgh, F., Selin, H., Selin, N. E., & Schreurs, M. (2022). When private governance impedes multilateralism: The case of international pesticide governance. *Regulation & Governance*. DOI: 10.1111/rego.12463

Status: Published (online in 2022 and in print in 2023).

Contributions: FK conceived the study, undertook the investigation (field work and participant observation) and analysis (interview analysis and quantitative data analysis), and wrote the original draft. HS, NS, and MS co-conceived the study, supervised the research process, and acquired financial support. All authors (FK, HS, NS, MS) contributed to the manuscript review and editing.

Abstract
Private standards play an increasingly important governance role, yet their effects on state-led policymaking remain understudied. We examine how the operation of private agricultural standards influences multilateral pesticide governance with a particular focus on the listing of substances under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, a treaty-based information-sharing mechanism that allows countries to refuse hazardous chemical imports. We find that private agricultural standard-setting bodies use the Rotterdam Convention's pesticide list to develop their own lists of banned substances. This alters the Rotterdam Convention's intended role, impeding efforts to add substances to the treaty, as attempts by private actors to impose stricter governance than state actors can undermine the potential for international state-based governance to become more stringent. We characterize this as a "confounding interaction" whereby institutional linkages between actions by public and private actors with broadly aligned goals results in unexpected negative consequences for governance.

Paper II: "The Politics of expertise in assessing alternatives to glyphosate in France"

Publication details

Kinniburgh, F. (2023). *Environmental Science & Policy.* DOI: 10.1016/j.envsci/2023.01.017

Status: Published in Special Issue, "Removing Pesticides."

Contributions: FK conceptualized the study, undertook the investigation and analysis, and wrote, edited, and reviewed the manuscript. NS, HS, and MS supervised the research process and acquired financial support.

Abstract

Transitions to sustainability require not only structural policy reforms, but a rethinking of how policy-relevant expertise is produced. Scholars of Science and Technology Studies have used the concept of boundary work to examine how governments mobilize experts to establish epistemic and political authority for public policies. Less attention has been paid to the ways in which boundary work affects the scope of policy options to advance sustainability transitions, notably in the context of sociotechnical lock-in of dominant technologies. This article analyzes French pesticide regulation on alternatives to glyphosate in agriculture to reveal the governance implications of the construction of expertise. It examines how state actors and scientific experts performed cognitive and sociopolitical boundary work to affect both the framing of government-commissioned scientific reports and the institutions and policy instruments through which the government addressed the glyphosate problem. The article analyzes the factors that shaped the development of a novel regulatory instrument which restricts the use of glyphosate based on the availability and costs of alternatives, rather than on health or environmental risks alone. This process limited the framing of glyphosate alternatives to practices considered economically and practically feasible by selected experts and excluded more systemic alternatives from policy debate and instrumentation. The adoption of this regulatory instrument reflects specific institutional contexts, power differentials between governmental ministries, and the hidden political influence of a powerful agricultural sector and agrochemical industry. This article shows how expertise design plays a key role in defining the scope of policy options and determining allocations of political power.

Paper III: "From substitution to transformation: examining pesticide phase-out policies using the case of glyphosate in Europe"

Status: Unpublished manuscript. Conference paper presented at the International Sustainability Transitions Conference, November 22, 2022 and revised thereafter.

Contributions: FK conceptualized the study, undertook the investigation and analysis, and wrote, edited, and reviewed the manuscript. NS, HS, and MS supervised the research process and acquired financial support.

Abstract

Phase-out policies have recently gained increased attention from scholars and policymakers to address sustainability challenges. Yet many proposed phase-out policies focus narrowly on the substitution of specific technologies or substances, neglecting the systemic nature of sustainability problems and underestimating the resistance of incumbent actors to such measures. This presents the risk of policy reversals or the entrenchment of further unsustainable lock-in dynamics. Further research is therefore needed on the potential role of phase-out policies in enabling systemic change. This article bridges research on sociotechnical lock-in and on the governance of discontinuation to examine France and Germany's policies to govern glyphosate, the most widely used pesticide in the world. I situate glyphosate within a broader sociotechnical system and identify the mutually reinforcing economic, political, and regulatory lock-ins which challenge a glyphosate phase-out. Because substitution-based measures alone cannot enable a 50 percent overall pesticide reduction, phasing out glyphosate in an EU policy context focused on strongly reducing overall pesticide use is fundamentally different from implementing past pesticide bans. Conceptualizing pesticides as part of a larger sociotechnical system points to the need to switch from command-and-control towards a mix of management-based instruments to ensure the long-term effectiveness of full phase-out policies. Phasing out glyphosate and reducing overall chemical herbicide use to reverse biodiversity loss necessitates changes in farming *systems* towards crops and agricultural land use with lower per-hectare pesticide use intensities. Due to the constitutive role of the state in subsidizing and shaping agricultural production, reforming public policies is critical to shifting the conditions of production which underly economic lock-in for farmers. A phase out which will not enhance dependency on other chemical pesticides instead requires an integrated approach to agricultural and trade policies which centers sustainability to enable a restructuring of actor networks, institutions, and power relations throughout national and EU food systems.

Book Chapter I: "Transformative biodiversity governance in agricultural landscapes: taking stock of biodiversity policy integration and looking forward"

Publication details
Zinngrebe, Y., Kinniburgh, F., Vijge, M. J., Khan, S. J., & Runhaar, H. (2022). "Transformative Biodiversity Governance in Agricultural Landscapes: Taking Stock of Biodiversity Policy Integration and Looking Forward." In I. Visseren-Hamakers & M. Kok (Eds.), *Transforming Biodiversity Governance* (pp. 264-292). Cambridge: Cambridge University Press. DOI: 10.1017/9781108856348.014

Status: Published.

Contributions: YZ, FK, HR co-conceived the study. YZ and HR developed the conceptual framework. YZ, FK, HR, and MV co-wrote the original draft. All authors (YZ, FK, MV, SK, HR) contributed to the investigation, data analysis, and manuscript review and editing. FK mainly contributed to writing sections 1, 2, 5, and 6.

Abstract
Current forms of agriculture are a major driver of biodiversity loss. Prevailing threats to biodiversity in agricultural landscapes are linked to management choices and habitat conversion. Biodiversity conservation in agricultural landscapes requires both setting aside valuable ecological areas (land-sparing), and radically changing agricultural practices (land-sharing). We employ the concept of *Biodiversity Policy Integration* (BPI) to assess to what extent biodiversity is integrated into agricultural governance in developed and developing countries. We find that biodiversity policies are predominantly 'add-on' and neither directly address biodiversity-threatening agricultural practices, nor specifically support more 'nature-inclusive' agriculture. Thus, existing knowledge on biodiversity-sound agriculture is not reflected in dominant agricultural policies and practices. We argue that political will can target the following leverage points to transform existing governance structures: (a) working towards a clear vision for sustainable agriculture; (b) building social capital; (c) integrating private sector initiatives; and (d) better integrating knowledge and learning in policy development and implementation.

III.PUBLICATIONS

Paper I

When private governance impedes multilateralism: The case of international pesticide governance

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When private governance impedes multilateralism: The case of international pesticide governance

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Abstract

Private standards play an increasingly important governance role, yet their effects on state-led policymaking remain understudied. We examine how the operation of private agricultural standards influences multilateral pesticide governance with a particular focus on the listing of substances under the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, a treaty-based information-sharing mechanism that allows countries to refuse hazardous chemical imports. We find that private agricultural standard-setting bodies use the Rotterdam Convention's pesticide list to develop their own lists of banned substances. This alters the Rotterdam Convention's intended role, impeding efforts to add substances to the treaty, as attempts by private actors to impose stricter governance than state actors can undermine the potential for international state-based governance to become more stringent. We characterize this as a "confounding interaction" whereby institutional linkages between actions by public and private actors with broadly aligned goals results in unexpected negative consequences for governance.

Keywords: certification schemes, global governance, international environmental agreements, private authority, private standards, sustainability.

1. Introduction

Private governance—the enactment of state-like governance functions by non-state actors—has come to challenge the role of the state in an increasingly complex global governance landscape (Haufler, 2001; Renckens, 2020). Private voluntary standards in the form of product and/or process requirements set by non-state actors play a growing role across a variety of resources and sectors, including in international food production (Henson, 2008). This rise of private standards has fueled debates about the role and effectiveness of private authority compared to public regulation (Cashore et al., 2004; Falkner, 2003; Vogel, 2008). This is also relevant to sustainability transitions, understood as "fundamental transformation processes through which established socio-technical systems

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shift to more sustainable modes of production and consumption" (Markard et al., 2012, p. 956). The United Nations and other actors pushing for sustainability advocate leveraging private governance to this end (Green, 2013; Renckens, 2020). A 2020 report from the International Trade Center (ITC), the joint agency of the World Trade Organization and the United Nations Conference on Trade and Development, states: "By adopting voluntary standards, the private sector can complement governments and international organizations in the pursuit of sustainable development" (Bissinger et al., 2020, p. 36). Various governments have encouraged the uptake of private standards, including by incorporating procurement requirements for privately certified sustainable products in trade policies or other public policies (D'Hollander & Marx, 2014; Vogel, 2008).

When encouraging the development of private standards, national governments, intergovernmental organizations, and civil society representatives that promote sustainability often explicitly or implicitly assume that such standards will complement public measures. Yet, research on relationships between public and private authority and the ways in which private standards help solve, or exacerbate, sustainability issues is relatively new. This research has focused mainly on a few sectors, notably forestry and fisheries, and on the interactions between transnational private actors and national governments (Grabs et al., 2021; Green & Auld, 2017; Hale, 2020). There is therefore a need to further analyze interactions between private standard-setting bodies and public policymaking fora—including potential for negative feedback effects—and to draw lessons to inform academic and policy discussions on the (potential) role of private standards in advancing sustainability. To this end, we focus on the case of international pesticide governance, a sustainability issue that is garnering greater public attention due to concerns about pesticide use on human health and ecosystems (Selin, 2010; UNEP, 2021).

Many hazardous pesticides are widely distributed in the environment, contributing to a decline of biodiversity, and are present as residues in food where they may pose risks to consumers (UNEP, 2021). They also pose severe health threats to farming and proximate residential communities: A recent survey found that over 40 percent of an estimated 860 million agricultural workers worldwide suffer from unintended acute pesticide poisoning, in addition to a wide range of adverse health impacts which are associated with chronic occupational and residential exposure (UNEP, 2021). There are three main global chemicals treaties which govern hazardous pesticides: the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, the 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the 2001 Stockholm Convention on Persistent Organic Pollutants (POPs). Both the Montreal Protocol and the Stockholm Convention ban the production, use, and trade of pesticides listed under each respective treaty. In contrast, the Rotterdam Convention facilitates information sharing on the transnational shipment of pesticides through a "prior informed consent" (PIC) procedure, allowing parties to refuse imports of pesticides listed under the treaty. On the private side, nongovernmental organizations (NGOs) and firms influence pesticide use through a wide range of voluntary standards, which restrict or ban the use of specific pesticides within supply chains.

In efforts to advance sustainability, the governance of hazardous pesticides has taken on new importance. Global governance of hazardous pesticides is increasingly shaped by a combination of the continuing implementation of the three main chemicals treaties and the growth of private voluntary agricultural standards. In this article, we analyze how the introduction and expansion of multiple private agricultural standards influence the implementation of global chemicals treaties addressing hazardous pesticides. We particularly focus on how actions and decisions taken by increasingly ambitious private standard-setting bodies influence multilateral decisionmaking under the Rotterdam Convention, and discuss the ways in which interactions between private standard-setting bodies and the Conference of the Parties (COP) to the Rotterdam Convention affect international pesticide governance more broadly. We address two interrelated research questions: First, how do private agricultural standard-setting bodies and parties involved in international treaty-based pesticide governance interact? Second, what are the effects of these interactions on pesticide governance?

The next section summarizes key insights from the literature on interactions between private standards and public policy and governance. Section 3 outlines the main global pesticide treaties, focusing particularly on the Rotterdam Convention, and provides examples of different private agricultural standards. Section 4 addresses the first research question, showing how a growing number of private standard-setting bodies have banned the use of pesticides listed under the three main global chemicals treaties as part of their individual and collective efforts to build political legitimacy and scientific credibility. Section 5 addresses the second question, arguing that, despite some reinforcing regulatory effects, overlaps in the pesticides covered by private agricultural standards and the Rotterdam Convention also have unexpected effects on Rotterdam Convention negotiations. Section 6 draws insights into theoretical and practical understandings of relationships between private and public governance, characterizing interactions between private agricultural standard-setting bodies and the Rotterdam Convention COP as an example of a "confounding interaction." The concluding section summarizes our main findings and identifies areas for future research.

2. Analyzing interactions between public and private actors and authority

Typically, "public" governance refers to state-centric governance while "private authority" has been conceptualized as the "performance of functions traditionally associated with national governments and inter-governmental organizations—rule-setting, dispute resolution, and public good provision—by private actors" (Cashore et al., 2021, p. 4). Private standards are requirements initiated and driven by private actors for products or for the processes underlying their production (Henson, 2008). The rise of private standards—and active promotion by their supporters—raises the question of what roles public and private actors *should* play, especially in addressing sustainability problems by deciding how these problems (and therefore potential solutions) are defined. To inform such normative questions, it is critical to understand the roles public and private actors *currently* play in different governance contexts, and the ways in which these interactions between public and private actors do, or do not, collectively contribute to achieving sustainability-relevant outcomes. Although a growing area of scholarship examines the role of non-state actors in multilateral environmental negotiations on, for example, climate change (Hale, 2016) and the ways international standards can complement public authority (Green & Auld, 2017), effects of the rise of private standards on multilateral processes has received little attention outside of legal scholarship on the World Trade Organization (Negi, 2020).

Recent literature has laid a conceptual foundation for analyzing public–private relationships and interactions. Eberlein et al. (2014) highlight the need to examine interactions involving public and private actors as dynamic *processes* in which there may be multiple phases. They propose a framework for examining interactions among actors in transnational business governance, focusing on six dimensions of interaction: (i) who or what interacts; (ii) the drivers and shapers of interactions; (iii) the mechanisms and pathways of interactions; (iv) the character of interactions; (v) the effects of interactions; and (vi) how interactions change over time. This framework is helpful for guiding empirical analysis of different aspects of actor relationships and interactions. The authors also propose a first typology for the "character" of interactions, identifying four main types: competition, coordination, cooptation, and chaos. This framework has been applied in a review of voluntary sustainability standards (Lambin & Thorlakson, 2018) and further developed in an overview of the literature on interactions between private authority and public policy (Cashore et al., 2021). Sustainability standards, which we address further in the next section, comprise "requirements that producers, traders, manufacturers, retailers or service providers may be asked to meet, relating to a wide range of sustainability metrics, including respect for basic human rights, worker health and safety, the environmental impacts of production, community relations, land use planning and others" (Lambin & Thorlakson, 2018, p. 370).

Cashore et al. (2021) distinguish between three main types of public–private interactions (which build upon Eberlein et al.'s (2014) "character" of interactions)—*complementary*, *competitive*, and *coexistent*—and several subtypes of interactions under each of these three main types. *Complementary* interactions occur when public and private actors work toward a common outcome and can take the form of collaboration, coordination, or isomorphism. Collaboration involves active and conscious partnership between public and private actors, such as in the case of public–private partnerships and multi-stakeholder organizations. Coordination involves independent governance efforts by public and private actors toward common goals without direct communication or explicit partnership. Isomorphism occurs when public and private governance take similar forms independently of each other, for example through common adherence to best practices. *Competitive* interactions involve antagonism among public and private actors competing in a limited governance space. This can happen through substitution or cooptation. Substitution may occur when firms adopt standards as a strategy to pre-empt or avoid government regulation or civil society campaigns. Public actors can coopt private governance by taking over private initiatives such as organic food standards, or crowd out private standards by adopting regulations. *Coexistent* public and private governance occupies a middle ground between the first two forms of interactions. Two sub-types of coexistent interactions are institutional layering, when public and private actors set up institutions that address different parts of a governance process, and chaos, when interactions between public and private bodies are unpredictable, undirected, and display no clear pattern. Interactions between public and private governance actors may change form over time or assume multiple forms at the same time. A collaborative process can become competitive (Renckens, 2021) or an interaction can be simultaneously complementary and competitive (Ponte et al., 2021), for example.

We use the six dimensions of interaction identified by Eberlein et al. (2014) in sections four and five to guide our analysis of relationships between private standard-setting bodies and treaty-based bodies in the area of international pesticide governance. We highlight the heterogeneity of public and private actors, enabling an analysis of their varied and potentially opposing intentions and interests as well as the ways in which interactions shape decisionmaking. We differentiate not only among private actors with goals that are broadly aligned with the chemicals treaties—i.e., different types of standard-setting bodies—but also among industry actors, such as the pesticide or agricultural industries, which may also influence the multilateral process to pursue a different set of private goals. The analysis is informed by three main types of data. First, information was gathered through participant observation at the joint Basel, Rotterdam, and Stockholm Conventions COP in April–May 2019 and the Rotterdam Convention Chemical Review Committee meeting in October 2019. Second, semi-structured interviews were conducted with country delegates, NGO representatives, past and present members of the Rotterdam Convention secretariat, and private sector actors, including from the pesticide industry and private agricultural standard-setting bodies. All interviews, in anonymized form, are listed in Appendix A (Table A1). Third, the analysis draws on public information on different private agricultural standards from certification bodies' and retailers' websites and documents, as well as data from a survey of supermarkets in the United Kingdom conducted by Pesticide Action Network UK (Pesticide Action Network UK, 2019, unpublished data).[1] We further discuss our selection of specific private agricultural standards in the following section.

3. International public and private pesticide governance

A first step toward understanding governance interactions is examining who or what interacts and what drives and shapes these interactions. We summarize here the public regulatory space and private governance mechanisms in international pesticide governance. We begin by focusing on the three main global chemicals treaties that cover hazardous pesticides as a public multilateral regulatory space, paying particular attention to the operation and implementation of the Rotterdam Convention. We then detail how private agricultural standards function as private governance mechanisms, highlighting their heterogeneity and growing importance in international pesticide governance.

The Montreal Protocol, the Rotterdam Convention, and the Stockholm Convention are the three major global treaties that address select pesticides (see Table 1). These multilateral agreements are subject to widespread participation by countries from all over the world. By early 2022, 197 countries and the European Union (EU) were parties to the Montreal Protocol while 184 countries and 164 countries were parties to the Stockholm Convention and the Rotterdam Convention, respectively (the EU is also a party to both these treaties). Among the world's largest economies, and pesticide producers and users, the United States stands out as a notable non-party to both the Stockholm Convention and the Rotterdam Convention (though it is a party to the Montreal Protocol). Over time, the parties to the Stockholm Convention and the Rotterdam Convention have increased the number of pesticides covered by each treaty. The Stockholm Convention list of pesticides has been expanded from 8 to the current 18 while the Rotterdam Convention list has grown from 19 to 36 (including severely hazardous pesticide formulations [SHPFs]). The Montreal Protocol, which addresses ozone-depleting substances, covers only one pesticide.

All three global chemicals treaties include their own individual lists of pesticides that are subject to specific requirements, and each treaty includes a separate mechanism that allows these lists to be expanded over time. However, the treaties differ in their regulatory approaches. The Montreal Protocol and the Stockholm Convention obligate parties to phase-out or severely restrict the production, use, and trade of listed chemicals within a determined time frame. The only pesticide covered by the Montreal Protocol is methyl bromide, and this pesticide is

Table 1 Major international treaties addressing pesticide production, use, and trade

Treaty	Adoption	Entry into force	Number of parties (as of early 2022)	Number of pesticides initially listed	Number of pesticides currently listed (as of early 2022)	Control mechanisms for listed chemicals	Process for adding chemicals	Pesticides currently listed (as of early 2022)
Montreal Protocol of the Vienna Convention	1987	1989	198	0	1	Parties obligated to phase out chemical over specified time period (with use exemptions for certain chemicals)	Amendments to the agreement	• Methyl bromide (with limited critical use exemptions for agriculture)
Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade	1998	2004	165	22	36	Parties required to follow prior and informed consent procedure for trade of listed chemicals	Nominations triggered through two or more national regulatory actions by parties; nominated chemicals are reviewed by the Chemical Review Committee and approved by consensus by the COP	**PIC list (Annex III)** • 2,4,5-T and its salts and esters • Alachlor • Aldicarb • Aldrin • Azinphos-methyl • Binapacryl • Captafol • Carbofuran • Chlordane • Chlordimeform • Chlorobenzilate • DDT • Dieldrin • Dinitro-ortho-cresol (DNOC) and its salts (such as ammonium salt, potassium salt, and sodium salt) • Dinoseb and its salts and esters • Dustable powder formulations containing a combination of benomyl at or above 7%, carbofuran at or above 10%, and thiram at or above 15% (SHPF†) • EDB (1,2-dibromoethane) • Endosulfan • Ethylene dichloride • Ethylene oxide • Fluoroacetamide • HCH (mixed isomers) • Heptachlor • Hexachlorobenzene • Lindane (gamma-HCH) • Mercury compounds, including inorganic mercury compounds, alkyl mercury compounds, and alkyloxyalkyl and aryl mercury compounds • Methamidophos • Methyl-parathion (emulsifiable concentrates [EC] at or above 19.5% active ingredient and dusts at or above 1.5% active ingredient) (SHPF†) • Monocrotophos • Parathion • Pentachlorophenol and its salts and esters • Phorate • Phosphamidon (soluble liquid formulations of the substance that exceed 1000 g active ingredient/L) (SHPF†) • Toxaphene (Camphechlor) • Tributyl tin compounds • Trichlorfon

(*Continues*)

Table 1 Continued

Treaty	Adoption	Entry into force	Number of parties (as of early 2022)	Number of pesticides initially listed	Number of pesticides currently listed (as of early 2022)	Control mechanisms for listed chemicals	Process for adding chemicals	Pesticides currently listed (as of early 2022)	
Stockholm Convention on Persistent Organic Pollutants (POPs)	2001	2004	185	8	18	Parties required to phase out or severely restrict production and use of chemical over specified time period	Nominations submitted by individual parties; proposed additions reviewed by the Persistent Organic Pollutants Review Committee according to criteria for persistent organic pollutants and approved by the COP (majority voting possible in case of disagreement)	**Elimination (Annex A)** • Aldrin • Alpha hexachlorocyclohexane (alpha HCH) • Beta hexachlorocyclohexame (beta HCH) • Chlordane • Chlordecone • Dicofol • Dieldrin • Endrin • Heptachlor • Hexachlorobenzene • Lindane • Mirex • Pentachlorobenzene • Pentachlorophenol and its salts and esters • Technical endosulfan and its related isomers • Toxaphene	**Severe restriction (Annex B)** • Dichlorodiphenyltrichloroethane (DDT) • Perfluorooctane sulfonic acid (PFOS), its salts, and perfulorooctane sulfonyl fluoride

†SHPF refers to "Severely hazardous pesticide formulation." SHPF nominations are based on a notification from a single developing country indicating domestic problems with a pesticide (see details in Section 3). *Source*: UNEP/FAO (n.d.-f, n.d.-g).

still subject to a limited number of use exemptions in the agricultural sector. The Stockholm Convention, with 18 pesticides listed as of early 2022, is the principal treaty for banning or severely restricting the production, use, and trade of pesticides identified as POPs, which pose risks through their toxicity, persistence, and ability for long-range environmental transport. Currently, parties must take measures to eliminate the production, use, and trade of 16 pesticides, and two other pesticides are under severe use restrictions (as well as strong limits to domestic production and trade, particularly with other parties).

In contrast to the bans on chemicals' production, use, and trade introduced by the Montreal Protocol and Stockholm Convention, the "governance by disclosure" approach of the Rotterdam Convention focuses on transparency as a driver for national policy action in the context of international pesticide trade (Jansen & Dubois, 2014). The Rotterdam Convention institutionalizes a PIC procedure for hazardous chemicals covered by the treaty. Under the PIC procedure, the government of a country where a firm that wants to export a chemical on the PIC list is located must ask the government of the country where the importing firm is based for import approval before the trade can proceed. This places the legal burden on exporting parties, which are required to ensure that exports do not occur if importing parties have not consented. A party that rejects the import of specific pesticides on the PIC list must also prohibit domestic production of that substance. The Rotterdam Convention's focus on transparency, stemming from a similar focus of the earlier voluntary information-sharing mechanism (Kummer, 1999; Selin, 2010), was the outcome of a political compromise during contentious treaty negotiations. Some actors—notably major environmental NGOs including Greenpeace and some developing countries mainly in Africa—fought for banning the manufacture and/or export of hazardous pesticides (Victor, 1998; Interview 10). However, strong opposition from the pesticide industry as well as many pesticide-producing and pesticide-using countries ultimately led to a non-banning approach focusing on the use of the PIC list to control trade (Selin, 2010; Victor, 1998).

There are four main pathways by which pesticides are nominated for possible addition to the PIC list (Fig. 1, step #1). All parties are required to submit a notification to the Rotterdam Convention Secretariat of any national ban or severe restriction on the use of a chemical that is adopted for human health and/or environmental reasons. Under the first three pathways (step #1, a–c in Fig. 1), a pesticide is nominated once the Secretariat has received notifications of: (a) at least two national bans, (b) at least two severe restrictions, or (c) at least one restriction and one national ban by two different parties. These three pathways require that notifications come from at least two out of seven different geographical regions identified under the Rotterdam Convention (the seven PIC regions are Africa, Asia, Europe, Latin America and the Caribbean, the Near East, North America, and the Southwest Pacific) (UNEP/FAO, 2010a). A fourth pathway involves nominations based on a notification from a single developing country indicating domestic problems with a pesticide (d in Fig. 1). These are classified as "severely hazardous pesticide formulations." The SHPF pathway aims to accommodate developing countries in two principal ways. First, it recognizes that developing countries may have lower regulatory capacity than

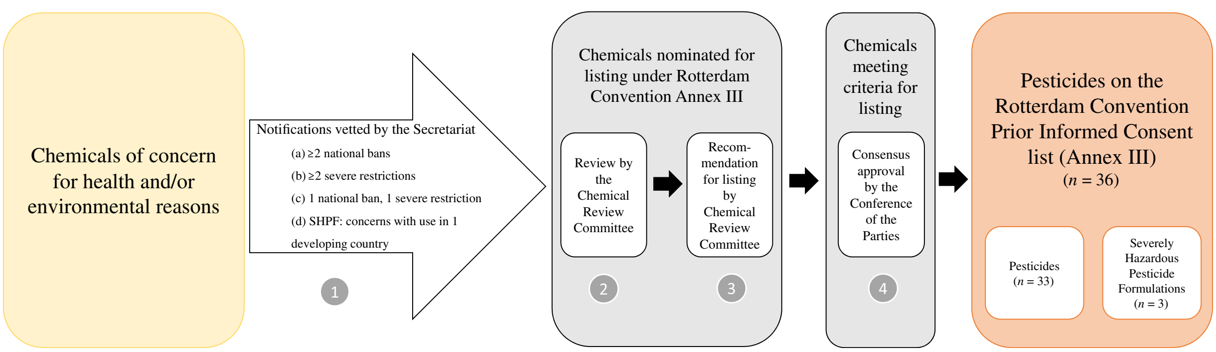

Figure 1 Processes for pesticide nomination and addition to the Rotterdam Convention Prior Informed Consent (PIC) list. According to the FAO (2004), a "severe restriction" is a partial ban, or restriction on all but one or two relatively small uses of the substance. A "severely hazardous pesticide formulation" (SHPF) is subject to a special nomination procedure based on domestic problems with the pesticide under its current conditions of use. The numbers in parentheses (n) refer to the number of pesticides listed under each category as of early 2022. *Source*: UNEP/FAO (n.d.-f).

industrialized countries. Second, it acknowledges that actual conditions of use differ in developing countries: protective equipment may be worn less because it is expensive, not readily available, or uncomfortable due to a warm climate (Boedeker et al., 2020).

The Secretariat to the Rotterdam Convention vets all notifications to ensure that all required information is included (Fig. 1, step #1). Next, complete nominations are passed on to and are reviewed by the Chemical Review Committee (Fig. 1, step #2), consisting of 31 government-designated experts in chemical management. These experts, who serve for a term of four years, are confirmed by the Rotterdam Convention COP based on criteria decided at the first COP meeting (Kohler, 2019; UNEP/FAO, 2010b). The Chemical Review Committee is mandated to verify whether each nominated pesticide meets the criteria for inclusion on the PIC list as set out in the treaty annexes. These criteria differ depending on whether a pesticide is nominated based on regulatory actions by two parties or use problems in a single developing country. If the Chemical Review Committee agrees to recommend a nominated chemical for listing on the PIC list, that recommendation is forwarded to the COP (Fig. 1, step #3). Finally, the COP must approve all additions to the PIC list by consensus (Fig. 1, step #4). This opens up the possibility for a single party to block a proposed addition (McDorman, 2004)—which has occurred multiple times in recent years.

Simultaneous to the development of the main global chemicals treaties, private standards have come to play an increasingly important role in the governance of agricultural supply chains. A wide range of private standards co-exist in the agri-food sector, including activist-backed standards, industry-backed standards, and multi-stakeholder initiatives (Henson, 2008; Lambin & Thorlakson, 2018). Activist-backed voluntary standards addressing environmental and social harms from production processes were initiated by NGOs such as the Rainforest Alliance in the 1980s (Djama et al., 2011). In the 1990s, a broad range of industry-backed standards emerged. Industry-backed standards may address environmental and social aspects of sustainability, but these standards are often primarily created to address issues of food safety and other quality attributes, managing supply chain risks, enhancing reputation, and gaining market shares (Bissinger et al., 2020; Busch, 2000; Fulponi, 2006; Henson & Reardon, 2005). These include standards developed or led by major food companies (such as Unilever) and commercial food retailers (such as Walmart, Tesco, or Lidl), which also sell own-brand products. Multi-stakeholder initiatives (such as Cotton Made in Africa) include a wide variety of stakeholders, including retailers or other commercial actors such as exporters or banks as well as environmental NGOs (Djama et al., 2011).

Private standards can be more important than public national regulations in determining farming practices due to their growing importance in agricultural supply chain management—notably in countries with weaker public regulations. Adhering to private standards has become a condition of entry for a growing number of producers of agricultural products into an increasing number of transnational supply chains, despite the "voluntary" (i.e., non-regulatory) nature of these standards. This is a result of their growing importance in food supply chain management, together with increasing vertical integration in global value chains and greater international market concentration among a smaller number of large buyers (Djama et al., 2011; FAO, 2017; Henson, 2008; Henson & Humphrey, 2009, 2011; McCluskey, 2007). Vertical integration enables retailers and major food companies to control their suppliers more directly, while concentration among these buyers reduces overall competition and market options for producers. Thus, many agri-food supply chains are "buyer-driven," allowing leading firms to dictate terms of production. These changes in market conditions have left many farmers with few options for market access aside from the major buyers, who have significant leverage for production conditions over farmers (Gereffi, 1996; Rastoin, 2000, 2008).

Private standard-setting bodies have become key actors in pesticide governance as they set criteria for agricultural production—including, for some standards, hazardous pesticides that cannot be used. Different private standard-setting bodies and their respective stakeholders determine their own criteria for controlling or banning the use of a particular pesticide (Interviews 13, 16). Many NGO-led certification schemes have their own standard-setting committees that make use of extensive consultation processes when determining the scope, context, and timelines of standards (Interview 16). They decide which pesticide uses are to be restricted and under what circumstances, and regularly review past decisions and consider new restrictions. Many private agricultural standards have a "core" reference list of banned pesticides. In addition, standard-setting bodies make decisions on a case-by-case basis regarding whether a specific pesticide may be used or if it must be phased out, based on consultations with stakeholders and based on different criteria including feasibility for producers (Interviews 13, 16). Some private standard-setting bodies also coordinate their decisions through umbrella organizations, such as the International Social and Environmental Accreditation and Labeling (ISEAL) Alliance in the realm of sustainability.

Our analysis focuses mainly on 11 major NGO-led agricultural sustainability standards and multi-stakeholder initiatives due to these standards' inclusion of pesticide control measures and data availability. There is currently no centralized database on all private agricultural standards, but the Standards Map of the ITC tracks the expansion of sustainability standards, including in the agricultural sector. Our selection of private agricultural sustainability standards is based on those covered by the most comprehensive report to date on markets of major products covered by sustainability standards by ITC's Meier et al. (2020). We focus on all of the private agricultural sustainability standards covered by this report aside from those for organic agriculture, since organic agriculture does not allow the use of synthetic pesticides. The 11 standards comprise a subset of the broader class of private standards which address agricultural issues. For these standards, the ITC reports detailed data for eight widely traded agricultural commodities: coffee, bananas, cotton, soybeans, palm oil, sugarcane, tea, and cocoa. Our selection is consistent with the standards covered in previous meta-analyses of sustainability certification schemes (DeFries et al., 2017; Tayleur et al., 2017). In addition, we use qualitative survey data on UK retailers from the Pesticide Action Network (PAN) to inform our analysis (Pesticide Action Network UK, 2019).

Commodities certified by private sustainability standards still occupy a relatively small part of the global agricultural market, but many of these standards are growing rapidly in their coverage of the overall market, as they are no longer serving only niche markets. The eight agricultural commodities included in the 11 selected standards in 2018 covered between 2 percent (soybeans) and 27 percent (cocoa) of the total global land area for these crops (Meier et al., 2020). The combined land area covered by these eight agricultural commodities grew by over 50 percent between 2014 and 2018, to a combined area of at least 19 million hectares (Meier et al., 2020). Growth rates have been particularly high for certain commodities: from 2014 to 2018, certified cotton acreage (which covers the largest area among certified commodities globally) grew by 173 percent, followed by cocoa (+90 percent) and sugarcane (+75 percent). In contrast, the total area of coffee produced that was covered by these 11 standards shrunk by 12 percent during the same time period (Meier et al., 2020).

4. Interactions between public and private actors in international pesticide governance

The growth in private sustainability standards raises questions regarding the mechanisms and pathways of interactions between private-standard setting bodies and public decisionmaking bodies in the global governance sphere. In this section, we address our first research question, examining how private agricultural standard-setting bodies and parties involved in international treaty-based pesticide governance interact. We pay particular attention to how decisions by private standard-setting bodies influence multilateral policymaking by parties to the Rotterdam Convention.

The lists of chemicals covered by the Montreal Protocol, the Stockholm Convention, and the Rotterdam Convention, as developed by the parties to these treaties, are part of the core list of banned pesticides for many private agricultural standards (Table 2). The use of the Stockholm Convention and Montreal Protocol lists of controlled pesticides as ban lists by private standard-setting bodies aligns with those treaties' own goals of phasing out the production, use, and trade of hazardous chemicals. In addition, private standard-setting bodies' inclusion of pesticides controlled by the two treaties on their individual ban lists can increase the geographical scope of these bans by also affecting agricultural producers in non-parties to the two treaties (in cases where pesticides controlled by the treaties are not banned by national authorities in non-parties). Fewer private standards use the Montreal Protocol list. However, since this treaty includes only one pesticide with limited remaining uses and applicability for these standards under the existing critical use exemptions, its more limited adoption is not surprising. Unlike the other two global chemicals treaties, though, the Rotterdam Convention was not designed as a banning instrument. The use of the Rotterdam PIC list as a ban list means that any new listing on the PIC list—regardless of whether the nomination was based on bans, severe restrictions, or local problems with use in a single country—leads to a ban for all producers complying with 10 of the 11 major private standards worldwide (see Table 2). For example, listing either carbosulfan (nominated by a single country as a SHPF; see step #1, pathway

Table 2 Adoption of international chemical treaty listings as a ban list by selected private standards

Standard	Background information for selected commodities				Chemicals lists used			Additional citations
	Year founded	Number of countries in which the standard has certified producers	Member of the IPM Coalition†	Commodities included	Rotterdam Convention	Stockholm Convention	Montreal Protocol	
Global Coffee Platform (formerly the 4C Association)	2003	28	✓	Coffee	✓	✓	✓	4C Association et al. (2016), ITC (2020)
Better Cotton Initiative (BCI)	2009	14‡	✓	Cotton	✓	✓	✓	Better Cotton Initiative (2018), ITC (2020)
Bonsucro	2011	10	✓	Sugarcane	✓	✓	✓	4C Association et al. (2016), ITC (2020)
Cotton Made in Africa	2005	10‡		Cotton	✓	✓		Cotton Made in Africa (2014, 2021)
Fairtrade International§	1997	75	✓	Bananas, cocoa, coffee, cotton, sugarcane, tea	✓	✓	✓	4C Association et al. (2016), Fairtrade (n.d.)
Global GAP	1997	136		Bananas				N/A
Proterra	2006	39		Soybeans, sugarcane	✓	✓		Proterra (2018)
Rainforest Alliance¶	1987	70	✓	Bananas, cocoa, coffee, palm oil, tea	✓	✓	✓	4C Association et al. (2016), Rainforest Alliance (2021a)
Roundtable on Sustainable Palm Oil (RSPO)	2004	16		Palm oil	✓	✓		RSPO (2018)
Roundtable on Responsible Soy (RTRS)	2006	9		Soybeans	✓	✓		ITC (2020), RTRS (2017)
UTZ Certified¶	1997	87	✓	Cocoa, coffee, tea	✓	✓	✓	4C Association et al. (2016), Auld (2010)

†The Integrated Pest Management (IPM) Coalition is a working group of the ISEAL Alliance formed in 2016 which "aims to reduce and eventually eliminate the use of highly hazardous pesticides, and to promote more sustainable alternatives. It also aims to harmonize approaches to pesticides between ISEAL member standards" (IPM Coalition, n.d.). ‡The 10 countries in which Cotton Made in Africa certifies producers are also recognized as meeting the benchmarked standard of the Better Cotton Initiative, which as a result counts 24 countries as members. The two are considered separately in our analysis to maintain consistency with the data and methodology in Meier et al. (2020). §Fairtrade International officially formed in 1997 but merged existing fair-trade initiatives, including the world's first fair trade certification mark (the Max Havelaar label), launched in 1988 (Fairtrade, n.d.). ¶The 1997 initiation date marks the foundation of UTZ Kapeh (Auld, 2010), which became UTZ Certified in 2002. Rainforest Alliance merged with UTZ Certified in 2018, forming a new organization that carries forward the Rainforest Alliance name (Rainforest Alliance, 2021b). We distinguish between the two since data are still reported separately in Meier et al. (2020). Data regarding the number of countries in which these two certifications have producers are from 2018. *Source*: Meier et al. (2020), IPM Coalition (n.d.), and individual standards' websites and reports listed in the additional citations column.

d in Fig. 1) or acetochlor (nominated through two bans each affecting many countries in two different regions; see step #1, pathway a in Fig. 1) would similarly result in an automatic use ban for certified producers.

Dynamics among private standard-setting bodies play an important role in affecting the overall uptake of the PIC list among a broader range of standards. This includes collective action and peer-to-peer learning, which can lead to greater harmonization and adoption of collectively established best practices, as well as competitive dynamics among standards (Fransen, 2015; Lambin & Thorlakson, 2018; Loconto & Fouilleux, 2014). ISEAL has a working group dedicated to decreasing the use of highly hazardous pesticides, the Integrated Pest Management (IPM) Coalition, in which 6 of the 11 standard-setting bodies participate (Table 2). In 2016, this group released a statement committing to banning pesticides listed under the Rotterdam Convention (as well as the Stockholm Convention and the Montreal Protocol), specifying that "if the international convention lists are updated, each of us will also update our banned lists accordingly as soon as possible" (4C Association et al., 2016). As an interviewee at one private agricultural standard-setting body involved in the IPM Coalition explained, "Because we are a voluntary standard, our mission is to improve cotton production over the baseline. […] And when you need to decide what pesticides to target, it does make sense to build on [the PIC list]" (Interview 13). The interviewee also emphasized the importance of competitive dynamics among sustainability standards. Both competition among standard-setting bodies and their need for political legitimacy are increasing in light of the rapid proliferation of private standards and mounting pressures from NGOs and consumers concerned with food system sustainability issues (Lambin & Thorlakson, 2018). Before ISEAL made a collective decision to ban PIC-listed chemicals, aligning with the pesticide standards set by peers within the ISEAL Alliance was a key motivating factor in driving the standard-setting bodies' decision to transition from the use of the PIC list as a non-mandatory criterion to a mandatory ban since these peers had already done so (Interview 13). These competitive dynamics may explain why other ISEAL members outside of the IPM Coalition have also adopted the PIC list.

Private standard-setting bodies' collective action strategies, including the incorporation of pesticides covered by the three global chemicals treaties on their own ban lists, are part of their ongoing strategic need to construct and maintain political legitimacy, in part based on scientific credibility (Bernstein & Cashore, 2007). Previous research suggests that the construction of political legitimacy among stakeholders (including farmers and industry and civil society organizations as well as consumers) is a critical component of private actors' ability to gain authority through "non-state market-driven governance" (Cashore, 2002; Partzsch et al., 2019; van der Ven, 2019). Private bodies setting sustainability standards (such as ISEAL) use collective action to create "meta-standards" as one part of this process, engaging external public and private actors in the standard-setting process to gain scientific credibility vis-à-vis donors, companies, and consumers as a "gold standard" in sustainability (ISEAL Alliance, 2021; Loconto & Fouilleux, 2014; Interview 13). Interviewees from standard-setting organizations and the pesticide industry explained that the adoption of the PIC list is also part of this process, as private standard-setting bodies generally lack in-house scientific expertise regarding each of the issues on which they are potentially setting guidelines due to capacity and resource constraints (Interviews 9, 13, 16).

Private standard-setting bodies differ in the extent to which they defer to lists from the international treaties in their own decisionmaking processes and generally use the PIC list as only one source for their decisionmaking. Even so, as stated by a representative of PAN, the PIC list is considered "the core list for all standards. Usually it's the Stockholm Convention, the Rotterdam Convention, and maybe the WHO [criteria for 'extremely hazardous' (1a) and 'highly hazardous' (1b) chemicals], but those [pesticides] are the ones they are the toughest on" (Interview 14). Because many private agricultural standard-setting bodies do not make a distinction between the three main global chemicals treaties, the PAN representative viewed the Rotterdam Convention PIC list as just "another list that standards or companies could just take off the shelf and apply" (Interview 14). Another interviewee from CropLife International similarly considered the PIC list as an example of different "resources that can be used as proxies for [standard-setting bodies'] decision-making" (Interview 9). The following shows how the PIC list's symbolic and practical role is interpreted by PAN, which is pushing for stronger global action on pesticides: "the Rotterdam Convention is about identifying problematic pesticides and sharing information […] and there was a lot of consensus that these pesticides are the problem pesticides" (Interview 14). As another interviewee from a standard-setting body noted:

> *It is an easy solution for us to refer to those because then we don't have to organize that consensus ourselves because this is effectively an outcome of a consensus already. We imply in our standards that all of this work—guidance, conventions—that has been issued by UN agencies that is relevant to our work (WHO, FAO, ILO, mostly) comes with a high level of credibility. (Interview 13)*

The above statement reveals how the PIC list is (mis)interpreted by someprivate standard-setting bodies as a reflection of an international "consensus" on hazards related to each pesticide, rather than as an acknowledgment that a pesticide has been included on the PIC list to control international trade according to specific criteria which may reflect a variety of underlying national and regional regulations, conditions, and problems. Representatives of standard-setting bodies interviewed were unaware of details of the negotiation dynamics in the Rotterdam Convention (Interviews 13, 16). One representative of a private standard-setting body also emphasized that stakeholders involved in that organization's consultation processes (such as producer networks, traders, and marketing organizations) see the PIC list as a "neutral" input, in contrast with how they view recommendations for banning issued by NGOs such as PAN (Interview 13). The representative argued: "PAN's list is PAN's own interpretation of the Highly Hazardous Pesticide concept. We would not consider that. PAN is not considered by our stakeholders as a neutral body" (Interview 13). Other standard-setting bodies do incorporate external scientific expertise and advice from NGOs in their decisionmaking process, but final decisions on which pesticides to ban are made internally, according to a representative of Fairtrade International (Interview 16).

In addition to the NGO-led and multi-stakeholder sustainability standards in Table 2, retailers play a role in transforming the PIC list into a ban list. First, some retailers are adopting the PIC list as a standard for their own-brand products (Pesticide Action Network UK, 2019, unpublished data; Interview 5). Supermarkets use different criteria to decide which active substances to prohibit, restrict, or monitor. For example, in the United Kingdom, both Tesco and Sainsbury's include the PIC list as a criterion for hazard classifications, while Asda and Marks & Spencer automatically ban PIC-listed substances (Asda, n.d.; Marks & Spencer, 2018; Pesticide Action Network UK, 2019). Retailers sometimes take these measures due to NGO pressure to decrease the use of pesticides in their supply chains (Interview 14). Given the size, concentration, and market power of a relatively small number of transnational food retailers, these internal standards are dominant in terms of the volume of agricultural production they influence globally through buyer-driven supply chain models (Fuchs et al., 2011). Retailers' uptake of the PIC list thus further extends the geographic scope of agricultural commodities affected by pesticide restrictions and bans beyond those instituted by multi-stakeholder and civil society-led certification schemes.

Retailers are also increasing their sourcing of externally certified agricultural commodities. This includes buying produce from ISEAL Alliance members such as Fairtrade (Pesticide Action Network UK, 2019). Many UK retailers report that the proportion of ISEAL-certified products they sell has grown over the past five years, and many have plans or policies in place to continue increasing such procurement in the future (Pesticide Action Network UK, 2019). The retailer consortium GlobalGAP is the only standard in Table 2 that has not adopted the PIC list, instead relying on national legislation for its decisionmaking processes. One potential explanation for this is its unique initial design as a retail consortium standard for which consumer labeling was initially not allowed (Henson & Humphrey, 2010), unlike all of the other standards in Table 2. GlobalGAP is not part of the ISEAL Alliance, and, until April 2021, was principally a business-to-business label that was not explicitly sustainability focused. GlobalGAP's members include many powerful retailers such as Walmart, Aldi, and Lidl, whose motivations for adhering to GlobalGAP relate more to market drivers such as competitive advantage than mission drivers such as minimizing environmental problems (Mook & Overdevest, 2021). In the next section, we discuss how the adoption of the PIC list by some standard-setting bodies affects the multilateral decisionmaking process independently of its degree of adoption by different standards.

5. Private governance impeding treaty-based governance

The increase in the scope and stringency of private agricultural standards raises questions about how this development may shape multilateral efforts to strengthen global treaty-based pesticide governance. In this section, we address our second research question of how interactions between private agricultural standard-setting bodies

Table 3 Pesticides approved by the Rotterdam Convention's Chemical Review Committee whose addition to Annex III did not reach consensus in the Conference of the Parties

Pesticide	Category	First regulatory action notification (PIC region)	Second regulatory action notification (PIC region)	Meeting at which pesticide was considered and blocked	Meeting at which pesticide was approved	Parties that raised objections to listing during a COP
Endosulfan	Pesticide	EU (Europe)	CILSS‡ countries (Africa)	COP-4 (2008)	COP-5 (2011)	Brazil, China, India, Iran, Pakistan, United States
Trichlorfon	Pesticide	EU (Europe)	Brazil (Latin America & the Caribbean)	COP-7 (2015)	COP-8 (2017)	India
Carbosulfan	Pesticide	EU (Europe)	CILSS countries (Africa)	COP-8 (2017)	Not approved	Brazil, India, Indonesia, Kenya
Fenthion	SHPF†	Chad (Africa)	N/A†	COP-7 (2015)	Not approved	Ethiopia, Kenya, Sudan, Uganda
Paraquat	SHPF	Burkina Faso (Africa)	N/A	COP-6 (2013)	Not approved	Chile, Guatemala, Honduras, India, Indonesia
Acetochlor	Pesticide	EU (Europe)	CILSS countries (Africa)	COP-9 (2019)	Not approved	Argentina, Chile

†SHPF refers to "Severely hazardous pesticide formulation." SHPF nominations are based on a notification from a single developing country indicating domestic problems with a pesticide (see details in Section 3). ‡CILSS: Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (Permanent Interstate Committee for Drought Control in the Sahel). CILSS comprises Benin, Burkina Faso, Cape Verde, Chad, Côte D'Ivoire, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal, and Togo. Inter alia, this group of Sahelian countries coordinates their pesticide approval processes and has submitted joint notifications of regulatory actions. *Source*: IISD (2008, 2011, 2013, 2015, 2017, 2019), UNEP/FAO (n.d.-a, n.d.-b, n.d.-c, n.d.-d, n.d.-e, 2014).

and parties involved in international treaty-based governance affects pesticide governance. To this end, we explore characters of interactions, the effects of interactions, and how interactions may change over time.

Private standard-setting bodies' banning of hazardous pesticides could be seen as complementary to the objectives of the global chemical treaties. By contributing to the implementation, monitoring, and compliance stages of the regulatory process, private agricultural standards may reinforce the goals of decreasing the human health and environmental impacts of hazardous chemicals—the broader goal of many governance instruments (including global chemicals treaties). This overlap in decisions taken by private standard-setting bodies and parties to multilateral chemical agreements in practice results in an increase in the number of people and ecosystems which are less exposed to hazardous pesticides. This suggests the existence of synergies between private and public governance, in particular as certain private agricultural standards increase in scope and stringency. However, the effects of relationships between public and private actors in the area of pesticide governance are changing over time.

In the case of the Rotterdam Convention, private standard-setting actors' adaptation of the PIC list to their own ends has started to affect treaty decisionmaking processes, slowing down the addition of more pesticides to the PIC list and thereby potentially weakening the Rotterdam Convention's effectiveness. At each COP since 2008, various parties to the Rotterdam Convention have begun blocking the addition of several chemicals approved by the Chemical Review Committee to the PIC list, starting with endosulfan (Table 3). During this time, the Chemical Review Committee approved the listing of five more pesticides that were subsequently blocked by a small number of parties during COP meetings (see Table 3 and steps 3 and 4 in Fig. 1). At COP-9 in 2019, all four pesticides considered for inclusion on the PIC list were blocked—including paraquat, which had been considered at four consecutive COPs (Earth Negotiations Bulletin, 2019). For each of these pesticides, the COP reached consensus that the criteria for listing had been met; in each case, however, a small number of parties objected and prevented these pesticides from being added to the PIC list (Table 3).

The growing political contention surrounding blocked pesticides since the late 2000s has led to a debate among Rotterdam Convention parties and other stakeholders around the effects of adding chemicals to the PIC list. In 2015, the COP established a working group to examine how to improve the listing process, after four out of the five nominated chemicals were not approved for listing at COP-7 that same year (UNEP/FAO, 2016). This working group attributed the lack of consensus for listing to "a variety of factors," including that "there might be a *misconception* amongst certain Parties that listing constitutes an outright ban on the use of the chemical" (UNEP/FAO, 2016; emphasis added). This point about a prevailing misconception was reiterated in a number of interviews with NGO representatives, government representatives, and staff at the Rotterdam Convention Secretariat (Interview 1, 15, 17, 18). However, this point was also strongly refuted by one national delegate to the COP: "Everyone reads the convention. The convention does not ban" (Interview 7). Instead, many parties are concerned about whether or not a new listing of a pesticide on the PIC list affects pesticide trade, prices, and use following actions by national governments (possibly impacting both producers and users).

Empirical studies show some evidence of market effects on commercially valuable pesticides following a listing on the PIC list (Núñez-Rocha & Martínez-Zarzoso, 2019; Whiting et al., 2017). These effects may include a reduction in trade volumes or market prices, though impacts vary for different listed pesticides and importing countries. The presence of some market effects may be explained by the fact that at least three kinds of actions by national governments can lead to reduced trade in PIC listed pesticides: party refusals of imports through the PIC procedure, national bans based on PIC listings, and intergovernmental work phasing out PIC-listed pesticides. Whiting et al. (2017) highlight the difficulty of differentiating the effect of listing a chemical under the Rotterdam Convention from other long-term trends affecting each pesticide's use and trade, as well as the difficulty of undertaking such analyses due to a lack of publicly available data. Moreover, as highlighted by several interviewees, trade effects should be "irrelevant" to the listing of a pesticide under the broader objectives of the Rotterdam Convention (Interviews 3, 4, 15). Nonetheless, the fear of potential trade or price effects may give pesticide-producing countries economic incentives to block the addition of new pesticides.

While countries with large pesticide manufacturers may have economic incentives to prevent the addition of more pesticides to the PIC list, data show that the countries which have blocked listings of additional pesticides at Rotterdam Convention COPs in recent years generally have not been major producers of the specific pesticides being considered for listing (see Table 3). Although internationally comparable data on pesticide production is difficult to obtain, we draw this conclusion based on self-reported data from parties to the Secretariat (UNEP/FAO, n.d.-a, n.d.-b, n.d.-c, n.d.-d, n.d.-e, 2014). Several parties where some of the world's largest pesticide producing firms are located, notably the EU and Switzerland (with the United States being a non-party to the Rotterdam Convention), have even actively pushed for additions to the PIC list of pesticides that chemical firms within their territories produce. The notable exception was endosulfan, for which Indian firms are major producers; India was the major party opposing the addition of endosulfan to the PIC list (IISD, 2008). The listing only succeeded following intensive NGO campaigning showing the detrimental effects of use within the country where farmers are major users of endosulfan (Interview 4).

The adoption of the PIC list as a ban list by private agricultural standard-setting bodies partially invalidates the argument that a PIC listing does not equal a ban, complicating the debate among parties and other stakeholders around the effects of adding a chemical to the PIC list. Countries have blocked negotiations for trade interests more directly related to pesticide production in the past (such as India with endosulfan), but in these cases the role of their national interests is so conspicuous that it is a difficult position to maintain diplomatically, because the PIC mechanism emphasizes the sovereign right of each party to make its own trade-related decisions. However, the mistranslation of the PIC list by private agricultural standard-setting bodies lends more weight to arguments related to negative trade and economic impacts made by some parties who seek to block listings. It also increases incentives for both pesticide-producing/exporting countries and pesticide-consuming countries to oppose a listing. Private standard-setting bodies' bans of PIC-listed pesticides may impact a larger number of countries relative to individual countries rejecting imports of PIC-listed pesticides or adopting national use bans. Decisions by standard-setting bodies affect agricultural production in all countries in which certified producers operate as well as the home countries of pesticide manufacturers. This includes non-parties to the Rotterdam and

Stockholm Conventions. For example, agricultural producers and pesticide manufacturers in the United States may be impacted by changes to private agricultural standards that both limit the use of a pesticide in the United States and decrease exports of US pesticide manufacturers.

The growing scope and importance of private agricultural sustainability standards influence the traditional sovereign rights of national governments to make decisions related to domestic pesticide use. While a party to the Rotterdam Convention could consent to the import of a PIC-listed pesticide because such use is not prohibited under national law, that pesticide may still be *de facto* banned for use on certified agricultural land within that country as a result of decisions by private standard-setting bodies. This indirectly challenges parties' sovereign right to make decisions about pesticide imports and use, also subverting the logic of allowing each party to make their own decisions on the possible import of PIC-listed chemicals which allowed the Rotterdam Convention to come into existence in the first place. This erosion of national sovereignty may be of particular relevance for developing countries that may not welcome transnational private governance initiatives for a variety of reasons, including due to perceived threats to their sovereignty (Marques & Eberlein, 2021; Schouten & Hospes, 2018).

Countries where use bans under private agricultural standards would have a large impact on the production of a specific agricultural commodity may be particularly sensitive to the addition of new pesticides to the PIC list. This is especially relevant if the area covered by private agricultural standards is growing. For example, a Brazilian delegate to the Rotterdam Convention COP cited potential impacts of listing carbosulfan (a pesticide that has been blocked for approval by the COP for two consecutive meetings) on the country's cotton-producing sector, which is highly dependent on this pesticide (Interview 11). Over 90 percent of Brazil's cotton was certified under Better Cotton Initiative (BCI) in 2018.[2] In anticipation of a potential BCI ban on the use of carbosulfan, the Brazilian cotton industry lobbied the government to block its listing (Interview 11). Similarly, at COP-9 in 2019, an Indonesian delegate expressed concern about listing paraquat due to its potential influence on the palm oil industry, which also has a large share of privately certified producers. Representatives of the pesticide industry consider the adoption of the PIC list by private standard-setting bodies to be the effect of listing pesticides under the Rotterdam Convention that countries are most concerned with (Interviews 5, 9, 12). One national delegate echoed that private standard-setting bodies' use of the PIC list has been a motivation for parties' blocking additional listings (Interview 11). The high degree of industry concentration (as a proportion of profit or sales, market share, production, or trade volume) of other key commodities covered by private agricultural sustainability standards—notably palm oil, cocoa, soybeans, bananas, and coffee—can also increase industry incentives and resources to mobilize against regulatory actions that may increase their costs of commodity production, including the addition of a pesticide to the PIC list (Folke et al., 2019).

Concerns by commodity users related to pesticide access and associated lobbying efforts are likely to grow over time since many of the pesticides in consideration for addition to the PIC list remain commercially valuable and in widespread use (Interview 5). Many of the 22 pesticides initially on the PIC list were already widely banned, but recent and proposed additions to the list include a growing number of pesticides that are in extensive use and have significant market value. The Rotterdam Convention Secretariat has received notifications of final regulatory action for over 200 pesticides from one region and for which one more notification from another region would warrant its review by the Chemical Review Committee (UNEP/FAO, 2019). Of these notifications, over 80 percent are bans and only 16 percent severe restrictions. At the Chemical Review Committee meeting in September 2021, seven pesticides were on the meeting agenda — more than at any previous meeting (UNEP/FAO, 2020). Many countries, however, have struggled to submit notifications that fully meet the specific procedural requirements set out in the Rotterdam Convention Annexes. With this in mind, the Food and Agriculture Organization of the United Nations has been working with countries to increase their regulatory capacities and ability to submit complete notifications. It is thus reasonable to expect that the number of complete PIC list nominations will continue to grow.

In the context of recent blockages of additions to the PIC list, the Rotterdam Convention decisionmaking process has come under scrutiny by various parties aiming to increase the treaty's effectiveness. This includes parties, such as the EU and Switzerland, which are actively pushing for PIC list additions to enhance the international control of hazardous chemicals. In 2017, a group of African countries[3] submitted a proposal to amend Article 22 of the Rotterdam Convention to change this decisionmaking process, as the effectiveness of the treaty depends on the ability to add chemicals over time (UNEP/FAO, 2017). Arguing that the Rotterdam Convention's

Table 4 Summary of dimensions of public–private interactions in international pesticide governance following Eberlein et al. (2014)

Dimension of interaction	Public–private interactions in international pesticide governance
Who or what interacts	• Parties to chemicals treaties • Private standard-setting bodies and their respective stakeholders
Drivers and shapers	• Goal to protect human health and the environment from hazardous pesticides • Processes for adding chemicals to treaties • Transnational supply chains • Scope and context of private agricultural standards
Mechanisms and pathways	• Standard-setting bodies adopt the Rotterdam Convention PIC list as a ban list
Type of interaction	• Confounding interaction
Effects of interaction	• Reductions in use of PIC-listed pesticides • Changes in Rotterdam Convention parties' interests with respect to listing new chemicals on the PIC list • Increasing difficulty in adding chemicals to PIC list • Potential reduction in effectiveness of the Rotterdam Convention
Change over time (from time of chemical treaties' adoption to 2022)	• From inclusion of small number of little-used, highly hazardous pesticides on the Rotterdam Convention PIC list to COP considering the addition of many widely used pesticides with high market value • From a global market context in which private agricultural standards played a marginal role to a context in which the reach of private standards is widespread and continually growing

Source: Authors.

effectiveness is undermined by the consensus-based listing process and opposition to listing from a small number of countries, this group proposed an amendment that would allow parties to list chemicals with a three-fourths majority vote as a last resort if all other efforts to reach consensus have been exhausted. This is equivalent to the current procedure for adding new annexes to the Rotterdam Convention and is also the same as the procedure for chemical additions under the Stockholm Convention (Interview 4). However, the amendment was opposed by several countries and dropped for consideration at future meetings (IISD, 2019). Such an amendment would likely have allowed for the addition of more pesticides than is possible through consensus-based decisionmaking. It could also have had mixed implications for private standards: though supporting the phase-out of hazardous pesticides, it may have created complications for standard-setting bodies' implementation of many new bans as these bodies already face difficulties in phasing out currently banned pesticides in some countries (Interview 13).

6. Discussion

This article examines how a rise in private agricultural standards influences multilateral decisionmaking processes under global chemical treaties and in particular the Rotterdam Convention. Table 4 summarizes the empirical results of our study following the six dimensions of interactions outlined by Eberlein et al. (2014). We show how private agricultural standard-setting bodies have adopted their own ban lists based on pesticides listed by parties to the three main multilateral agreements addressing pesticides, including the Rotterdam Convention PIC list. These actions by private standard-setting bodies may at first appear to be both complementary and competitive in character relative to actions taken by bodies under the chemicals treaties, as a reduction in the use of hazardous pesticides by farmers adhering to private standards is consistent with treaty-related goals of protecting the environment and human health. However, private standards' use of the PIC list to develop their own ban lists also changes the Rotterdam Convention parties' interests with respect to the listing of new chemicals on the PIC list. This is because this transparency mechanism related to the international trade of hazardous pesticides becomes a *de facto* ban list for pesticide use by farmers complying with certain private agricultural standards. This, in turn, has negatively impacted the ability of the parties to the Rotterdam Convention to reach consensus on adding more pesticides to the PIC list, potentially reducing the Rotterdam Convention's effectiveness over time.

Our results are of direct relevance for theorizing public–private interactions, for understanding important dynamics in Rotterdam Convention negotiations, and for understanding private standard-setting processes. First, our findings have implications for theorizing interactions between public and private actors in international governance. Insights from public and private pesticide governance reinforce arguments in the literature suggesting that temporal dynamics play a critical role in defining the nature of interactions (Cashore et al., 2021; Eberlein et al., 2014). Building on the notion that public–private interactions must be examined as a process, we have shown how relationships change dynamically, particularly in the context of global treaties designed to allow for ratcheting up controls over time. Simultaneous to negotiations regarding additions to the PIC list, the rapid expansion of private agricultural standards that are sustainability focused makes them a stronger potential "threat" to pesticide producers and users. This can lead to stronger lobbying of national governments who are parties to the chemical treaties, both by national industries and by non-parties affected by pesticide additions who participate at the negotiations as observers. Their appeals may carry stronger rhetorical weight when a non-banning mechanism has been translated into a ban by transnational private actors.

Our findings reveal dynamics in relationships between public and private authority in the area of pesticide governance that do not fit neatly within a single interaction "type" in Cashore et al.'s (2021) theoretical framework. Although, as noted above, private standards share a broad objective with the chemicals treaties of protecting human health and the environment from hazardous chemicals, the interaction that we document cannot be considered complementary as it does not involve active pursuit of a similar goal on behalf of public and private actors (such as in the case of collaboration or coordination), nor the convergence of similar governance mechanisms under the pursuit of dissimilar goals (such as in the case of isomorphism). Since representatives from the standard-setting bodies interviewed were unaware of the negotiation dynamics in the Rotterdam Convention and private standard-setting bodies are not intentionally or antagonistically interacting with treaty-based bodies, this suggests a more indirect form of interaction than competition. Due to their shared overarching goals, governance efforts by private standard-setting bodies and treaty bodies cannot be considered to be coexistent either, as this type of interaction is characterized by divergent governance goals and strategies in a shared governance space.

Adding to the three types of interactions defined by Cashore et al. (2021), we use the term *confounding* to describe a new, fourth type of interaction in which indirect interactions between public and private actors with broadly aligned goals result in unexpected counteracting feedback effects. As demonstrated by our analysis, a confounding interaction occurs when public and private governors share overarching objectives, but private actors seeking to gain legitimacy by adopting certain components of public governance inadvertently affect public regulatory decisionmaking processes and provoke consequences that are contrary to their own goals. Such unintended consequences involving institutional linkages between (international) public law and private standards may be more likely in cases where the shared problem definition among public and private actors is broad. Confounding interactions may be mediated by intermediary actors such as NGOs pushing for more stringent private standards, which can play a role in alerting private actors of specific public governance processes or instruments.

Our findings highlight the importance of considering actors' intentionality and the heterogeneity among private actors in analyses of their interactions with public regulatory processes, consistent with previous research on sustainability governance (Lambin & Thorlakson, 2018; Verbruggen & Havinga, 2017). A growing literature, for example, examines the conditions in which competition between standards leads to a "race to the bottom" or "race to the top" and consolidation or differentiation among standards (e.g., Overdevest, 2010). Even among those private standards we analyze, standard-setting bodies differ in the extent to which they defer to lists from the international treaties in their own decisionmaking processes. Some private standards have banned the use of many more pesticides than those on the international treaty lists, while others appear to rely on the international lists more heavily. Organizational and political economy perspectives on standards, such as those applied by Brunsson et al. (2012), highlighting the heterogeneity and dynamic aspects of standards could help explain how different standard-setting bodies make decisions on different issues (e.g., which pesticides to ban) and the factors that influence these decisions (such as competition among standards) (Dietz & Grabs, 2021). Such perspectives are currently underrepresented in the regulation literature.

Second, our findings help explain recent negotiation blockages under the Rotterdam Convention. Several parties opposing new listings of pesticides on the PIC list may do so out of a concern that such a listing would automatically result in a use ban of listed pesticides by private standard-setting actors. This use of the PIC list by private standard-setting bodies can enhance economic concerns for parties with strong agricultural sectors which have a large portion of commodities grown adhering to private standards. This is especially true as pesticides recently considered for addition to the PIC list are in more widespread use than most of those pesticides that were initially added to the PIC list, and private agricultural standards' importance continues to grow. These dynamics both increase the potential for lobbying from powerful pesticide manufacturers and users and potentially undermine the sovereignty of parties wishing to allow the use of PIC-listed pesticides within their national borders. Although private actors' adoption of the PIC list as a ban may be considered favorably by actors advocating for more stringent global pesticide controls, it contradicts one of the foundational principles which allowed the Rotterdam Convention to come into existence.

Third, our findings call attention to the ways in which private standards' own legitimating strategies are often intertwined with state-based decisionmaking. Private standards are sometimes presented by scholars as "technical" and "transcendent" of politics in a way that allows them to move faster than government regulation (Bartley, 2011). Yet, much literature has shown how standards reflect political dynamics of norm creation involving different interest groups during standard-setting processes, in the private as well as the public realm (Büthe & Mattli, 2014). We demonstrate how many private agricultural standards use international decisionmaking processes to bolster their own political legitimacy- and scientific credibility-building processes. Adopting internationally agreed-upon lists allows standards to avoid the lengthy and politically charged consultation process which may accompany adding pesticides individually. Pesticide regulation differs across countries precisely because it reflects value-laden interpretations of what kinds of risks are acceptable for society (Jasanoff, 1999). Appealing to "technoscientific values" (such as independence and objectivity, e.g., through the use of evidence from external experts) by relying on outcomes of internationally agreed processes allows private standard-setting bodies to eschew the responsibility and ensuing politics that surround controversial decisions associated with regulating pesticides (Arcuri & Hendlin, 2020; Bain et al., 2010).

Private standard-setting bodies are equipped with processes to add pesticides to their ban lists independently of the Rotterdam Convention. The PIC list is only one component of such lists; it was adopted because stakeholders considered it to be a legitimate input. Research on standard-setting bodies highlights the variability of internal politics affecting their legitimation strategies and decisionmaking processes (Loconto & Fouilleux, 2014; Schleifer, 2019). Some standard-setting bodies are more constrained to balancing the interests of their internal stakeholders than others, and thus may depend more strongly on external processes to bolster their own legitimacy. Activist-backed standards may have more leeway to ratchet up than industry or multi-stakeholder initiatives, even if the latter purport to prioritize sustainability goals. Fairtrade International, for example, already bans a wide number of pesticides not included on the PIC list as a result of competition dynamics among standard-setting bodies and internal efforts to increase ambition. This and other examples (such as in organic agriculture; Fouilleux & Loconto, 2017) show how some private actors institutionalize stringent standards which build upon, but go beyond, national or supranational public standards. Such an approach involves using alternative sources of authority for evaluating pesticides to ban within their supply chains, such as independent scientific expertise. Making banning decisions based on scientific input nonetheless involves value-based judgments regarding which specific criteria to prioritize and which knowledge to base decisionmaking on. Standard-setting bodies with more leeway to incorporate independent scientific expertise may therefore have more potential to ratchet up ambition on pesticide restrictions independently of multilateral processes.

7. Conclusion

Our analysis highlights the need for scholars and policymakers to more fully consider complex interactions between public and private actors that may lead to unintended consequences within the current institutional patchwork of global governance. Using the case of pesticide governance, we show how private agricultural standard-setting bodies indirectly affect the multilateral decisionmaking processes of the Rotterdam Convention by adopting the PIC list to develop their own lists of banned substances. This alters the Rotterdam Convention's intended role, impeding efforts to add substances to the treaty by influencing the interests of some Rotterdam Convention parties with respect to the listing of new chemicals on the PIC list. This case illustrates how attempts by private actors to impose stricter governance than state actors can undermine the potential for multilateral governance to become more stringent. Adding to the *complementary*, *competitive*, and *coexistent* interaction types defined by Cashore et al. (2021), we use the term *confounding* to describe this type of interaction in which institutional linkages between public and private actors who share broadly aligned goals results in unexpected and negative feedback effects. As demonstrated by our analysis, a confounding interaction can occur when private actors seeking to gain legitimacy by adopting certain components of public governance inadvertently affect treaty-based regulatory decisionmaking processes.

Similar dynamics of confounding interactions whereby private actors aiming for more stringent action unintentionally impact public decisionmaking processes could also exist in other sustainability areas beyond pesticide governance. Future research could examine the potential for confounding interactions in other international environmental issue areas. Such interactions may occur as a result of broad problem definitions and simultaneous efforts by public and private actors with heterogeneous interests to address these goals and ratchet up ambition through diverging and sometimes overlapping means. Additional empirically based analyses of interactions between private standard-setting bodies and multilateral decisionmaking under specific treaties or in other international fora could help to further clarify and expand upon interaction types and mechanisms theorized in the governance literature and to inform public policy debates on the potential role(s) of private standards in advancing sustainability. Better understanding the heterogeneity and motivations of private actors as well as power dynamics relative to the public sector is also critical to help inform discussions on bolstering sustainability outcomes more broadly. The potential for private governance to create feedback effects on public policymaking demonstrates the importance for researchers and policy-makers to more fully consider the roles of public and private sector actors in addressing sustainability issues in the global governance sphere.

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Endnotes

1 Pesticide Action Network UK shared specific data from this survey with the authors upon email request; it is currently unpublished.

2 Based on BCI-certified area in 2018 (1,121,000 hectares) (Meier et al., 2020) and total post estimates for harvested area in 2018/2019 (1,200,000 hectares) (USDA, 2018).

3 The group of countries comprised the governments of Botswana, Cameroon, Ghana, Kenya, Lesotho, Malawi, Mozambique, Namibia, Nigeria, Swaziland, Tanzania, and Zambia.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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APPENDIX

Table A1 List of interviews

Interview	Organization	Type of actor	Date
1	Toxics Link	NGO	2 May 2019
2	Delegate, Nigeria	Government	3 May 2019
3	UNEP (formerly)	Intergovernmental	6 May 2019
4	Pesticide Action Network	NGO	6 May 2019
5	CropLife International	Private sector: pesticide industry	6 May 2019
6	Pesticide Action Network	NGO	9 May 2019
7	Delegate, Africa region	Government	20 May 2019
8	Pesticide Action Network	NGO	3 June 2019
9	CropLife International	Private sector: pesticide industry	4 June 2019
10	Pesticide Action Network (formerly)	NGO	7 June 2019
11	Delegate, Latin America and the Caribbean region	Government	9 October 2019
12	Bayer	Private sector: pesticide industry	11 October 2019
13	Anonymous	Private agricultural standard-setting body	9 January 2020
14	Pesticide Action Network	NGO	13 January 2020
15	Secretariat of the Rotterdam Convention	Intergovernmental	15 January 2020
16	Fairtrade International	Private agricultural standard-setting body	30 January 2020
17	President of the Rotterdam Convention, COP-9	Intergovernmental	10 November 2020
18	Delegate, Switzerland	Government	10 November 2020

Abbreviations: COP, Conference of the Parties; NGO, nongovernmental organization; UNEP, United Nations Environment Programme.

Paper II

The Politics of expertise in assessing alternatives to glyphosate in France

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The politics of expertise in assessing alternatives to glyphosate in France

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Science-policy interface

ABSTRACT

Transitions to sustainability require not only structural policy reforms, but a rethinking of how policy-relevant expertise is produced. Scholars of Science and Technology Studies have used the concept of boundary work to examine how governments mobilize experts to establish epistemic and political authority for public policies. Less attention has been paid to the ways in which boundary work affects the scope of policy options to advance sustainability transitions, notably in the context of sociotechnical lock-in of dominant technologies. This article analyzes French pesticide regulation on alternatives to glyphosate in agriculture to reveal the governance implications of the construction of expertise. It examines how state actors and scientific experts performed cognitive and sociopolitical boundary work to affect both the framing of government-commissioned scientific reports and the institutions and policy instruments through which the government addressed the glyphosate problem. The article analyzes the factors that shaped the development of a novel regulatory instrument which restricts the use of glyphosate based on the availability and costs of alternatives, rather than on health or environmental risks alone. This process limited the framing of glyphosate alternatives to practices considered economically and practically feasible by selected experts and excluded more systemic alternatives from policy debate and instrumentation. The adoption of this regulatory instrument reflects specific institutional contexts, power differentials between governmental ministries, and the hidden political influence of a powerful agricultural sector and agrochemical industry. This article shows how expertise design plays a key role in defining the scope of policy options and determining allocations of political power.

1. Introduction

International expert bodies are calling for societal transformation at an unprecedented pace and scale to address the joint environmental crises of climate change, biodiversity loss, and chemical pollution (IPBES, 2019; IPCC, 2022). In this context, the role of expertise in policymaking processes — particularly the mobilization and use of knowledge by policy actors involved in governing change — has renewed importance (Jasanoff, 2004, 2020). The role of expertise is particularly relevant to debates around potential policies to support the phase-out of technologies and substances such as fossil fuels and hazardous chemicals. Many technologies have become “locked in” at the system level, hindering the development and use of alternatives. The technical (non-)feasibility of alternatives to targeted technologies is often brandished as a discursive weapon by opponents to change (Rosenbloom, 2018). Phase-outs therefore prompt questions around which alternatives are considered credible and by whom, and how policies can nurture the development of alternatives and support their deployment.

Pesticides have become a key pillar of intensive agricultural production despite widespread recognition of their myriad risks. While the European Union (EU) is generally recognized as having the most comprehensive and stringent pesticide regulations in the world (Kudsk and Mathiassen, 2020), a growing number of policy actors recognize their weaknesses and the need to address pesticide use within a broader agenda of transforming food systems (Möhring et al., 2020; Oliver et al., 2018). Glyphosate — the most widely used herbicide worldwide — can be seen as a bellwether for experimenting with policy options to reduce pesticide use given its ubiquitous use for a wide range of crops and applications worldwide (Antier, 2020; Benbrook, 2016). Despite many EU member state governments’ concerns about glyphosate’s risks to human health and the environment, glyphosate was controversially reauthorized by a qualified majority of member states for five years in 2017 (Tosun et al., 2019). A few member states subsequently announced national restrictions, but few have enacted total bans in the agricultural sector. In 2017, France was the first country to announce an intention to

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ban glyphosate within three years and the only country in Europe with an overall pesticide reduction target of 50%, equivalent to the EU's 2030 goal under the Farm to Fork Strategy (European Commission, 2020). Nevertheless, France has failed to reduce pesticide use (Cour des Comptes, 2019). In 2020, instead of instituting a full ban on glyphosate, France announced new regulations which further restrict use authorizations for products containing glyphosate *based on the availability of alternatives*, rather than on glyphosate's inherent risks.

I build on the concepts of "co-production" (Iles et al., 2016; Jasanoff, 2004) and "boundary work" (Gieryn, 1983) to examine the development of regulations designed to address glyphosate use in the agricultural sector in France. Science and Technology Studies (STS) scholars argue that "a full-blown political analysis of science and technology seeks to illuminate the 'co-production' of scientific and social order" (Latour, 1990). Boundary work refers to the ongoing and active processes of delimiting credible from non-credible knowledge, governance instruments, and actors to establish epistemic and governance authority. Drawing on semi-structured interviews and document analysis, I address two interrelated questions: First, how do governments participate in the construction of expertise to inform policy choices on credible alternatives to dominant technologies for the governance of sustainability transitions? Second, what factors influence the boundary work undertaken by government actors and how do these impact policy outcomes?

This article examines how expertise was mobilized to assess alternatives to glyphosate, revealing the embedded power structures and political interests behind regulatory decisions which crystallize certain alternatives as more credible than others. Section 2 conceptually integrates the distinct literatures in STS and sustainability transitions on boundary work and sociotechnical lock-in. Section 3 outlines France's pesticide reduction policies and previous expertise assessing alternatives to pesticides. Section 4 shows the boundary work undertaken by the French National Research Institute for Agriculture, Food and Environment (INRAE) to fulfill a mandate from the government requesting a cost evaluation of glyphosate alternatives. Section 5 examines the political conditions which resulted in the development of a new regulatory instrument and the translation process undertaken by the French Agency for Food, Environmental, and Occupational Health and Safety (ANSES) to establish regulations based on INRAE's cost evaluations. Section 6 examines the exclusionary consequences of these different types of boundary work and the implications of the case for the governance of locked-in technologies.

2. An interdisciplinary approach to science-policy interfaces

2.1. Examining expertise as boundary work in the context of sustainability transitions

Literature on sustainability transitions builds upon notions of path dependency to analyze the lock-in of sociotechnical systems around specific technologies (Loorbach and Avelino, 2017). For pesticides, barriers to the adoption of alternative technologies occur at multiple interacting levels. Knowledge lock-ins and the concentration of corporate power, alongside declining public investment in agricultural research, hinder innovation in alternative forms of agriculture using fewer or no pesticides, such as agroecology and organic farming (Bellon and Penvern, 2014; Clapp, 2021; Vanloqueren and Baret, 2009). Infrastructural and technological lock-ins arise from structural economic incentives such as the EU Common Agricultural Policy (CAP) subsidies and the regional organization of specialized supply chains (Cowan and Gunby, 1996; Hüesker and Lepenies, 2022; Kuokkanen, 2017; Guichard et al., 2017). Institutional and regulatory lock-ins arise from complex regulatory structures, the production of regulatory ignorance (Dedieu, 2021; Jouzel, 2019), and regulatory capture (Hüesker and Lepenies, 2022). Behavioral and cultural lock-ins result from farmer preferences for easily applicable practices (Guichard et al., 2017) and consumer preferences for cheap and aesthetically-pleasing food (Hüesker and Lepenies, 2022).

These multiple overlapping lock-in mechanisms have led transitions scholars to suggest that public policies — and the knowledge which informs them — are critical for guiding successful phase-outs of specific technologies which buttress dominant systems (Kuokkanen, 2017; Rosenbloom and Rinscheid, 2020; Stegmaier et al., 2021). Knowledge processes can either open up or constrain policy options. This has been demonstrated in the context of global environmental assessments, wherein the process of mobilizing experts and the design choices made by experts shape the realm of policy options (Beck and Mahony, 2018; Beck and Oomen, 2021; Turnhout and Hulme, 2016). In this way, knowledge becomes performative by "co-creating causes, effects, potential solutions, and affected constituencies" (Beck et al., 2016, 1077). Analyses of scientific advisory processes suggest that knowledge mobilized for decision-making is likely to be most effective in influencing social responses when decision-makers consider it to be salient (directly relevant to their needs), legitimate (produced in a way which is considered fair, unbiased, and cognizant of different stakeholders' values), and credible (scientifically sound) (Cash, 2003).

I focus on knowledge production to reveal the inconspicuous means through which voices of certain (powerful) economic actors are prioritized over others and to examine how struggles over epistemic authority affect the allocation of political power (Henry, 2021; Jasanoff, 1987). For some pesticides, such as neonicotinoids, EU regulatory agencies have mobilized expertise to substantiate stronger regulation (Rimkutė, 2015). Yet scholars have also drawn attention to the ways pesticide regulations are adversely impacted by overt lobbying and regulatory capture by the agrochemical industry (Hüesker and Lepenies, 2022), as well as institutional dynamics which lead to the systematic exclusion of uncomfortable knowledge in national regulations (Dedieu, 2021; Jouzel, 2019). The influence of powerful actors is often exerted in the *making* of specific institutions and policy instruments used to govern, becoming invisible to outside actors once established (Henry, 2021; Lascoumes and Le Gales, 2007). Key to these knowledge politics are the arenas in which instruments are negotiated and the processes by which they are developed — including which knowledge they are based upon and the actors involved in defining assessment criteria (Caby, 2021; Henry, 2021).

The interrelated concepts of "boundary work" and "boundary objects" are useful for examining how information flows between science and politics (Beck, 2016; Star and Griesemer, 1989). While initially conceptualized by Gieryn (1983) as the ideological efforts to differentiate "science" from "non-science," the concept of boundary work has been extended to examine policymaking processes, where actors on both sides of "science" and "politics" are involved in negotiating the boundaries of each sphere with the goal of enhancing the credibility and legitimacy of each (Beck and Mahony, 2018; Demortain, 2017; Jasanoff, 1990). Because the political legitimacy of policies is dependent upon the perceived credibility of its scientific underpinnings, boundaries between science and politics are under constant negotiation (Jasanoff, 1987).

Building on Beck and Mahony (2018), I distinguish between cognitive and sociopolitical levels of boundary work. The cognitive level refers to the types of knowledge taken into account and treated as credible, operationalized through experts' design choices for scientific assessments. Sociopolitical boundary work involves active demarcation between different actors and processes, such as which experts and institutions are entrusted with governance tasks and which are excluded. Scientists may be involved in generating "boundary objects" for policymaking which facilitate cooperation between actors in different social worlds by creating a new discursive space which both worlds understand (Guston, 2001). Boundary objects — such as risk assessments, models, reports, or classification systems — are characterized by their interpretive flexibility, allowing actors to attribute viewpoint-specific meanings to them. This ambiguity allows for the coexistence of potentially contradictory agendas carried by different policymaking actors. Designing policies and regulations consequently involves a process of *interpretation* or *translation* of scientific findings presented in a given boundary object (Demortain, 2017; Jasanoff, 1990).

I examine how different actors perform boundary work to affect the breadth of possible policy options to phase out glyphosate in France's agricultural sector in the multi-level EU policy context. The article contributes to the study of agency perspectives in sustainability transitions through the integration of STS concepts (Fischer and Newig, 2016) and to a growing body of social science research on strengthening EU pesticide governance (Bureau-Point et al., 2022; Helepciuc and Todor, 2021; Möhring et al., 2020; Storck et al., 2017). Despite the EU's objectives to reduce pesticide use and risks, its policies have thus far had little homogenizing effects on the development and harmonization of member states' pesticide action plans (Helepciuc and Todor, 2021). Lee et al. (2019) argue that pesticide use reduction necessitates a mix of policy instruments applied at multiple scales, highlighting the need for multi-level analyses and an enhanced understanding of how science is produced and mobilized to develop new policy instruments.

2.2. Methods

Following interpretive approaches to policy analysis, this paper draws on expert interviews and policy documents to understand how policy issues were interpreted and problematized within French institutions (Garcia and Hoeffler, 2015). Semi-structured interviews were conducted primarily in French by the author between October 2020 and February 2022 with actors in the agricultural sector and experts in pesticide policies (Appendix A). The study focuses on the period when glyphosate became a specific target of public policy in France (2017–2020), prompting the government to commission public expertise to inform new policies. At the time, there were intensive debates regarding the possible phase-out of glyphosate in France and the next vote for EU re-authorization, initially scheduled for December 2022.[1] The document analysis includes French policy and regulatory documentation identified through the institutions involved in the Glyphosate Exit Strategy and national pesticide action plans, along with scientific expertise reports, press releases, and documents identified through a literature review and interactions with stakeholders. Experts for interviews were identified based on the document analysis and through snowball sampling. Documents and interviews were first coded inductively using the software MaxQDA, following a grounded theory approach to qualitative data analysis to identify recurring themes and to select an analytical framework (Charmaz, 2006; Glaser and Strauss, 1967). Interviews were deductively coded a second time using codes and subcodes based on concepts from boundary work theory defined in the previous section. "Choosing experts," "designing methodology," "defining feasible alternatives," "interpreting INRAE's reports," and "constructing legitimacy," are examples of the codes used in the second instance.

3. Pesticide governance in France

When President Macron vowed to ban glyphosate in 2017, the French government had over a decade of policy experience on pesticides and had acknowledged its repeated failure in reaching its goals (Guichard et al., 2017) (see Fig. 1). Pesticide policies have been steered by a strong central government and influenced by a long history of institutional arrangements between the state and farmers' organizations and unions — a corporatist "co-management" model of agricultural policy (Labarthe, 2009, 2014; Muller, 2000). The agricultural ministry has quasi-exclusive government authority over agricultural policy, which continues to focus principally on increasing productivity and competitiveness, despite reforms which target broader social and environmental objectives (Cornu et al., 2018). In contrast, the ministries involved in pesticide governance have evolved progressively since the development of France's first 10-year pesticide reduction plan, "Ecophyto 2018" (hereafter Ecophyto I), released in 2008 (French Ministry of Agriculture, 2008). While the first plan involved only the Ministry of Agriculture, its most recent version, Ecophyto II+ (released in 2018), involves a collaboration between four ministries with competing agendas: the Ministry of Agriculture, the Ministry of the Environment, the Ministry of Health, and the Ministry of Research and Education (French Ministry of Agriculture, 2018).

French agricultural and pesticide policies are supported by various agronomic research institutes. INRAE (INRA prior to institutional reforms in 2020[2]) is the main public agricultural research institute, operating under the joint authority of the ministries of agriculture and research and supported by substantial public investments. The second pillar of agricultural research comprises agricultural technical institutes (ATIs), which are national applied research and extension organizations for specific sectors (e.g. cereals). Although ATIs are formally independent, they are jointly funded by farmers and the Ministry of Agriculture and overseen by farmers' representatives, generally aligning with the positions of FNSEA, France's dominant farmers' union (Aulagnier, 2020).

The French government has commissioned scientific expertise by public research institutions as input for policies on pesticides since the early 2000 s (Aulagnier and Goulet, 2017; Guichard et al., 2017). At that time, it established INRAE's institutional mission as a provider of expertise for policy decisions on strategic political questions (Sabbagh et al., 2014), which INRAE defines as "the expression of a knowledge formulated *in response to a request from those who have a decision to make, knowing that this response is intended to be integrated into a decision-making process*" (INRA, 2011, 3, emphasis added). France's approach to pesticide risk reduction — focused on reducing the total volume of pesticides *as a way to* reduce impacts of pesticide use — was based on the findings of a "collective expertise" report on pesticides from INRAE and CEMAGREF[3] from 2005 ordered by the ministries of agriculture and environment (Aubertot et al., 2005). This initial framing of the problem focuses on the quantity of pesticides used rather than the risks they pose, in contrast with national plans developed by other EU member states (Aulagnier and Goulet, 2017; Helepciuc and Todor, 2021; Guichard et al., 2017). Highly ambitious for its time, Ecophyto I established France's target of reducing pesticide use by 50% by 2018, "if possible;" the deadline has since been pushed back to 2025 (French Ministry of Agriculture, 2008, 1, 2018).

Alternatives to pesticides occupy a diverse spectrum of solutions. Two overarching approaches to pesticide reduction — an efficiency-based approach and an approach based on system redesign — have different implications for the agricultural sector and its governance (Aulagnier and Goulet, 2017; Tittonell, 2014). An efficiency approach involves producing more of the same crops with lower adverse impacts, often through optimization and/or the substitution of problematic pesticides with other substances. In contrast, the redesign of agricultural production systems involves *system-wide changes* going beyond the farm level and conceived over pluriannual periods. Although certain practices under this approach may involve the use of pesticides, system redesign

[1] The EU vote to renew the authorization of glyphosate (which was initially set to expire December 15, 2022) has been pushed back due to a delay of EFSA's delivery of its report on the peer review of the glyphosate risk assessment which, as of December 2022, is expected in July 2023. Glyphosate's use authorization has been temporarily extended to December 15, 2023.

[2] The current institutional acronym INRAE is used throughout this paper for consistency although references to "INRAE" prior to 2020 actually designate INRA. INRAE is the result of the merger between INRA and IRSTEA as of January 2020.

[3] CEMAGREF was another French public agricultural research institute which later became IRSTEA and was fused with INRA to create INRAE in 2020.

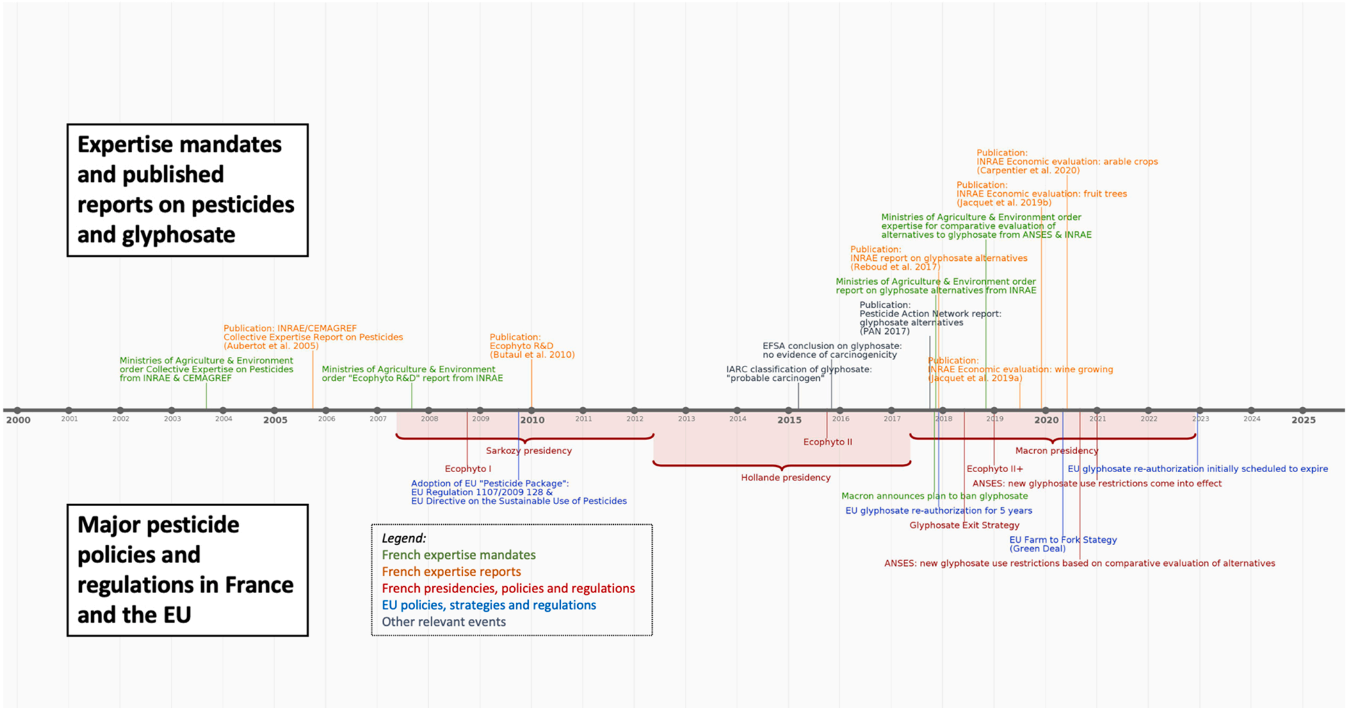

Fig. 1. Timeline of major events.

aims to decrease pest pressure through measures such as crop diversification and the adoption of pest-resistant varieties, thus enabling significantly lower pesticide use. System redesign encompasses a broad range of agricultural models including agroecology, organic agriculture, and diversified farm systems (Tittonell, 2014; Butault, 2010). These also allow for the reduction of other agricultural inputs such as fertilizers, simultaneously producing numerous environmental benefits (Therond et al., 2017).

A 2010 report by INRAE investigating strategies which would allow France to reach its 50% pesticide reduction target concluded that an efficiency approach could decrease use by 30%, while a 50% reduction necessitated system redesign (Butault, 2010). Yet the efficiency approach became dominant in the government's revisions of its initial pesticide reduction strategy due to France's failure to deliver on its goals within the early years of its first strategy, during which the government embraced a systemic approach (Aulagnier and Goulet, 2017; Guichard et al., 2017). The dominance of efficiency also arose because of a split between INRAE and the ATIs (Aulagnier, 2020). An analysis of actor dynamics in INRAE's 2010 report found, notably for field crops, that agricultural actors, and ATIs in particular, opposed system redesign, particularly in cases where a system approach could lead to any decrease in yields (Barbier et al., 2010). The analysis attributed the reluctance to change to sociotechnical lock-in, "essentially explained by the technological trajectories in agriculture (which determine farmers' practices) and by the *dominant economic models of farms where the price structure predominates over the exploration of alternative solutions*" (Barbier et al., 2010, XXIV, emphasis added).

4. INRAE's government-mandated cost evaluations of glyphosate alternatives

In 2017, the French government mobilized scientific expertise to inform its EU and national positions regarding glyphosate prior to the vote for EU re-authorization. The four ministries involved in Ecophyto commissioned INRAE to lead a study on the main uses of glyphosate in France and to identify alternatives, specifically seeking out INRAE's expertise because of its legacy as a highly credible provider of salient expertise for policymaking (Cornu et al., 2018; Interview 9). This initial government mandate and the mobilization of public agronomic expertise created a first major sociopolitical boundary around the actors involved in problematizing glyphosate. Rather than treating glyphosate as part of a broader *socio*-technical system, the government initially framed the problem as a predominantly technical issue. This sidelined relevant social and political questions, as well as scientists from other fields such as environmental science or public health, in the consideration of alternatives.

Consistent with the government's request, INRAE's report focused on *non-chemical* alternatives to glyphosate, drawing a first cognitive boundary that reflected a problem framing conditioned by France's larger political ambition of reducing pesticide use (Reboud et al., 2017). This choice was made in consultation with the government and ANSES, which is responsible for pesticide regulation in France[4] (French National Assembly, 2018). The report's focus on non-chemical alternatives reflects not only the limited chemical alternatives available on the EU market,[5] but also a view that the widespread and excessive use of any substitute chemicals would likely provoke similar problems as those caused by glyphosate (Interview 3). The impacts of herbicides, including glyphosate, on biodiversity result not only from their direct effects on target and non-target organisms via toxicity, but also from indirect impacts through the destruction of habitats of non-target organisms, including pollinators (IPBES, 2016). Despite its widespread use for various purposes, and unlike many other pesticides with few

[4] Although previously under the purview of the Ministry of Agriculture, pesticide regulation was transferred to ANSES in 2015 following reforms due to a public scandal to decrease pressure from the agricultural sector on the regulatory process (Dedieu, 2021).

[5] The two main authorized chemical alternatives are dicamba and the hormone 2,4D, which are currently more costly than glyphosate, potentially more toxic, and not effective for certain uses (Interview 3, Carpentier et al., 2020).

non-chemical alternatives, many interviewees considered glyphosate to be a "simple" or straightforward case from a technical perspective and one that ATIs have long been working on (Interviews 5, 9, 11).

The 2017 INRAE report confirmed that various non-chemical alternatives to glyphosate exist for the vast majority of uses authorized in France, although no single alternative meets all of the functions of glyphosate simultaneously (Reboud et al., 2017). The report details the main non-chemical substitution-based alternatives to glyphosate available in the short term, while also highlighting system redesign as an important tool to reduce herbicide dependence beyond glyphosate in the longer term. The INRAE report vindicated the results of a similar report on glyphosate alternatives by the Pesticide Action Network (PAN) financed by the European Green Party prior to the EU reauthorization vote. Released a few months before INRAE's, PAN's report similarly identified a wide range of practices which could replace different glyphosate uses, concluding that "we already have all the tools necessary to gradually start building a pesticide-free agricultural model and to confirm that weed control is possible using other means than harmful herbicides" (PAN Europe, 2017, 5).

Once the availability of alternatives had been demonstrated by commissioned expertise, the government undertook a second phase of boundary work to frame legitimate alternatives as those that are economically viable in the short term at the farm level. This phase involved selecting an appropriate policy instrument to address the glyphosate problem, which created new boundaries around included actors and institutions. In June 2018, the French government pivoted towards the use of a regulatory instrument for glyphosate based on a specific provision of EU Regulation 1107/2009 on pesticide authorization.[6] Article 50.2 of this regulation requires member states to pursue a comparative assessment examining the potential for substitution of the specific pesticide to make use of this regulatory clause: "An assessment of *the* alternative shall be performed to demonstrate whether it can be used with similar effect on the target organism and *without significant economic and practical disadvantages to the user* or not" (emphasis added).

ANSES's new glyphosate regulations based on Article 50.2 comprise an additional layer supplementing its usual procedure for regulating pesticides (Interview 11). These regulations are usually based on a scientific evaluation of risks to human health and the environment under guidelines specified in national and EU regulations (ANSES, 2021; Interview 11). The ongoing debate regarding the carcinogenicity of glyphosate (Paskalev, 2020) and absence of an EU-wide ban made ANSES's conventional risk evaluation inapplicable for enacting a national ban at the time (ANSES, 2021; Interview 11). Although the EU's pesticide regulations are based on the precautionary principle and are among the strictest in the world (Bozzini, 2017), its risk assessment process systematically excludes certain types of knowledge and risks to human health and the environment (Robinson, 2020; Storck et al., 2017; Hendlin et al., 2020). The detrimental impacts of pesticides (including many which are currently authorized) on human health and biodiversity have been demonstrated in other French expertise reports (INRAE, 2022; Inserm, 2019). Recognizing these issues and aiming to restrict glyphosate use nationally, the French government pursued the option of using Article 50.2 as a "mode of withdrawal" for an active substance still authorized at the EU level (Grimonprez, 2021). Designing a new regulatory instrument for glyphosate marked a turning point for ANSES, a generally conservative regulatory institution due to its reputational challenges with pesticide regulation (Dedieu, 2021).

In order to fulfill the requirements of Article 50.2, the government mandated INRAE to produce a new form of policy-relevant knowledge: a comparative economic evaluation of alternatives.[7] The production of these boundary objects required INRAE to develop a new assessment methodology, which was validated by the cabinet of the prime minister (Interviews 3, 4). Due to the short political timeframe of the expertise mandate, this expertise process deviated from the usual procedures institutionalized by INRAE in the early 2000 s to provide policy-relevant knowledge (Interview 3). Due to differences in uses across agronomic sectors and the regulation of pesticide by area of use, INRAE evaluated costs of alternatives to glyphosate in three major areas: field crops ("grandes cultures": cereals and protein crops), wine growing, and fruit trees (Carpentier et al., 2020; Jacquet et al., 2019a,b). INRAE's analyses show a wide range of estimates for additional costs of adopting alternatives in each of the three areas, depending on farm characteristics, cropping practices, and labor costs, among other variables (see Table 1). The main costs associated with shifting to glyphosate alternatives are equipment for mechanical alternatives and additional labor and fuel for equipment operation.

For this series of reports, INRAE's sociopolitical boundary work is reflected in its decision to collaborate with the main ATIs for each of the three major use areas (Interviews 3, 4, 5, 6; Carpentier et al., 2020). This collaboration and the use of publicly available data were both key to building credibility and legitimacy vis-à-vis the policy's target audience, the agricultural community (Interview 4, 6), since experts within the ATIs and farmers perceive INRAE as distant from realities on the ground (Interviews 6, 13): "If you want something operational, you need the support of the ATIs" (Interview 6). Due to the ATI's tightknit cooperation with the agricultural sector, their involvement helped prevent contestation of the results by opponents to a ban. Through this collaborative process, interviewees considered that the credibility of INRAE's economic evaluations was not questioned by the agricultural sector (Interviews 4, 9). Although the ATIs did not want to publicly endorse the reports' results by appearing as co-authors due to the tense relationship between INRAE and farmers (Interview 4), the ATIs' inclusion in the expert process created a certain form of closure regarding additional economic costs associated with phasing out glyphosate. Invoking exorbitant costs had become a rhetorical device allowing the agricultural sector to contest a possible glyphosate ban (Interviews 3, 4).

The government's political mandate for an economic evaluation to fulfill the requirements of Article 50.2 played a fundamental role in shaping the cognitive boundaries of INRAE's economic evaluations. The reports limit the geographical and temporal scope of alternatives to those available at the farm level and in the very short term. This framing obscures the effects of sociotechnical lock-in on the availability of alternatives and their costs. The widespread, longstanding applications of glyphosate make it stand out as a clear winner relative to other currently available alternatives if judged mainly on economic criteria, as highlighted by one of the report authors at INRAE:

> *If the criterion is purely economic and one of feasibility and ease of use,* well, glyphosate has organized and oriented 20, 30 years of the evolution of agriculture around its existence. And so certain models of agriculture have developed *because* glyphosate is there. So obviously […] when we say, we're going to take it away, none of the alternatives have had the same level of development, have found themselves as much at the center of a paradigm of agriculture based on chemicals… and so *all of the alternatives are less good* — they are more expensive, they don't work as well, they are much more complicated to deploy, there is no technical support, there is not the right equipment… and so, *if the comparison is just on economic and*

[6] This regulation provides harmonized rules for approval of pesticide active ingredients, while pesticide formulations (the products containing approved active ingredients combined with other chemicals) are regulated at the member state level.

[7] The Ministries of Agriculture, Environment, and Health initially addressed the expertise request to ANSES in November 2018. When ANSES judged that the necessary agronomic expertise lay outside the agency's competencies (Interviews 9, 11), a second complementary request was therefore addressed to INRAE to supply expertise to ANSES.

Table 1
Production of boundary objects (INRAE cost evaluations): actors involved and summary of main scientific findings.

Production of boundary object			
Areas of use	Actors involved (characteristics in brief)	Boundary object	Summary of findings
Wine growing	• French central government • INRAE (National publicly-funded research institute) • Agricultural technical institutes (National applied research institutes organized by agricultural supply chain, jointly funded by farmers and the Ministry of Agriculture, overseen by farmers' representatives)	Expertise report: *Alternatives to glyphosate in wine growing: Economic evaluation of weed control practices* (Jacquet et al., 2019a)	• Average additional cost of €210/ha for wide vines and €408/ha for narrow vines • High variability across the 9 different wine regions studied: additional cost varies from €12 to €553/ha depending on the production area
Fruit trees	(Same as above)	Expertise report: *Alternatives to glyphosate in fruit trees: Economic evaluation of weed control practices* (Jacquet et al., 2019b)	• Average additional cost of €148/ha and €388/ha for different hypotheses depending on type of crop and techniques for mechanical weed control • High variability: additional cost varies from €120 to €432/ha
Field crops	(Same as above)	Expertise report: *Alternatives to glyphosate in field crops: Economic evaluation* (Carpentier et al., 2020)	Average additional costs depending on different techniques for weed control: • Systematic tillage: 4€/ha • Frequent tillage: 7€/ha • Occasional tillage: 9€/ha • Simplified cultivation techniques: 26€/ha • Direct seeding: 80€/ha

Sources: Carpentier et al. (2020), Ecophyto et al. (2021), Jacquet et al. (2019a,b). Note: Additional costs represent the difference between chemical and mechanical costs (i.e. cost of production with and without glyphosate, respectively).

> *feasibility criteria*, oriented by an agricultural choice, then obviously the only light that is green in the system is the glyphosate light. (Interview 3, emphasis added, author's translation).

A framing and methodology in which glyphosate use is the baseline inevitably makes farming without glyphosate appear to be a net loss for farmers, since it cannot account for the ways in which higher costs could be compensated by higher revenues in the short-term, nor how a transition to another system over a longer period may lead to net gains. One alternative evaluation methodology to that developed by INRAE's team could involve using surveys to compare costs between farms currently using glyphosate versus those not using them (Interview 4). However, INRAE's cost evaluations use statistical methods to compare costs for farms' use of glyphosate to costs of use of non-chemical alternatives, *all other conditions equal*. The effects of this ceteris paribus framing explain why organic agriculture is largely obscured as a viable alternative, despite fulfilling the requirements of Article 50.2 of current widespread use:

> In this case, we were asked [by the ministries], technically, those who want to farm without glyphosate — *of course, they keep the rest the same* — what do they do? To say, "it is enough for you to become a farmer in organic farming" — that is proposing a system change. *That was not the question*. The question was, if tomorrow there is no more glyphosate, the people who used it, what will they do? (Interview 3, emphasis added, author's translation).

Various interviewees highlighted the possibility of developing different marketing channels for crops and/or using agri-environmental schemes to compensate for potentially higher costs (Interviews 2, 3, 4, 9). Economic valorization through alternative markets — such as those for organic products, for which farmers obtain higher prices — is discussed but not quantified in the economic evaluations (Jacquet et al., 2019a,b).

Moreover, a broader evaluation of glyphosate alternatives encompassing criteria other than economic costs — such as various environmental and social indicators — was not considered (Interview 3). A multi-indicator approach or comprehensive cost-benefit analysis designed to evaluate tradeoffs of glyphosate-free agriculture could incorporate such variables. At a broader scale, alternative assessments could account for the hidden economic costs of pesticides borne by the French government (BASIC, 2021). The executive director of the European Food Safety Agency identified the need for more balanced assessments:

> What I hope for the next glyphosate reauthorisation is that there's also an assessment on what would it mean, if glyphosate or herbicides are not used anymore, for biodiversity, water, farmers' income, food prices, availability of foods and so on. This was what we missed in the previous glyphosate discussion. (Fortuna, 2019).

Capturing both the full costs and benefits of glyphosate alternatives, even in the short term, would have represented a more balanced perspective of the multi-faceted societal problems posed by glyphosate than that evoked by INRAE's government-commissioned micro-economic cost evaluations.

5. ANSES's new regulatory approach for restricting glyphosate use

The comparative evaluation required by Article 50.2 had not been undertaken previously in any member state for a product in widespread use (Interviews 9, 11).[8] When initially consulted by government experts about Article 50.2, experts at ANSES had considered the clause "inapplicable" in practice (CGEDD et al., 2017, 41). The French government nonetheless pursued this new approach for restricting glyphosate use, leading ANSES into unchartered territory. As of 2021, France began regulating products containing glyphosate using both the first traditional "layer" of risk-based substance evaluation[9] and a second "layer" based on ANSES' implementation of Article 50.2 (ANSES, 2021;

[8] This procedure had been undertaken once before by Sweden for a product with very limited uses, in contrast with glyphosate's widespread applications (Interview 11).

[9] This led to the market withdrawal of many glyphosate-based substances in France still permitted in other EU member states, such as those containing the co-formulant POE-tallowamine tallowamine (ANSES, 2021; Interview 11).

Interview 11).

The political selection of a new policy instrument based on Article 50.2 reflects sociopolitical boundary work leading to the inclusion of specific institutions at the expense of other actors and policy instruments. Interviewees from INRAE and the Ministry of the Environment emphasized the high-level political deliberations underpinning France's glyphosate strategy, developed in a context of high political pressure (Interviews 3, 4, 9). Since glyphosate phase-out was an important component of the newly-elected President's agenda (Interviews 9,12), high-level discussions were convened on a regular basis (Interviews 4, 9). As two interviewees at the Ministry of the Environment explained:

> Interviewee 1: It has been a very politically charged issue. […] There was high-level reporting.
>
> Interviewee 2: Yes, yes. It was quite *unprecedented*. I mean, there were meetings at the ministerial cabinet level with INRAE, with ANSES, […] and they were quite frequent… relative to the agendas of the ministerial cabinets, it's quite unusual to have meetings that bring together actors like INRAE and ANSES on such a technical subject so often. So it was watched very, very closely. (Interview 9, emphasis added, author's translation).

The government's choice to use Article 50.2 to enact new use restrictions rather than to pursue other policy instruments reflects the construction of legitimacy vis-à-vis specific groups of powerful actors, enabled through sociopolitical boundary work. First, the government sought to achieve legitimacy for its new regulations vis-à-vis the agricultural sector, as reflected by INRAE's collaboration with the ATIs. Although acceptability by the agricultural sector was a central concern in the development of Ecophyto from its outset (Interview 2), this concern weighed particularly heavily in the case of glyphosate, likely due to heavy polarization and high media coverage regarding the issue (Lock, 2020). The glyphosate controversy also unfolded alongside social unrest related to other environmental policies adopted under President Macron's administration (Mehleb et al., 2021). Farmers, primarily via the FNSEA union, were raising concerns over constant criticism from citizens and broader social movements ("agribashing"). The FNSEA portrayed farmers as the victims of ever-increasing regulation whose essential services were not appreciated by citizens (Horel, 2020). The glyphosate ban was a flagship issue for President Macron's first Minister of the Environment, Nicolas Hulot. When Hulot resigned in 2018, he specifically cited an inability to collaborate with the Minister of Agriculture and aggressive corporate lobbying regarding pesticides and the glyphosate ban in his resignation speech (Allard-Huver, 2018).

Although largely invisible in the policymaking process on glyphosate alternatives, agrochemical companies comprise a second powerful constituency whose influence played a role in the government's selection of Article 50.2 as a new regulatory instrument. In addition to the systemic power of the pesticide industry due to their permeation of agricultural knowledge and information systems in France (Jas, 2021), their power is also manifested through systematic litigation against regulatory decisions by ANSES — including when the agency refused market authorizations for glyphosate-based products based on its traditional regulatory procedure in 2019 (Interviews 9, 11; CGEDD et al., 2017, 45). The government judged that a strategy based on Article 50.2 was "the most solid, legally" (Interview 9). A complete ban was considered imprudent in light of the Macron administration's experience with a unilateral national ban on neonicotinoids, which spurred tensions with the European Commission since active substances are supposed to be regulated at the EU level to ensure harmonization across member states (Interview 9). Regulating glyphosate by using Article 50.2 was thus attractive in the multi-level EU context and legally compelling due to the potential for litigation from pesticide producers (Interviews 9, 11).

ANSES is accountable to both the scientific and political worlds which it mediates. Through a government mandate, ANSES induced the production and use of INRAE's economic evaluations of alternatives. It then established new glyphosate use restrictions across the different areas of use (ANSES, 2020d,e,f) through a translation of these boundary objects, involving actors from both sides of the institutionalized boundary between science and politics, along with actors to mediate between the two. The formulation of new use restrictions was steered by ANSES's Market Authorization Monitoring Committee (hereafter "the Committee"), which is composed of independent experts, selected by inter-ministerial decree, who serve three-year terms. It is consulted when the directorate responsible for market authorizations faces problems which cannot be easily addressed (Interview 13). For the Committee meetings regarding glyphosate (ANSES, 2020a,b), 10 members were present, designated as experts in their role as pesticide users (three), a biocide user (one), agronomists (three), and specialists on the environment (three), as well as an additional agronomist chairing the meeting. Though the members of this Committee are intended to represent different interests, a majority are connected to or employed by ATIs (Interview 13). For glyphosate, the Committee interviewed experts from INRAE, ATIs, and the Ministry of Agriculture, while representatives from ANSES's General Directorate and Directorate for Market Authorization acted as mediators across both sides of the carefully constructed science-policy boundary.

The translation of INRAE's scientific results into new glyphosate regulations based on the requirements of Article 50.2 required the Committee to draw a final cognitive boundary around "significant economic and practical disadvantages to the user." Although asked to define what would qualify as a "significant" economic cost, INRAE experts refused to make this value judgment, considering it to be a political decision (Interview 4). Since Article 50.2 had not previously been used by any member state to restrict pesticide use, the Committee was required to make this judgment in the absence of European guidelines (Interview 11). Yet it did not determine regulatory thresholds based on INRAE's estimates of additional costs for alternatives, considering that the economic analysis did not correspond directly to the requirements of Article 50.2 (Interviews 11, 13; ANSES, 2020c,d,e).

ANSES's final regulations codify the Committee's interpretation of Article 50.2, in which "significant practical disadvantages to the user" posed by the adoption of alternatives were considered to be those that could impact the functioning of farms in the short term (ANSES, 2020d,e,f; Interview 11). The Committee's judgments regarding these disadvantages reflect not only technical considerations, but also a variety of social and political value judgements. Internal Committee deliberations led to regulatory decisions in which some glyphosate uses are banned, while many continue to be allowed under lower dosages (see Table 2).

Economic viability of production remained a central concern in the development of the new regulations. One Committee member explained that banning glyphosate outright would leave organic agriculture as the main alternative that ATIs could recommend; this option was dismissed with the understanding that organic agriculture has advantages and disadvantages that differ by sector and that switching to organic may not necessarily be profitable for farmers (Interview 13). INRAE experts were not directly consulted for their input on ANSES's final regulatory decisions (Interview 4). As one INRAE report author stated:

> I really felt that they were taking our result backwards, precisely on no-till and glyphosate — basically, by saying […] something like, "[…] farms that don't plow have the right to use glyphosate." Well, it's exactly the opposite that should be said… that maybe one should plow in order to not use glyphosate. (Interview 4).

The differing interpretations of INRAE's scientific results among actors shows the critical role ANSES played in translating these results into policies through their own boundary work regarding "significant disadvantages."

Table 2
Translation of boundary objects into policies: actors and summary of regulations.

Boundary object translation into policies			
Areas of use	**Actors involved**	**Policy output**	**Summary of new glyphosate regulations**
Wine growing	• ANSES General Directorate and Directorate for Market Authorization (2 directorates within the national regulatory institution responsible for pesticide authorizations and chemicals regulation more broadly) • ANSES Market Authorization Monitoring Committee(Composed of independent experts serving 3-year terms.For glyphosate, the Committee comprised: 3 pesticide users,1 biocide user,4 agronomists,3 specialists on the environment)	• Glyphosate regulations for wine growing based on EU Regulation 1107/2009 Article 50.2 • Policy document: *Comparative Evaluation Report: Case of glyphosate-based products. Examination of alternatives in viticulture* (ANSES, 2020e)	• Ban on using glyphosate between rows of vines: the alternative is allowing grass to grow or carrying out mechanical weeding • Use is authorized in situations where mechanical weeding is not possible: steeply sloping or terraced vineyards, stony ground, rootstock nurseries • Maximum authorized annual rate restricted to 450 g of glyphosate per hectare, with applications limited to 20% of the plot area, i.e. an 80% reduction compared to the maximum rate currently authorized
Fruit trees	(Same as above)	• Glyphosate regulations for fruit trees based on EU Regulation 1107/2009 Article 50.2 • Policy document: *Comparative Evaluation Report: Case of glyphosate-based products. Examination of alternatives in arboriculture* (ANSES, 2020c)	• Ban on using glyphosate between rows of fruit trees: the alternative is allowing grass to grow or carrying out mechanical weeding • Use is authorized in situations where mechanical weeding is not possible: mechanical harvesting of fruits on the ground (walnuts, cider apples, etc.) or bushy crops (hazelnuts, small fruits) • Maximum authorized annual rate restricted to 900 g of glyphosate per hectare, with applications limited to 40% of the plot area, i.e. a 60% reduction compared to the maximum rate currently authorized
Field crops	(Same as above)	• Glyphosate regulations for field crops based on EU Regulation 1107/2009 Article 50.2 • Policy document: *Comparative Evaluation Report: Case of glyphosate-based products. Examination of alternatives in arable crops* (ANSES, 2020d)	• Ban on using glyphosate when the plot has been ploughed between two crops (with certain specific exceptions) • Use is authorized in situations of regulated mandatory control • Maximum authorized annual rate restricted to 1080 g per hectare, i.e. a 60% reduction compared to the maximum rate currently authorised

Sources: ANSES (2020c,d,e)

6. Discussion

Through successive stages, the French government has come to define the political "solution space" to address the glyphosate problem by steering the production of boundary objects by INRAE and their subsequent translation into regulations by ANSES. The close collaboration between the French government and appointed experts ultimately created a new type of policy-relevant knowledge intended to be used specifically as an input for a new regulatory process for pesticides based on Article 50.2, as opposed to a classical risk assessment.

France's experience in developing a new regulatory instrument to further restrict glyphosate use illustrates the consequences of different types of boundary work for governance (summarized in Table 3) and can inform discussions on alternative forms of glyphosate governance for other EU countries. Making the boundary work undertaken in the French case transparent reveals paths not taken to open up the consideration of alternative policies, including options which could be pursued by other EU member states in the context of strong EU framework policies and in the absence of an EU-wide glyphosate ban.

To grasp the inclusions and exclusions resulting from these phases of boundary work, one can first imagine the production of *alternative boundary objects*. Selecting different experts at various stages of the creation and translation of boundary objects could enable an alternative policy problematization. The framing of the question of alternatives as solely a narrow economic issue impedes the consideration of broader factors raised by civil society actors in the glyphosate controversy, such as the environmental and social costs and tradeoffs of glyphosate use. Just as global environmental assessments create global representations of the environment which may not be suitable for national or subnational policymaking (Turnhout and Hulme, 2016), knowledge assessments focusing on the farm level also create their own logics of intervention for targeting a specific level of governance.

Alternative assessments of glyphosate phase-out could also examine different geographic and temporal scales. Regarding geographic scale, French experts and policymakers have highlighted the diversification of crops, cropping systems, and landscapes as key levers for agricultural transition which could decrease the use of pesticides (Butault, 2010; CGEDD et al., 2017; Potier, 2014). Assessing such approaches would acknowledge that lock-in extends beyond the farm level and could lead to policies recognizing the need to engage actors along entire agri-food supply chains, from seed producers to distributors (Interview 11) and, in particular, all actors comprising the agricultural advisory system (CGAAER, 2013). Similarly, transitions in the whole agri-food system which would address a wide variety of social and environmental issues imply vastly different time horizons compared to a substitution-based perspective focused on farm-level changes alone (Interview 2). The idea of a need for longer time horizons for planning transitions in the agricultural sector aligns with analyses of governing transitions in the energy sector, in which developing "pathways" with short-term milestones is critical to achieving longer-term goals (Rosenbloom, 2017).

Second, one can imagine how the mobilization of other actors could have resulted in *alternative translations* even of the boundary objects produced by INRAE. One interviewee from the Ministry of Agriculture found INRAE's cost evaluations useful from the perspective of discussing options for compensating farmers for estimated additional costs of using alternatives to glyphosate through changes to national agricultural subsidies (Interview 2). A wide range of actors, including some French government advisors and officials, argue that fundamental restructuring

Table 3
Boundary work for glyphosate governance in France.

Sequence	Level of boundary work	Boundary work	Actors creating and legitimizing the boundary	Purpose	Inclusions	Exclusions
1	Sociopolitical	Choice of experts involved in assessing glyphosate alternatives	Central government; INRAE directors	Problem framing; salience for policymaking; scientific credibility	A small group of agronomic and economic scientists at INRAE	Other agronomic scientists (at INRAE or elsewhere); Scientists originating from other scientific disciplines
2	Cognitive	Definition of alternatives to glyphosate	Central government; INRAE; ANSES	Problem framing; salience for policymaking	Non-chemical alternatives to glyphosate (primarily mechanical and biological)	Chemical alternatives to glyphosate (other chemical herbicides)
3	Cognitive	Definition of main criteria for the legitimacy of glyphosate alternatives	Central government	Problem framing; legitimacy vis-à-vis farmers	Alternatives considered by experts as economically and practically viable at present when counting currently internalized market costs and farm structures and systems as reflected by current survey data	Alternatives economically viable under different farming systems/ production models or through mandated internalization of currently externalized costs; legitimacy as defined by a wider range of social and environmental factors and indicators
4	Sociopolitical	Choice of policy instrument and delegation of authority	Central government	Salience for policymaking; legitimacy vis-à-vis farmers and the pesticide industry	Substance-based regulation/use restrictions based on Article 50.2 of EU Regulation 1107/2009, delegated to a regulatory institution (ANSES)	Changes to agricultural policy and/or subsidies through reforms to the Common Agricultural Policy (notably France's National Action Plan under CAP 2023–2027), through the Ministry of Agriculture and Food
5	Sociopolitical	Choice of experts collaborating on the development of boundary objects for the economic evaluation of glyphosate alternatives	INRAE	Scientific credibility and legitimacy vis-à-vis farmers	Main technical institutes for the three different areas of use analyzed	Technical institutes for organic agriculture
6	Cognitive	Specification of geographic scale of analyses	INRAE; agricultural technical institutes	Salience for policymaking	Farm-level analyses	Landscape and system-level analyses
7	Cognitive	Specification of temporal scale of analyses	Central government	Salience for policymaking	Evaluation of alternatives available in the short-term	Assessment of longer-term transitions or scenario analysis examining different "pathways" over time
8	Cognitive	Definition of a "significant practical or economic disadvantage"	ANSES Market Authorization Monitoring Committee	Salience for policymaking; legitimacy vis-à-vis farmers and the pesticide industry	Boundary of "significant" disadvantages defined based on the judgment of experts selected without transparent and precise criteria	Potential design of a policy instrument intended to compensate incurred costs of alternatives

Source: Author.

of agricultural subsidies at the national and EU levels is essential for deeper transformations of the agri-food sector (Cour des Comptes, 2019; Fondation Nicolas Hulot, 2021; France Strategie, 2019; Pe'er et al., 2020; Potier, 2014). In winegrowing, agri-environmental schemes have contributed to a decrease in the use of herbicides by 38–52% (Kuhfuss and Subervie, 2018). Yet, currently, less than one percent of public funding for France's agri-food sector addresses pesticide reduction (Fondation Nicolas Hulot, 2021).

This case demonstrates the strategic nature of boundary work and how it is both conditioned by and determines allocations of political power. The lack of clear responsibility for pesticide use reduction reflects the institutional separation between actors responsible for pesticide reduction policies and for agricultural subsidies (notably the CAP), split between both regulatory agencies and the agricultural ministry as well as within different directorates of this ministry itself (Interview 9). Though the glyphosate controversy created a rare window of opportunity for policy and/or institutional reform within a broader agricultural transition agenda, the agricultural ministry was exempt from responsibility in the case of glyphosate. Agricultural policy reforms to address the drivers of glyphosate use were not pursued despite the renewed authority member states have over the national allocation of funding under CAP reforms taking effect in 2023. ANSES recognized the limits of delegating an important part of France's glyphosate governance to a regulatory authority:

> In all cases of agricultural production […], this type of withdrawal raises questions about the value system in agriculture and the maintenance of the current system. The withdrawal of glyphosate would visibly lead to a change of system and presuppose a different type of agriculture that requires policy support for a *real transition*. This is beyond the scope of the comparative assessment to be carried out at ANSES. (ANSES, 2020a, 7, emphasis added, author's translation).

In the context of a controversial topic that drew significant media attention, the display of INRAE's expertise underlying ANSES's new regulations can also be considered a form of "public drama" in which science is "performed" to create policy closure (Hilgartner, 2000). Displaying the credibility of commissioned expertise and the stabilized results of scientific advice "front stage" while keeping political negotiations "backstage" allowed the French government to legitimize policy choices and to de-politicize the glyphosate issue rather than undertaking politically contentious agricultural policy reforms.

Addressing both the social and technical dimensions of sustainability transitions likely requires the re-politicization of issues often delegated to technical decision-making bodies and a rethinking of the role of expertise in governance. Scholars and policymakers alike should turn increased attention to how path dependency and power asymmetries shape not only traditional political processes but also the design of expertise processes, affecting knowledge outputs for sustainability governance. The politics of expertise in this case corroborate earlier analyses showing how processes of knowledge co-production affect how governments act upon the environment (Turnhout and Hulme, 2016). The case also suggests that while governments' mobilization of public expertise can be used to perpetuate existing power relations, it could potentially guide and legitimize new forms of knowledge production for transitions and engage a broader range of actors in the translation of boundary objects. The fulfillment of France's — and the EU's — broader pesticide goals requires a co-production of knowledge and policies designed to support transitions, requiring shifts in the distribution of political power and the empowerment of actors committed to transformative change.

Declaration of Competing Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Author contributions statement

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Appendices A. List of interviews

Number	Institution	Description of institution	Date	Number of interviewees	Language
1	Vivea	Mutualized insurance fund for farmers' training	19.10.20	1	FR
2	Ministry of Agriculture	Federal ministry	30.04.21	1	FR
3	INRAE	National research institute	28.04.21	1	FR
4	INRAE	National research institute	01.06.21	1	FR
5	Arvalis	Agricultural technical institute	27.10.21	1	FR
6	Terres Inovia	Agricultural technical institute	29.10.21	1	FR
7	Bayer	Pesticide manufacturer	29.04.21	1	EN
8	Pesticide Action Network UK	Non-governmental organization	23.04.21	1	EN
9	Ministry of the Environment	Federal ministry	02.12.21	2	FR
10	Ministry of Research	Federal ministry	03.12.21	1	FR
11	ANSES	Federal regulatory agency	14.12.21	1	FR
12	Ministry of Agriculture	Federal ministry	16.12.21	1	FR
13	ITAB (Institut de l'agriculture et l'alimentation biologiques)	Agricultural technical institute	02.02.22	1	FR

Appendices B. List of translations

Acronym or common use	Full name (English)	Full name (French)
ANSES	Agency for Food, Environmental, and Occupational Health and Safety	Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail
ATI	Agricultural technical institute	Institut technique agricole
CEMAGREF	Center for the Study of Agricultural Machinery and Rural Engineering of Water and Forests	Centre d'Étude du Machinisme Agricole et du Génie Rural des Eaux et Forêts
CGAAER	General Council for Agriculture, Food and Rural Areas (Ministry of Agriculture)	Conseil général de l'alimentation, de l'agriculture et des espaces ruraux
CGEDD	General Council for the Environment and Sustainable Development (Ministry of the Environment)	Conseil général de l'environnement et du développement durable
CSAMM	Market Authorization Monitoring Committee (ANSES)	Comité de suivi des autorisations de mise sur le marché
DAMM	Directorate for Market Authorization (ANSES)	Direction des autorisations de mise sur le marché
Ecophyto I	The Ecophyto 2018 Plan for Reduction in Pesticide Use over the Period 2008–2018 (France's National Pesticide Reduction Plan under the EU Sustainable Use Directive (SUD)) (2008)	Plan Ecophyto 2018
Ecophyto II	Ecophyto II Plan for the Reduction in Pesticide Use (France's 2nd National Pesticide Reduction Strategy under the EU SUD) (2015)	Plan Ecophyto II
Ecophyto II+	Ecophyto II+ Plan for the Reduction in Pesticide Use (2018)	Plan Ecophyto II+
FNSEA	National Federation of Farmers' Unions	Fédération nationale des syndicats d'exploitants agricoles

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Acronym or common use	Full name (English)	Full name (French)
IGAS	General Inspectorate of Social Affairs	Inspection Générale des Affaires Sociales
INRA	National Agronomic Research Institute	Institut national de la recherche agronomique
INRAE	National Research Institute for Agriculture, Food and Environment	Institut national de recherche pour l'agriculture, l'alimentation et l'environnement
Inserm	National Institute of Health and Medical Research	Institut national de la santé et de la recherche médicale
IRSTEA	National Research Institute of Science and Technology for Environment and Agriculture	Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture
ITAB	The French Research Institute for Organic Farming	Institut de l'agriculture et l'alimentation biologiques
Ministry of Agriculture	Ministry of Agriculture and Food	Ministère de l'Agriculture et de l'Alimentation (MAA)
Ministry of the Environment	Ministry of Ecological Transition	Minstère de la Transition Ecologique (MTE)
Ministry of Health	Ministry of Solidarity and Health	Ministère des Solidarités et de la Santé (MSS)
Ministry of Research	Ministry of Higher Education, Research and Innovation	Minstere de l'enseignement superieur, de la recherche et de l'innovation (MESRI)

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Paper III

From substitution to transformation: examining pesticide phase-out policies using the case of glyphosate in Europe

Fiona Kinniburgh

From substitution to transformation:
examining pesticide phase-out policies using the case of glyphosate in Europe

Fiona Kinniburgh

Abstract

Phase-out policies have recently gained increased attention from scholars and policymakers to address sustainability challenges. Yet many proposed phase-out policies focus narrowly on the substitution of specific technologies or substances, neglecting the systemic nature of sustainability problems and underestimating the resistance of incumbent actors to such measures. This presents the risk of policy reversals or the entrenchment of further unsustainable lock-in dynamics. Further research is therefore needed on the potential role of phase-out policies in enabling systemic change. This article bridges research on sociotechnical lock-in and on the governance of discontinuation to examine France and Germany's policies to govern glyphosate, the most widely used pesticide in the world. I situate glyphosate within a broader sociotechnical system and identify the mutually reinforcing economic, political, and regulatory lock-ins which challenge a glyphosate phase-out. Because substitution-based measures alone cannot enable a 50 percent overall pesticide reduction, phasing out glyphosate in an EU policy context focused on strongly reducing overall pesticide use is fundamentally different from implementing past pesticide bans. Conceptualizing pesticides as part of a larger sociotechnical system points to the need to switch from command-and-control towards a mix of management-based instruments to ensure the long-term effectiveness of full phase-out policies. Phasing out glyphosate and reducing overall chemical herbicide use to reverse biodiversity loss necessitates changes in farming *systems* towards crops and agricultural land use with lower per-hectare pesticide use intensities. Due to the constitutive role of the state in subsidizing and shaping agricultural production, reforming public policies is critical to shifting the conditions of production which underly economic lock-in for farmers. A phase out which will not enhance dependency on other chemical pesticides instead requires an integrated approach to agricultural and trade policies which centers sustainability to enable a restructuring of actor networks, institutions, and power relations throughout national and EU food systems.

Keywords: phase-out, sustainability transitions, governance, deliberate destabilization, agricultural policy, pesticides

1) Introduction

In light of the urgent need to decarbonize global economies and halt biodiversity loss, global expert bodies are calling for transformative change across all sectors (IPBES 2019; IPCC 2022). Practitioners and scholars alike propose societal transformations that require the development and scaling up of new technologies and practices across different sectors, including food systems (Scoones et al. 2020; Springmann et al. 2018; Zurek, Hebinck, and Selomane 2022). Yet there is also increasing recognition that moving away from specific locked-in technologies and infrastructures may require active governance measures to accelerate transitions (Smith, Stirling, and Berkhout 2005). Phase-out policies for technologies and substances, such as nuclear energy and harmful chemicals, are examples of state-led governance of deliberate technological decline or "discontinuation" (Stegmaier 2023; Trencher, Rinscheid, Rosenbloom, and Truong 2022). Although initially discussed in scientific literature in the 1970s, attention to national and international phase-out policies has grown, particularly as the scientific case for a rapid phase-out of fossil fuels is more widely accepted. Yet, for both chemicals and fossil fuels, evidence shows that bans may lead to substitution with alternatives which themselves further environmental degradation (Levain et al. 2015; Rinscheid et al. 2021). In the case of chemicals, their ubiquity in the global environment suggests that phase-outs have been too narrowly focused on the substitution of specific substances with other, supposedly less problematic ones rather than enabling a shift to more sustainable modes of production and consumption (Rinscheid et al. 2021; UNEP 2019). It is therefore of theoretical and practical importance to examine limitations to existing phase-out policies and to propose alternative approaches which can enable systemic change.

The EU has been a leader in stringent chemical policies, strictly regulating or banning more substances than any other region in the world — yet overall pesticide use has failed to decrease in a majority of member states (European Court of Auditors 2020; Helepciuc and Todor 2021). Growing evidence of the detrimental direct and indirect effects of pesticides on biodiversity has led to broader recognition among scholars and policymakers of the importance of reducing pesticides as a key component of transitions towards sustainability in the agri-food sector (Lee, den Uyl, and Runhaar 2019; Melchior and Newig 2021). This is reflected in the European Union (EU)'s 2020 Green Deal proposals, which laid the groundwork for a systemic transformation of the EU's food system. Addressing biodiversity loss is now a central part of these policy goals, alongside the longer-standing goal of reducing pesticides' impacts on human health (Hough 1998). The 2020 Farm to Fork Strategy sets out the goal of decreasing pesticide use and risks by 50 percent by 2030 (European Commission 2020). Although the EU overhauled its pesticide governance through the 2009 Pesticides Package, overall failures to decrease pesticide governance since then suggest that current policies are not effective and that reforms of current governance mechanisms are necessary to accelerate transitions towards agri-food systems with significantly lower pesticide use (Möhring et al. 2020).

Phase-out policies alone do not inherently enable systems change, since incumbent actors are known to resist policy change which runs counter to their interests, and technologies themselves are often locked-in through a variety of interconnected mechanisms (Baker, Newell, and Phillips 2014; Geels 2014; Stokes 2020). Phase-out policies without comprehensive planning may instead lead to reversals and/or reinforce existing lock-ins, as has happened, for example with nuclear phase-out proposals in multiple European countries and with the phase-out of neonicotinoid pesticides in France (Rinscheid et al. 2021).

A growing recent literature therefore focuses on the governance of discontinuation as part of broader sustainability transitions (A. Kuokkanen et al. 2018; Stegmaier 2023; Turnheim 2023). Although thematically dominated by the study of decarbonization in energy systems (Koretsky et al. 2023; Rosenbloom and Rinscheid 2020), this concept has also been applied to other areas, notably the agri-food sector (for example, Frank and Schanz 2022). Discontinuation refers to an "actively pursued exit from a sociotechnical regime," or assemblage of interdependent social and technical (f)actors (Stegmaier 2023, 78). Active governance is required not only for promoting innovation, but also for discontinuing incumbent sociotechnical systems by creating conditions favorable to the destabilization of the incumbent regime (Stegmaier, Kuhlmann, and Visser 2014; Turnheim 2023). Previous work has recognized that effective discontinuation policies require addressing context-specific politics and political economy factors which influence support for or resistance against them (Baker, Newell, and Phillips 2014; Kern and Markard 2016; van Oers et al. 2021). There is therefore a need to elucidate how discontinuation governance can be embedded within broader governance of systemic change and to shed light on the context- and case-specific political challenges which arise in doing so.

This article focuses on policies adopted by France and Germany to phase out glyphosate, the most widely used pesticide in the world. Representing a third of herbicide use by volume in the EU, glyphosate is emblematic of the dependence of European agriculture on herbicides and pesticides more broadly (Antier et al. 2020). While a highly effective herbicide, glyphosate poses varied risks to human health and to the environment (Van Bruggen et al. 2018). In France and Germany, agricultural uses comprise 95 and 90 percent of all glyphosate sales, respectively, in line with the EU-wide average of 91 percent (Antier et al. 2020).[i] After its controversial re-approval at the EU level in 2017, glyphosate became an object of active discontinuation governance by a few EU member states including France and Germany, which independently announced plans to fully ban glyphosate by 2022. As of 2023, France and Germany's adopted policies remain partial bans for the agricultural sector, while a full ban in either country is contingent on an EU-level ban.[ii] This example of policy retrenchment — understood as the weakening and/or restructuring of policy targets that reduces their efficacy at addressing a given problem (Stokes 2020) — is useful for understanding the flipside of transitions and for examining why lock-ins persist despite attempts to govern change. Given that the EU has among the world's strictest pesticide regulations, its experiences serve as a useful case study for assessing effective public policies for pesticide reduction. This article examines the following research questions: First, (how) can glyphosate be understood as part of a broader sociotechnical regime? Second, what are the lock-in mechanisms challenging the legitimacy of member state-led glyphosate phase-out in the absence of an EU-wide ban? Third, how does a broader understanding of sociotechnical regimes and lock-ins for specific substances or technologies inform choices about different governance approaches to phase-out?

I use the case of glyphosate to further understandings of how single-technology phase-out policies relate to transitions governance and can be designed to help enable systemic change. The paper examines state-led governance of discontinuation by characterizing the sociotechnical regime within which glyphosate is embedded and identifying key lock-in mechanisms, drawing on political economy and multi-level governance (Hoffmann, Weyer, and Longen 2017; Karlsson 2004). The next section introduces the concepts of sociotechnical lock-in (Clapp 2021; Anna Kuokkanen et al. 2017) and the governance of discontinuation (Borrás et al. 2014; Stegmaier, Kuhlmann, and Visser 2014). Section 3 outlines the case of glyphosate, examining the European regulatory context and situating glyphosate within a larger pesticide-intensive European agricultural regime. Section 4 examines different solutions to the glyphosate problem and the actors who directly and indirectly affect farmers' use of glyphosate. Section 5 explores the lock-in and power dynamics which challenge the discontinuation of glyphosate use in the EU. Section 6 contrasts command-and-control approaches to phase-out with alternative approaches, examining France and Germany's policy instruments for glyphosate discontinuation. Section 7 discusses the implications of the glyphosate case for European pesticide governance to foster a deeper understanding of the potential role of phase-out policies within the governance of systemic change.

2) Theoretical background

2.1 Discontinuing sociotechnical regimes

Research on sustainability transitions takes as a starting point the need for fundamental transformations to more sustainable sociotechnical systems, recognizing that existing systems are fundamentally unsustainable (Geels and Schot 2007). Transitions studies are characterized by a recognition of multi-dimensional sources of stability underlying sociotechnical systems and a focus on the central role of incumbent actors, who are well-established in existing sociotechnical configurations (Geels and Schot 2007; Turnheim 2023; Turnheim et al. 2015). Sociotechnical transitions involve trade-offs between different goals, take time, and are likely to shift power dynamics in existing systems, creating new economic and social "winners" and "losers."

Existing systems are understood as "locked in" or stabilized through a variety of self-reinforcing technological and social mechanisms, including through technologies, infrastructure, institutions, discourses, and behaviors and norms (for example, Buschmann and Oels 2019 and van Oers et al. 2021). While literature on sociotechnical lock-in has mainly focused on different dimensions of carbon lock-ins (Fisch-Romito et al. 2021; Seto et al. 2016; Unruh 2002), this concept has also been used to explain the persistence of unsustainable agricultural practices. The lock-in of pesticide use in different institutional contexts has been attributed to similar mechanisms as carbon lock-in wherein "initial conditions, increasing economic returns to scale, and social and individual dynamics act to inhibit innovation and competitiveness of low-carbon alternatives" (Cowan and Gunby 1996; Hammond Wagner, Cox, and Bazo Robles 2016; Hüesker and Lepenies 2022; Seto et al. 2016, 426). The concept of lock-in emphasizes the path dependency of present sociotechnical systems, suggesting that incumbent systems are difficult to change. Evolutions in previous sociotechnical systems shows that lock-in is neither permanent nor inevitable, but enabling change requires better understanding different lock-in mechanisms and possible interventions to "unlock" them. Characterizing lock-ins notably requires a "longitudinal approach to understand *how sociotechnical configurations have stabilized* [...] and evaluative-descriptive approaches to how stable sociotechnical configurations actually are" (Turnheim 2023, 46, emphasis added).
Literature focusing on politics and power within transitions debates emphasizes the need to examine different strategies of resistance to transitions from incumbent regime actors. Since deep sectoral transformations may cause significant redistributions of wealth and resources, policies designed to enable transformations are likely to face strong resistance from actors currently benefitting from the status quo (Aklin and Urpelainen 2013; Stokes 2020). Incumbent players' dominant role is stabilized by structural advantages, such as political arrangements, policies, institutions, and powerful strategic alliances (Turnheim 2023). Incumbent players are known to deploy dynamic strategies to maintain their dominance, for example to block phase-out policies, especially when such policies target individual industries reliant on the use of a

specific substance (Brauers, Oei, and Walk 2020; Steckel and Jakob 2021). In the cases of nuclear, fossil fuels, and agrochemicals, industry has organized powerful opposition and successfully derailed phase-out policies in many countries (Donley 2019; Geels 2014; Steckel and Jakob 2021). Given the size of these industries and their contribution to local and regional economies, resistance is often buttressed by opposition from workers within the industry, as well as the public and politicians (Trencher, Rinscheid, Rosenbloom, Koppenborg, et al. 2022). Incumbent actors therefore play a key role in enacting the stability of existing systems, often challenging attempts to delegitimize their activities and simultaneously attempting to undermine the legitimacy of alternative technologies and sociotechnical arrangements, notably through discursive means (Gürtler, Löw Beer, and Herberg 2021; Rosenbloom, Berton, and Meadowcroft 2016; Trencher et al. 2019).

In recognition of the sociopolitical challenges of dismantling incumbent regimes, transitions literature has increasingly addressed the role of governance in guiding sociotechnical change and in discontinuing incumbent sociotechnical systems (Kivimaa and Kern 2016; Smith, Stirling, and Berkhout 2005; Stegmaier, Kuhlmann, and Visser 2014). Phase-outs are one form of discontinuation governance which aim to "terminat[e] specific technologies, substances, processes, or practices that are considered harmful" (Rinscheid et al. 2021, 27). Phase-outs can be understood as an objective (i.e. a quantifiable reduction or elimination), a form of intervention (i.e. a policy), and a process (i.e. a long term reconfiguration of technological production and use). This broader conception of phase-outs creates openings for examining *how* governance is undertaken (Turnheim 2023).

The strong role of states in driving phase-outs makes public policy a critical aspect to investigate when considering the governance of discontinuation (Stegmaier 2023; Trencher, Rinscheid, Rosenbloom, and Truong 2022). However, state-led approaches towards phasing out *substances* and *technologies* have fundamentally differed. Trencher et al. (2022) examine the wide range of policy instruments which have been used for phase-outs worldwide and contrast different approaches to various environmental problems. Three main types of policies have been used for phase-outs:

- *command-and-control instruments*, which typically include environmental standards and other regulations which may ultimately lead to a complete ban
- *management and planning instruments*, which typically include phase-out schedules with specific targets and may include compensation and other measures to restructure affected industries and/or regions
- *economic instruments*, such as changes in public subsidies, pollution pricing (including taxation measures), or financial support for specific technologies.

Command-and-control instruments have been the primary interventions for phase-outs overall and are used particularly often for substances (such as lead, flame retardants, or ozone depleting substances). In contrast, management and planning instruments have been primarily used for phase-outs of technologies (such as nuclear power, internal combustion engines, and coal technologies) (Trencher, Rinscheid, Rosenbloom, Koppenborg, et al. 2022). A notable such example is that of Germany's coal phase-out, for which a "Coal Commission" was tasked with developing an integrated package of measures which includes compensation for affected regions (David and Gross 2019). Economic instruments have mainly been explored for fossil fuels and rarely discussed for chemicals (Trencher, Rinscheid, Rosenbloom, and Truong 2022).

This paper integrates concepts from political science and political economy with the concepts of discontinuation governance and sociotechnical lock-in to examine the economic context, actors, instruments, and institutions involved in the governance of glyphosate discontinuation in France and Germany. Multi-level governance refers to "an open system where decision-making at every governance level [...] is influenced by vertical linkages to other governance levels and horizontal linkages to governance in other sectors at the same level" (Karlsson 2004, 195). Building on work examining political and economic mechanisms influencing pesticide lock-in at different governance levels (Clapp 2021; Hüesker and Lepenies 2022), I examine the connections between national lock-in mechanisms and broader European and international political economy dynamics to evaluate the potential role of different public policy instruments in enabling a successful glyphosate phase-out aligned with broader systemic change. To connect policies with sustainability outcomes, this paper integrates research on agricultural transformation (Skrimizea et al. 2020; Young et al. 2022) and farming systems research, which "investigates how spatial, technical and social relations are constructed, represented, materialized and contested by a broad range of societal actors" (Darnhofer, Gibbon, and Dedieu 2012, 7).

2.2 Methodological approach

This analysis is based on an interpretive approach, drawing on mixed qualitative and quantitative methods. The main temporal scope of analysis (2015-2022) encompasses the period during which glyphosate became an object of active discontinuation governance by a few EU member states pending the expected EU-level vote on the reauthorization of glyphosate. Semi-structured interviews were conducted by the author between May 2018 and August 2022 with actors in the agricultural sector, non-governmental organizations, political spokespeople, and policymakers at national and subnational levels (Appendix A); with French stakeholders, these interviews were primarily in French and were in English with German stakeholders. Experts for interviews were identified from document analysis and through snowball sampling. A corpus of documents was constructed from policy and legal papers from the French and German governments, EU policymakers, and other prominent actors outlined in Section 5; press releases; scientific literature; industry reports; NGO statements and reports; and media articles. Qualitative analysis of the documents and interviews consisted of a first inductive coding of the documents and interviews using MaxQDA software, following a grounded theory approach to qualitative data analysis (Glaser and Strauss 1967). The corpus was then recoded deductively after the development of the paper's framework for the analysis of the sociotechnical governance of change. To supplement the qualitative analysis, descriptive statistical methods were applied to analyze agricultural production and pesticide use data from selected national governments and research institutions.

3) Regulations and policies

3.1 EU Regulatory context

The immediate European context within which France and Germany proposed glyphosate bans was marked by scientific and political controversy. In 2015, the intergovernmental International Agency for Research on Cancer (IARC)[iii] under the World Health Organization deemed glyphosate a "probable carcinogen," accelerating societal concern regarding a chemical which had already been under global public scrutiny for decades. Two years later, the EU agencies European Food Safety Authority (EFSA) and the European Chemicals Agency

(ECHA) both concluded that glyphosate could not be classified as a carcinogen (Kudsk and Mathiassen 2020).

The authorization of pesticides and the design of agricultural policies are both constrained by specific multi-level policy interactions. At the EU level, major reforms of pesticide governance initiated in 2006, known as the "pesticide package," form the framework under which member states operate. Under *Regulation (EC) No 1107/2009 of the European Parliament and of the Council of Oct 21, 2009, concerning the placing of plant protection products on the market* (hereafter Regulation 1107/2009), pesticide active ingredients (such as glyphosate) are regulated at the EU level based on risk assessments performed by EFSA and ECHA, while pesticide formulations containing these active ingredients (i.e. marketed products) are regulated by product and by use by individual member states. An active substance cannot be (re)authorized if it is found to be carcinogenic or corresponds to six other specifically defined hazards (Bozzini 2017). Once an active substance is authorized at the EU level, pesticide formulations are regulated by member states. A formulation containing the same active substance(s) may therefore be available to farmers in different EU member states and authorized for different uses. The *Directive 2009/128/EC of the European Parliament and of the Council of Oct 21 2009 establishing a framework for Community action to achieve the sustainable use of pesticides* (Sustainable Use Directive, hereafter SUD) marked the beginning of an EU policy agenda aiming to promote a shift towards integrated pest management (IPM) practices and the use of low-risk pesticides. Its primary objective is the "reduction of pesticide use and risks," to which end the SUD required each member state to develop a National Action Plan (NAP).

The contrasting classifications from IARC versus EFSA and ECHA prevented the EU from automatically banning glyphosate using the criterion of carcinogenicity (Leonelli 2018). Growing public pressure for action on glyphosate was encapsulated by a "European Citizen's Initiative," which gathered over a million signatures, urging decision-makers to block the EU re-authorization of glyphosate. In 2017, EU member states reached a qualified majority vote to re-approve glyphosate use for 5 years after several rounds of voting, only due to Germany's last-minute change in position from abstaining to a vote in favor of renewing approval (Kudsk and Mathiassen 2020).[iv] The 5 year re-authorization reflects a political compromise for glyphosate specifically, since active substances are typically re-authorized for 15 years. Though initially set for December 2022, the EU vote to renew the authorization of glyphosate has been pushed back due to a delay of EFSA's delivery of its report on the peer review of the glyphosate risk assessment which, as of December 2022, is expected in July 2023. Glyphosate's EU-level use authorization has been temporarily extended to December 15, 2023. ECHA's 2022 glyphosate risk assessment again concludes that glyphosate is not carcinogenic (ECHA 2022).

Under significant public pressure, France and Germany vowed to ban glyphosate earlier than the next possible EU-level ban in 2022, in 2017 and 2019 respectively. Although other European countries have attempted to ban glyphosate, France and Germany are both among the top three largest agricultural producers and highest users of glyphosate in the EU (Antier et al. 2020; PAN Europe 2023). The two countries' participation in common EU policy frameworks and leading roles in the agricultural sector provide a useful comparative basis for disentangling multi-level governance dynamics to shed light on the design and role of phase-out policies within a broader sustainability transitions agenda for agri-food systems.

3.2 France and Germany's glyphosate discontinuation instruments

France's Glyphosate Exit Strategy, presented in June 2018, marked a retrenchment relative to Emmanuel Macron's initial ban promise. The Strategy is subsumed under the broader framework of the revised national pesticide reduction plan, Ecophyto II+, which reiterates a previous goal to decrease the volume of pesticide use by 50 percent by 2025. For glyphosate, the aim is to "eliminate *major uses* of the substance within three years and within five years for all uses, *while not leaving farmers in a bind*" (French Ministry of Agriculture 2018; emphasis added). Prior to the 2017 policy debate, France had already reduced the number of glyphosate-containing products on the national market by withdrawing 132 authorizations for products containing a co-formulant, POE-tallowamine, which was found to pose unacceptable risks to human health and the environment (ANSES 2016). The government subsequently called upon ANSES to develop a series of new regulations on glyphosate use in accordance with Article 50.2 of Regulation 1107/2009, adding a new layer of regulations to the agency's usual procedure for regulating pesticides based on risks to human health or the environment (Kinniburgh 2023). This "mode of withdrawal" for an active substance still authorized at the EU level is based on an assessment demonstrating that the adoption of alternatives does not pose "significant economic and practical disadvantages to the user" (Grimonprez 2021). Based on comparative economic evaluations of glyphosate alternatives for the three major glyphosate-using agricultural sectors in France (arable crops, viticulture, and arboriculture), ANSES banned certain glyphosate uses for which substitution with non-chemical alternatives was deemed possible, while reducing the allowed doses in other cases (Carpentier et al. 2020; Jacquet, Delame, Lozano-Vita, et al. 2019; Jacquet, Delame, Thoueille, et al. 2019).[v] The government estimates that the overall impact of its new regulations will be a 50 percent decrease in glyphosate use (French Government 2021; Interview 12). In addition to these regulatory measures for glyphosate, France developed educational resources for the agricultural sector, proposed modest financial support for farmers, and developed new instruments under Ecophyto II+ to complement its previous strategies (French Government 2018). The financial instruments adopted to facilitate transitions away from glyphosate include a tax credit for farmers who declare that they did not use glyphosate in 2021 and/or 2022 and 80 million euros in extra funds for farmers for investments for new equipment (French Ministry of Agriculture 2020).

Germany has also taken a primarily legislative path to glyphosate phase-out, marking a continuity with its strong recourse to regulatory approaches in environmental policymaking more generally. Following significant debate about possible policy approaches, the joint plan to phase out glyphosate presented by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMUV) in September 2019 set out Germany's plan to implement several reduction strategies starting in 2020 and to ban pesticides containing glyphosate after December 31, 2023.[vi] However, Germany's proposed total ban is contingent on an EU-level ban (Umweltinstitut Munchen 2021). Germany's reduction of glyphosate use is enshrined within an Insect Protection Package approved by the federal government in February 2021. This package of laws is framed primarily around the problem of insect loss and its links to broader biodiversity loss. The latter issue rose sharply on the political agenda following the publication of a study demonstrating the loss of more than 75 percent of insects in German protected areas over a 27 year period (Hallmann et al. 2017). Growing societal concern and "high expectations" for policy action were reflected in the adoption of regional policies to "save the bees" (German Federal Ministry of the Environment 2018). Rather than a new law, the legal component of the Insect

Protection Package consists of modifications to two existing laws: the Federal Nature Conservation Act and the Plant Protection Application Ordinance. Glyphosate is specifically treated in the amendment to the latter. Recognizing its negative impacts on biodiversity, the amendment restricts glyphosate use in nature reserves, national monuments, and protected areas under the Natura 2000 program of the EU Habitats and Birds Directive ("FFH areas"), which include some agricultural land. Although FFH areas are the largest among these tracts of land, exemptions for the cultivation of most crops in these areas effectively allow continued glyphosate use. Agricultural cultivation outside FFH areas is not affected (Umweltinstitut Munchen 2021). A timeline of relevant events in France, Germany, and at the EU level are presented in Figure 1.

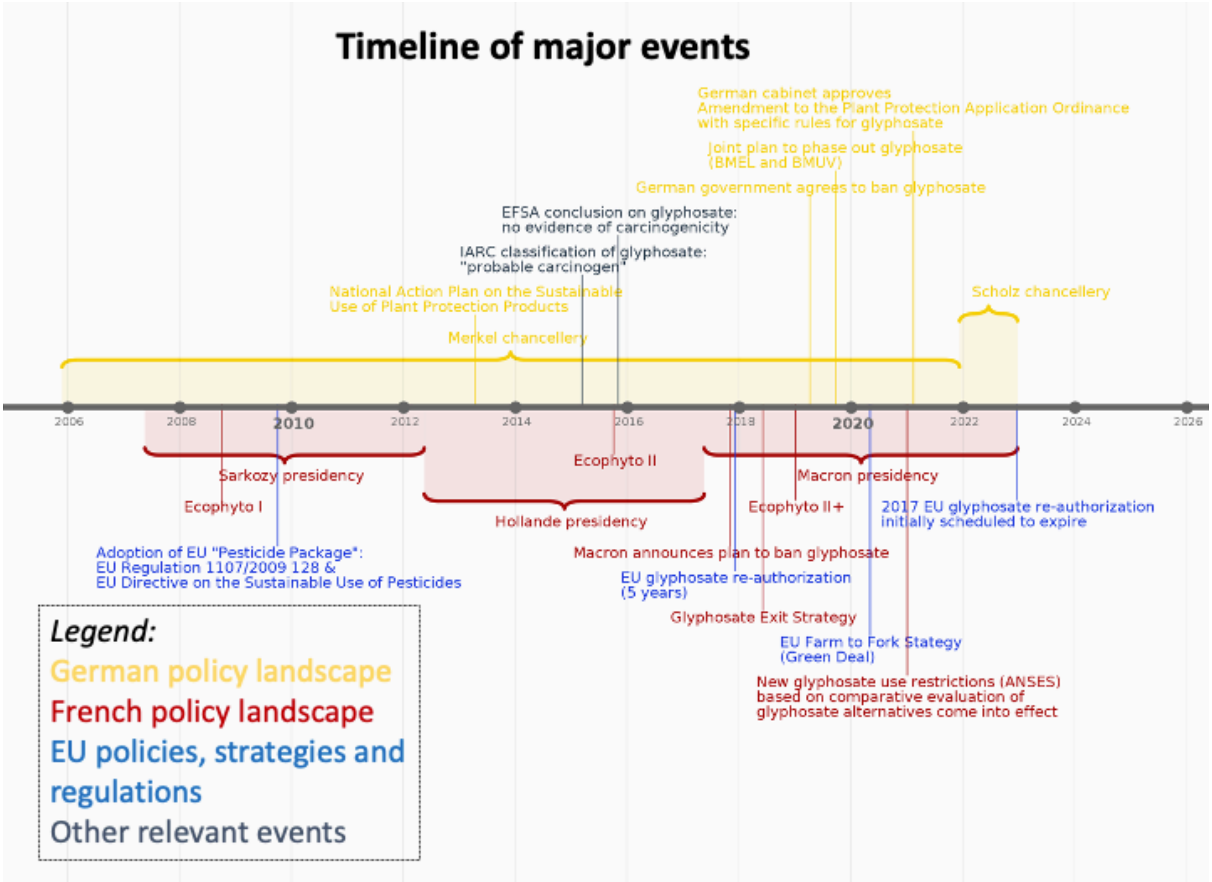

Figure 1: Timeline of major events. Source: Author.

4) Glyphosate: a contested pillar of a pesticide-intensive regime

4.1 Regime trends and glyphosate use

Agricultural producers' choices — including decisions on the use of glyphosate and other pesticides as well as what to produce — depend on the sociotechnical system within which producers operate. Producers develop strategies adapted to the specific conditions under which competition occurs (Grando et al. 2019). These conditions are shaped by public policies, notably the EU Common Agricultural Policy (CAP). Commanding about one-third of the overall EU budget, the subsidies provided by the CAP are the main policy instrument influencing farmers' crop choices and environmental practices (European Parliament 2022).

The case of glyphosate illustrates how the increased use in pesticides is a key strategy which producers use to maintain competitiveness in an environment with continuous downward pressure on prices. Surveys examining glyphosate use in Europe reveal that it is not only a "classical" herbicide used for weed control, but an agronomic instrument farmers employ for a broad range of uses as a means to reduce labor and machinery costs, save time, and thereby enhance competitiveness (Antier et al. 2020; Danne, Musshoff, and Schulte 2019; Steinmann, Dickeduisberg, and Theuvsen 2012).

The main non-chemical glyphosate alternatives — if farming systems stay as they are today – – involve mechanical weeding, often using tractors or other machinery (Reboud et al. 2017). These non-chemical alternative methods reduce threats to biodiversity and human health by reducing exposure to glyphosate, but may involve tradeoffs and likely increase labor time and production costs. The modern industrial productivist model of farming — which aims primarily to achieve high productivity and increase crop yields — relies heavily on pesticides and other synthetic inputs, such as artificial fertilizers, which are fossil-fuel based (Clapp 2021; Shattuck 2021). Alternative production models (such as organic agriculture or agro-ecology), though expanding rapidly, remain marginal relative to the pesticide-intensive regime which has determined the evolution of European agriculture and land use since the Second World War (Aubert et al. 2018).

Arable crops account for the largest use of land in both France and Germany (as well as Europe more broadly) and are therefore particularly important for pesticide reduction, and the reduction of herbicide use in particular. The three main single glyphosate-using crops in Europe are winter wheat, maize, and oilseed rape. These occupy 48, 23 and 9 percent of total acreage of major crops using glyphosate in Europe, followed by orchards (with various fruits and olives collectively occupying 16 percent) and vineyards (occupying 4 percent) (Antier et al. 2020). In France, 70 percent of pesticides (by volume) are applied to arable crops, with wheat and rapeseed as the major users (Faraldo et al. 2021a). The application of glyphosate for arable crops is linked to the type of crop grown, being used more often to support cultivation of soybeans, wheat, and rapeseed; to the intensity of cropping practices; and to farm size, with larger farms using more glyphosate (Reboud et al. 2017). In Germany, nearly two-thirds of glyphosate is applied to just three crops: rapeseed, winter wheat, and winter barley (Steinmann, Dickeduisberg, and Theuvsen 2012). High ratios of cereals and oilseeds in crop sequences have high risks of weed infestation, but are the common "state of farming practices" in Europe due to their high profitability (Andert and Ziesemer 2022).

Changes in land use and the relative distribution of land among different crops in the EU have been driven by public policies and market forces. Cereals (such as wheat, barley, rye, oats, and maize) are Europe's main agricultural crops, covering a larger land area than all other crops combined. The area devoted to oilseed cultivation has increased, starting in the late 1970s and accelerating since 2009 as a result of the Renewable Energy Directive and the use of rapeseed for biofuels. Meanwhile, the area of protein crops — which can help reduce greenhouse gases, be used as animal feed, and act as substitutes for animal-based protein for humans — has declined significantly. These dynamics of regional specialization are in part driven by European trade policies which facilitated low-cost protein crop imports from the U.S. (Magrini et al. 2018).

4.2 Diverging solutions to phasing out glyphosate

Glyphosate's arrival on the EU policy agenda occurred in the context of debates on means to reduce the risks of pesticide use more generally in light of the SUD, which frames its objective as the "reduction of pesticide use *and risks"* (emphasis added). The inclusion of both "use and risks" leads to ambiguity in the means of implementation that member states should adopt to achieve SUD's goals, since risk reduction can be achieved through a variety of means and could comprise a bigger component of member states' strategies than reductions in use. This implementation ambiguity is reinforced by a lack of publicly-available and harmonized data across member states (and worldwide) which would enable a more systematic evaluation of the drivers of pesticide use and the effectiveness of different governance measures (Berthier et al. 2022; Dermine and Burscher-Schaden 2022; European Commission and Eurostat 2019; Shattuck 2021).

As a result, national actors have developed different responses to EU pesticide policies which can be broadly divided into two major competing paradigms: a risk-based approach and a volume-based approach. At present, France is the only country to have adopted a volume-based approach in its NAP, with a target to reduce the use of pesticides by 50 percent by 2025 (French Ministry of Agriculture 2018). In contrast, Germany's 2004 chemical pesticide reduction program was built on a risk reduction approach, while its 2013 NAP explicitly rejected generic reductions in quantities (Frank and Schanz 2022). In the risk paradigm, risk depends on the hazard of a given substance (for example, the toxicity of an active substance to human health) and the exposure of an agent to that hazard. The risk approach, which currently dominates pesticide governance worldwide, suggests that intensive agricultural production systems can be maintained if risks are reduced or contained through risk-reducing strategies, such as farm workers' use of protective equipment or the reduction of pesticide dispersal in the environment through enclosed agricultural production systems (e.g. greenhouses with pollution control technologies) (Interview 2). In contrast, the volume-based approach affirms that pesticides' impacts on human health and the environment can only be reduced through a decrease in their use (Aubertot et al. 2005; Guichard et al. 2017). This approach is precautionary and internalizes the notion that not all risks can be known prior to market authorization and use of a substance and that risk regulation processes inherently grant value to specific agents over others by deciding which risks are worth taking into account. As one NGO interviewee highlighted: "If you put restrictions on pesticides based on human health, it does not automatically cover the threats to biodiversity" (Interview 8). Such risks to biodiversity need to be considered in their own right, requiring measures which go beyond those designed to minimize health risks. By 2019, Germany's Ministry of Agriculture had shifted positions to align more closely with France, acknowledging the need for a goal for reducing the *use* of pesticides (Frank and Schanz 2022). However, Germany has thus far failed to quantify any specific volume targets.

Practices such as diversification — both within crop rotations and at the landscape level — and longer, more varied crop rotations are key strategies for simultaneously reducing pesticide and synthetic fertilizer use (Andert et al. 2016; Guyomard et al. 2020). Crop diversification is particularly important for farmers to reduce synthetic herbicide use (Andert and Ziesemer 2022). Because diversification means growing different types of crops and moving away from a monoculture model, such strategies fall under the category of redesigning farming systems.

Scientific findings point to the need for shifting the understanding of pesticide alternatives from substitute products to changes in land use towards more diversified crops than are currently grown. Analyses commissioned by the French government show that a 50 percent reduction in pesticide use (the magnitude set out in EU policy objectives) requires ecological redesign and de-intensification of agricultural systems (Butault et al. 2010; Guyomard et al. 2020). Increasing the *efficiency* of pesticide use can be achieved through optimization techniques, such as precision farming, such that only the necessary volume of substances is applied. Risks to either human health or the environment can also be decreased through the *substitution* of highly toxic chemical pesticides with less toxic ones (according to criteria for toxicity for specific organisms) or of chemical pesticides with non-chemical alternatives, such as biocontrol agents or mechanical weed control (Aulagnier and Goulet 2017). However, these approaches fundamentally differ from an approach targeting the *redesign* of cropping and farming systems according to ecological principles, which involves *system-wide changes* going beyond the farm level and conceived over pluriannual time periods. Although efficiency measures and the substitution of harmful pesticides with more benign alternatives are still important, these alone cannot enable necessary reductions in overall pesticide use. Redesign encompasses a broad range of agricultural models, including agroecology, organic agriculture, and diversified farm systems (Butault et al. 2010; Tittonell 2014). Although certain practices under this approach may involve the use of pesticides, the aim is to decrease pest pressure and pesticide use through measures such as the adoption of pest-resistant varieties. French expertise commissioned to examine strategies to achieve France's 50 percent reduction goal showed that this goal could only be achieved via shifts towards low-input systems through redesign (Butault et al. 2010). This finding was reconfirmed in a report which concluded that achieving the EU's Green Deal goals and objectives require a policy mix favoring farming systems which rely more on biological cycles and less on chemical inputs, including an expansion of organic agriculture and mixed crop-livestock systems (Guyomard et al. 2020).

4.3 Actors and institutions

Farming system research conceptualizes farmers' strategies and practices, which influence their performance and environmental impacts, as part of a broader sociotechnical system. Situating glyphosate within a broader pesticide-intensive regime reveals that pesticide use is dependent not only on farm-level actors, but also those shaping the larger socioeconomic context. This socioeconomic context is influenced by public policies from the national and EU levels and includes factors including regulations and policies, markets, the availability of inputs and technologies, environmental conditions, cultural and behavioral aspects, and the advice, knowledge and support provided by socioinstitutional structures (Antier et al. n.d.; Aubert et al. 2018) (Figure 2).

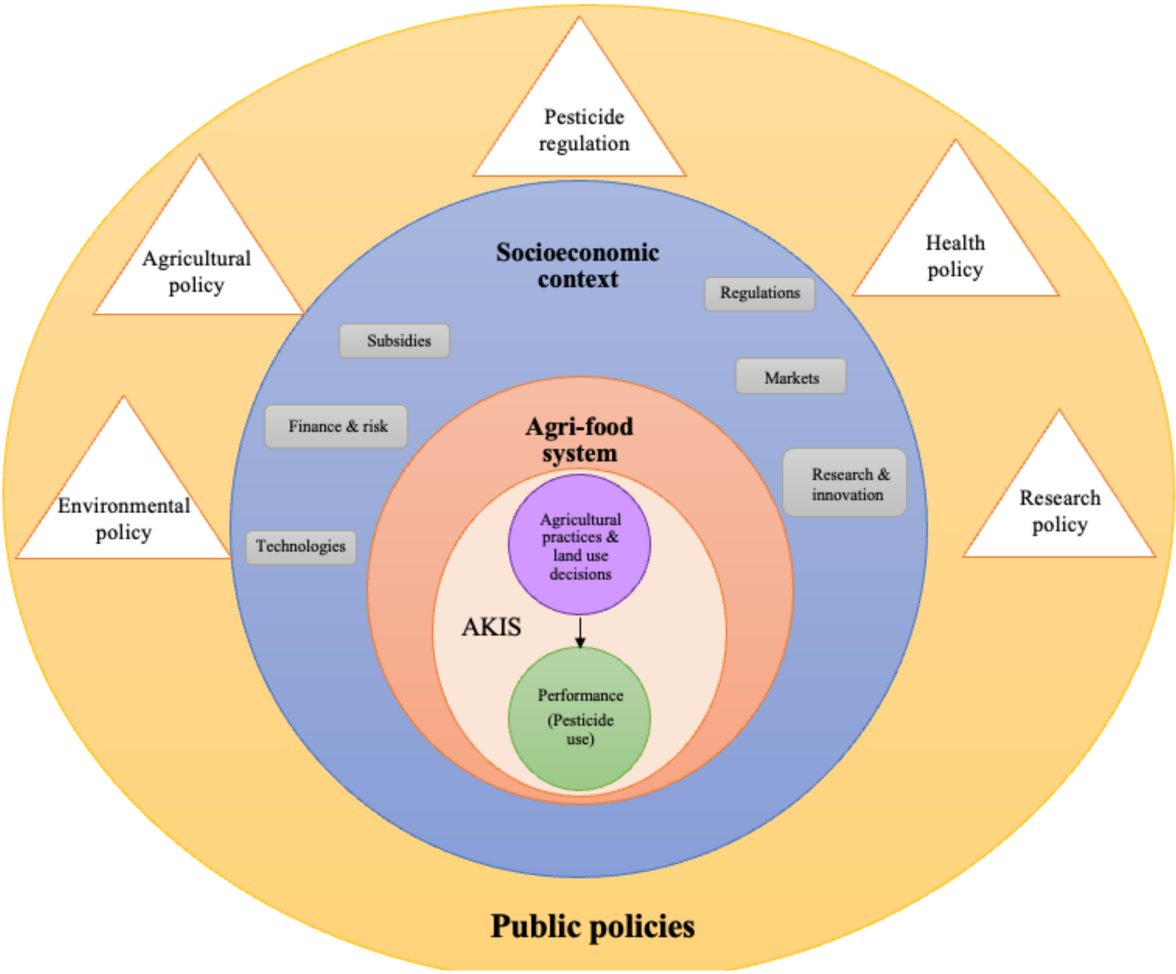

Figure 2: Multi-scale framework linking farmers' performance and pesticide use to public policies. AKIS signifies "Agricultural Knowledge and Information Systems." Source: Author, based on Aubert et al. (2018).

Pesticide policies sit at the intersection of a variety of instruments targeting food production, human health, environmental protection, and research and innovation (Möhring et al. 2020). Each of these different policy areas influences pesticide use directly and indirectly, reflecting a fragmented EU and national policy landscape. Pesticide regulation directly targets pesticide users: farmers, in the case of agriculture. Though under the primary supervision of federal agricultural ministries in both countries, pesticide regulation falls under the purview of independent regulatory agencies. Farmers can adopt efficiency or substitution measures which do not fundamentally change their agricultural practices or land use decisions in order to conform to new pesticide regulations and restrictions.

A mix of policies across these different areas shape the socioeconomic context more indirectly, affecting other actors in the agri-food system which affect farmers' practices. The agri-food system includes actors upstream and downstream of farmers, such as input suppliers (pesticide producers and associated industry associations) upstream and food retailers (such as supermarkets) downstream. Within the agri-food system, farmers are also embedded within Agricultural Knowledge and Information Systems (AKIS). These link diverse actors from the public, private and non-profit sectors relating to agriculture to promote mutual learning, to generate, share, and utilize agriculture-related technology, knowledge, and information, with influential national actors supporting different parts of the knowledge system (Knierim and

Prager 2015). AKIS include national public research institutes, farmer advisory services, agricultural technical institutes, chambers of agriculture, farmers' cooperatives, and farmers' unions. Prominent institutions affecting pesticide governance in France and Germany are summarized in Table 1.

In both France and Germany, the main opponents of a glyphosate ban are farmers, pesticide companies, and agricultural ministries, along with some actors in AKIS, particularly technical institutes for major conventionally-produced commodities, such as cereals. The main actors advocating for a glyphosate ban in France and Germany are civil society organizations representing a variety of public interests, such as victims of pesticide poisoning, beekeeping associations, and environmental NGOs.

Table 1: Institutional mapping: pesticide governance in France and Germany. Selected institutions illustrate the main actor groups and institutions in each country which directly or indirectly affect pesticide use, based on the policy areas and actor groups identified in the analysis. The list is indicative rather than exhaustive as the actor networks in each country are highly complex. Source: Author.

	Policy areas and actor groups	Type of institution	Institutions			
			France		Germany	
Public policy	Pesticide regulation	Pesticide regulatory agencies	Agence nationale de sécurité sanitaire de l'alimentation, l'environnment et du travail	ANSES	Bundesamt für Verbraucherschutz und Lebensmittelsicherheit	BvL
		Pesticide risk assessment agencies			Bundesinstitut für Risikobewertung	BfR
	Environmental policy	Environmental ministries	Ministère de la Transition écologique	MTE	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz	BMUV
	Agricultural policy	Agricultural ministries	Ministère de l'Agriculture et de la Souveraineté alimentaire	MASA	Bundesministerium für Ernährung und Landwirtschaft	BMEL
	Research and innovation policy	Research and education ministires	Ministère de l'enseignement supérieur et de la recherche	MESRI	Bundesministerium für Bildung und Forschung	BMBF
	Health policy	Health ministries	Ministère des Solidarités et de la Santé	MSS	Bundesgesundheitsministerium	BMG
Agri-food system	Agricultural knowledge and innovation systems (AKIS)	Public research institutes	Institut national de recherche pour l'agriculture, l'alimentation et l'environnement	INRAE	Julius Kühn Institut	JKI
			Centre de coopération internationale en recherche agronomique pour le développement	CIRAD	Thünen Institut	
			Institut de recherche pour le développement	IRD		
		Private research institutes: Agricultural technical institutes	15 institutes specialized according to production sectors (pork, poultry, ruminants, wine, fruits and vegetables, cereals, etc). It is coordinated by an association, Le réseau des Instituts des filières animales et végétales (ACTA)	ACTA	Private research is undertaken directly by private companies and advisory services	
		Farmer advisory services	Diverse public and private organizations (farmer cooperatives, chambers of agriculture, associations, private firms, etc)		Diverse public and private organizations (chambers of agriculture, associations, private firms, etc)	
	Actors upstream of farmers	Pesticide companies	E.g. Bayer, Syngenta, Corteva, BASF			
		Other input providers	E.g. Seed and fertilizer producers			
	Actors downstream of farmers	Farm cooperatives	A wide variety of actors and institutions situated between farmers and vendors; specific to the type of crop, market destination, etc.			
		Intermediaries				
		Processing facilities				
		Supermarkets and other vendors	E.g. Carrefour, Casino, Intermarché		E.g. Edeka, Lidl, Aldi	

5) Lock-in mechanisms and power dynamics

Given the partial glyphosate discontinuation policies adopted by France and Germany, this section examines the main sociopolitical lock-ins which challenge the practicability and legitimacy of a complete phase-out of glyphosate in the EU.

5.1 Knowledge and research lock-ins

First, the dominance of few major crop varieties, such as wheat, corn, and rapeseed, has been fueled by decades of agricultural research and development focusing strongly on the optimization of these crops at the expense of minor crops currently grown on smaller areas, such as hemp, peas, and linseed. These crops are critical to reaching Farm to Fork objectives, since they can be used to diversify agricultural production and decrease pesticide and fertilizer use, in turn contributing to climate change mitigation through decreased emissions from fertilizer production and direct emissions from soils (Crews, Carton, and Olsson 2018; Magrini et al. 2018; Meynard et al. 2018). Trajectories of research and development in agriculture (Vanloqueren and Baret 2009) and crop protection (Joly and Lemarie 2002) in Europe have locked in specific innovations characteristic of intensive agriculture while "locking out" alternative agricultural paradigms such as agroecology. As a result, minor crops have lower yields on average and have not been incorporated into agricultural supply chains despite their environmental benefits.

Second, a majority of farmers in the EU have been and continue to be trained according to a productivist paradigm, in which glyphosate and other herbicides are a staple of production and a means to reduce costs (Interview 7; McIntyre B., Herren H.R. 2009). Organic and agro-ecological practices are knowledge-intensive as they require more fine-grained knowledge of local conditions and ecological interactions (Möhring et al. 2020; Therond, Duru, Roger-estrade, et al. 2017; Young et al. 2022; Interview 15). Studies examining barriers to the adoption of low-pesticide practices show that farmers lack the knowledge, training, and support to shift to low or pesticide-free practices (Young et al. 2022). Such practices may also be more labor-intensive, potentially increasing production costs and requiring reorganization of time management and investment in labor.

Third, the domination of pesticide research by industry actors shapes both the alternatives to glyphosate available on the market and the research which is used to substantiate regulations. Increasing regulatory costs since the 1980s have led to strong concentration among pesticide companies, creating a landscape in which only four transnational corporations control the majority of the pesticide market and conduct the majority of research and development (Clapp 2021; Ollinger and Fernandez-Cornejo 1998; Shattuck 2021; Watson 2018). The economic viability of new pesticides is central, disincentivizing innovation and producing an increasingly restricted pesticide market (Hüesker and Lepenies 2022). At the same time, industry-dominated research affects glyphosate regulation. The majority of scientific research on glyphosate has focused on agricultural science, while analysis of toxicology or environmental effects began only in 2000 and remains limited (Sosa et al. 2019). In 2017, the leak of internal documents (the "Monsanto Papers") revealed Monsanto's scientific malpractice in influencing scientific studies on the safety of glyphosate to downplay its risks (McHenry 2018). Independent research on glyphosate carcinogenicity is scarce due to a lack of funding (Demortain 2020). When France aimed to fill this gap by launching a research program on glyphosate carcinogenicity, the research consortium initially nominated to conduct research withdrew following public controversy (ANSES 2020; Interview 9). This demonstrates how reputationally risky glyphosate research has become, discouraging the independent analyses which are critical to informing regulatory processes. For glyphosate, industry-sponsored studies were used not only to cast doubt on its carcinogenicity, but to show lost profits for farmers phasing it out and to undermine the legitimacy of alternatives. Many such industry-funded studies have since been retracted by the scientific journals due to such malpractices (e.g. Schmitz and Garvert (2012)). However, retraction often occurs too late to influence their use as part of lobbying tactics in public policy debates (Lock 2020).

5.2 Economic and politico-institutional lock-ins

Self-reinforcing economic dynamics underpinned by public policies and research trajectories were most frequently discussed by interviewees as barriers to glyphosate phase-out. The state has played a constitutive role in subsidizing and shaping agricultural production, notably through the CAP, as well as through additional national financing schemes.

National and EU agricultural and trade policies play a determinant role in affecting farmers' land use choices and pesticide use by constituting market conditions and providing economic support, thereby creating a form of economic lock-in (Bosc and Bélières 2015). Consequently, the need to reform CAP subsidies to decrease pesticide and glyphosate use was reiterated by a variety of interviewees (Interviews 2, 9, 12, 16, 17). As an interviewee at the French Ministry of Agriculture working on the Ecophyto strategy summarized:

> We realize that the systemic change lever is perhaps the essential lever. The difficulty we have is that, in the end, the choice of crops for farmers *is above all an economic choice and not necessarily an agronomic one.* Differences between us and the directorate that deals with CAP funds (were) on [...] crop rotations. The CAP [reform of 2023-2027], on crop rotations, is going to be far from demanding [...] But unfortunately the choice of farmers is based on economic considerations, and so we end up with the smallest rotations possible. (Interview 12)

Research shows that redirecting and better monitoring the nearly €60 billion budget of the CAP (2015) could not only protect biodiversity by enabling lower pesticide use, but could also contribute to climate change mitigation and to reducing inequality in farm incomes (Scown, Brady, and Nicholas 2020). In winegrowing, for example, agri-environmental schemes have contributed to a decrease in the use of herbicides by 38 to 52 percent (Kuhfuss and Subervie 2018). Currently, less than one percent of public funding for the agri-food sector in France addresses pesticide reduction (Faraldo et al. 2021b). The 2023-2027 CAP reform has, meanwhile, been criticized by NGOs and scientists alike for not aiming at a systemic shift in agricultural production (Guyomard et al. 2023; Möhring et al. 2020; Pe'er et al. 2020). On the other hand, it gives member states greater discretion over the allocation of funds to support agri-environmental schemes, thereby opening possibilities for ambitious national action by member states. However, neither France's nor Germany's implementation plans for the current CAP embody structural reforms that could support low-input agriculture (Dahm 2022; Struna 2022).

Since increasing competitiveness is a central part of EU and member states' agricultural policy, interviewees and scientists highlight the need for both internal policy convergence within the EU due to the Common Market and adjustments in national trade policies (Guyomard et al. 2023; Interviews 2, 3). These would help prevent distortion of trade competition among member states and race-to-the-bottom effects due to differing environmental standards. According to one official: "One should not underestimate the fact that, on an intra-European scale, there are many competitiveness issues between Member States — even though we are all supposed to live [...] according to the same rules" (Interview 2). EU producers already face higher quality and hygiene standards than a majority of other competing trading nations (Interview 2). These competitiveness concerns are of particular importance for France and Germany, which are among the EU's top exporters of agricultural products to non-EU countries (Eurostat 2022). Glyphosate-dependent cereal and oilseed crops are among both countries' top exports by volume.

Institutional lock-in further limits the power of actors aiming to discontinue glyphosate use. The historical separations between institutions governing pesticide use through substance-based regulations and those governing agricultural policy are accompanied by strong power differentials, with agricultural ministries commanding significantly more power and financial resources than environmental ministries in both France and Germany (Interviews 9, 16, 20; Kinniburgh 2023). As one actor in a German state environmental ministry explained:

> We are affected by the whole pesticide debate even though we are not in control. The control lies more or less completely in the agricultural pillar and that means basically that they define the key concerns and interests. From a biodiversity point of view, one has to raise the argument, "oh look at the insects, look at the birds... look at the small-scale mammals which are possibly affected" — but this is all from [...] a perspective of representative of the victims. But we are not in a key function to decide the policy and define the use of pesticides. (Interview 16)

Similarly, representatives of the French Ministry of the Environment considered the CAP as a policy area which is politically "guarded" by the Ministry of Agriculture (Interview 9). In both countries, actors stressed personal disagreements between agricultural and environmental ministers. The glyphosate reauthorization vote in 2017 caused tension between German ministries because the agriculture minister at the time voted in favor of reauthorization without the agreement of the whole government, an unprecedented move in German politics (Interviews 7, 16, 21). Lobbying by the agrochemical and agricultural sectors was seen by many interviewees to significantly influence decisions by agricultural ministries at both the national and EU levels (Hüesker and Lepenies 2022; Interviews 4, 16, 17). This influence is generally manifested through political channels and is largely invisible (Interview 8).

5.3 Regulatory lock-ins

Several forms of regulatory lock-in limit the ability of regulatory institutions to ban glyphosate despite growing scientific evidence demonstrating previously unknown risks to both human health and biodiversity (Hendlin et al. 2020). Scientific analyses and interviewees alike point to significant deficiencies of EU pesticide regulation, notably regarding environmental impacts and the exclusion of systemic risks to biodiversity (Hendlin et al. 2020). Although the 2017 reauthorization of glyphosate stipulated that member states assess glyphosate risks to biodiversity in their approval processes, there are no risk assessment methodologies approved by EFSA to assess the indirect risks glyphosate poses to biodiversity at the trophic levels scientifically proven to be of concern, i.e. beyond its direct impact on weeds. According to a risk assessment expert at Germany's UBA:

> There are some risk areas that are quite well represented in the assessment schemes, such as the direct toxicological effects on mammals or aquatic organisms, [...]. But since the 1980s, we know that one of the most severe kinds of effects is those set on the application areas itself. 50 percent of the landscape, for instance, in Germany — but it's representative of the whole EU — is agricultural land and is treated in principle with plant protection products. And the assumption that you can bring poison to such a high percentage of the landscape without having severe effects on the ecosystem is wrong. This is known since the 1980s, but irrespective of that, there is no proper methodology available — or in place — for this kind of assessment. (Interview 21)

While many actors are working to improve these regulatory procedures, the regulatory "lock-in" effect is primarily due to a highly complex regulatory infrastructure which has been established through lengthy negotiation processes with various stakeholders at multiple levels of governance. This has self-reinforcing dynamics due to the involvement of legal, scientific, and economic institutions in the risk regulation process (Hüesker and Lepenies 2022). A second example of regulatory lock-in is the regulation of pesticides built around the authorization of single chemical substances, which omits any risks posed by the interactive and synergistic "cocktail" toxic effects of pesticides (Robinson et al. 2020). The focus of actors aiming to phase out glyphosate — namely a wide coalition of NGOs — on carcinogenicity reflects these lock-ins (Interview 8).

This regulatory environment allows powerful agrochemical actors to maintain a discursive and regulatory advantage based on the premise of scientific uncertainty. The lack of consensus regarding carcinogenicity does not reflect an absence of scientific evidence pointing to different carcinogenic effects, but rather differences in regulatory procedures among agencies which lead to the inclusion and exclusion of different kinds of knowledge (Interview 8; Bozzini 2020). The domination of industry in toxicological research and decreasing public funds for independent research results in the "weight of evidence" often tending in favor of the industry (Interview 8). This regulatory environment also has implications for the perceived legitimacy of phase-out measures vis-à-vis the agricultural sector, in which the legitimacy of a ban is centered around glyphosate's possible carcinogenicity (Interviews 6,7).

6) Phase-out policies and sectoral sustainability transitions

6.1 Command-and-control approaches

Policymakers in both France and Germany have adopted a primarily regulatory approach to substance phase-out for glyphosate, which was criticized by many interviewees in both countries. In France, the new restrictions are innovative within the EU pesticide regulatory environment, in that they restrict use based on the availability of alternatives; as such, they comprise only partial bans. For arable crops, for example, the reduction in allowed doses was calculated by regulators in coordination with the agricultural sector, with new restrictions representing approximately one fewer glyphosate application per cultivation period (Interview 13). As a result, while there may be some decrease in glyphosate usage, the government's 50 percent expected reduction is likely to be optimistic (Interview 9).[vii] Similarly, French interviewees both in the agricultural sector and within the Ministry of Agriculture were skeptical of the effectiveness of the tax credit intended to compensate farmers who buy equipment for mechanical weeding, due both to its temporary nature and to the identification of a lack of equipment as a main barrier to the adoption of alternative practices (Interviews 5, 6, 9). A technical institute representative considered that farmers' decisions not to plow were not the result of a lack of available machinery but of other factors, such as the size of the farm or agronomic conditions (Interview 5). In Germany, the current ban primarily targets nature reserves and FFH areas, which represent only a small percentage of Germany's agricultural land (Umweltinstitut Munchen 2021; Interview 21). Moreover, federal states have the authority to amend the obligations of the regulation (Interview 21). The German ban is moreover contingent on the EU-level decision. While the outcome of the vote is uncertain, many actors expressed doubts that a ban would pass and that even governments formerly in favor of a ban may instead advocate for stricter restrictions on use (Interview 3).

Significant changes to land-use governance and agricultural policy require long-term thinking. The need for longer time horizons for planning transitions in the agricultural sector aligns with analyses of governing transitions in the energy sector, in which developing "pathways" with short-term milestones is seen as critical to achieving longer-term goals (Rosenbloom 2017). Using scenarios to evaluate different pathways enables policymakers and agricultural experts to examine the compatibility of specific pesticide phase-outs (such as glyphosate) with the overall pesticide reduction goal of 50 percent, or with more ambitious action aiming for complete pesticide phase-out.

The concept of "pathways" is useful for contrasting different options for glyphosate phase-out. Pathway analysis is increasingly used for governing transitions in the energy sector to help identify different options for reaching specific objectives and to contrast the different impacts and tradeoffs of each, based on pre-defined criteria (Rosenbloom 2017; Waisman et al. 2019). An emerging literature in agricultural science similarly conceptualizes pathways or trajectories of changes in farmers' practices which can lead to specific goals (Chantre, Cerf, and Le Bail 2015). Based on this idea, I characterize three heuristic pathways for glyphosate phase-out for field crops: 1) the redesign of cropping and farming systems; 2) substitution-based measures; or 3) no policy-induced changes. Table 2 summarizes these pathways and their implications at the farm level (cropping systems and land use) and beyond (supply chains).

Table 2: Three pathways for glyphosate phase-out, illustrated for field crops. Source: Author.

Pathway	Cropping systems	Land use	Supply chains
1) Redesign of cropping & farming systems	• Diversified farming systems • Introduction of new crops into rotations including varieties requiring longer rotations	Shift towards use of land for larger variety of different crops	Downstream actors required to buy different crops
2) Substitution-based measures	• Substitution of glyphosate with mechanical weed control or alternative chemical herbicide • Domination of monocultures	No changes	No changes
3) No policy-induced changes	• Domination of monocultures	No changes	No changes

Pathways 1 and 2 are conceptualized as the result of a policy intervention, while Pathway 3 reflects a maintenance of the status quo. The notion of pathways also highlights path dependency. In pathway 2, farmers may become further locked-in to their current farming systems through new capital investments, such as for tractors, if farmers pursue mechanical alternatives (Chantre, Cerf, and Le Bail 2015). Such investments would suggest that farmers face additional barriers to adopting alternative pathways. Alternatively, substitution with other chemical herbicides would not catalyze further lock-in effects but could make the substitute chemical ubiquitous and catalyze biodiversity loss similar to glyphosate. Figure 3 shows the expected impacts of each pathway relative to five criteria: glyphosate use, other pesticide use (i.e. other herbicides, or fungicides and insecticides), biodiversity impacts, greenhouse gas (GHG) emissions, and crop yields. These criteria do not reflect concerns of all stakeholders, but are included for illustrative purposes and intend to highlight principally the environmental impacts of selected pathways, along with one major agronomic criterion (crop yield). As Figure 3 shows, there may be trade-offs between different goals, for example the environmental goals and crop yields (Pathway 1) or between decreasing pesticide use and other environmental goals (Pathway 2).

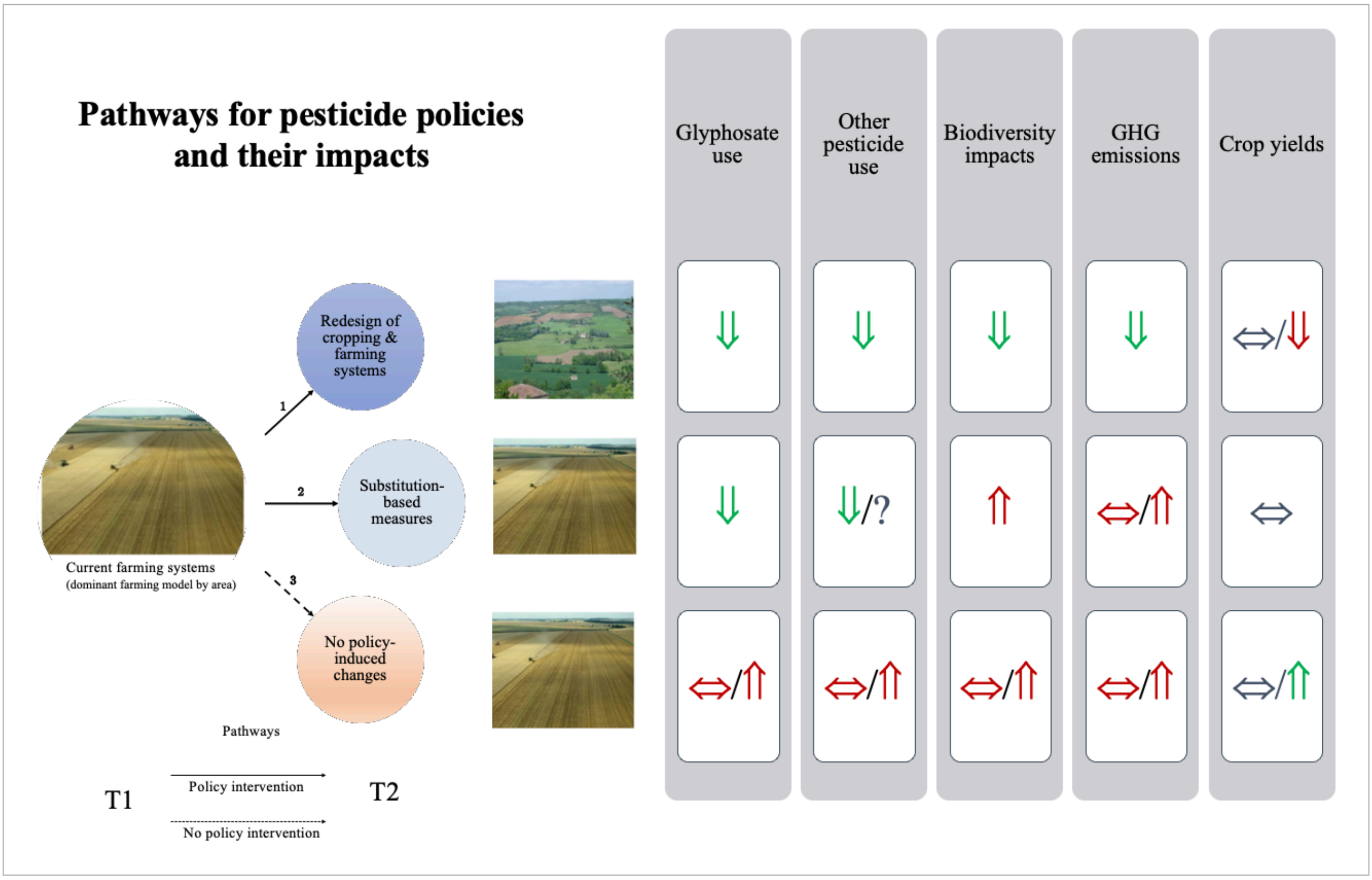

Figure 3: Expected impacts of three pathways for the future of glyphosate in France & Germany. Source: Author, based on interviews, Reboud et al. (2017), Butault et al. (2010) and Guyomard et al. (2020). Down arrows indicate a decrease in the indicator, up arrows indicate an increase, and side-to-side arrows indicate that the indicator will likely stay the same. Green is used to indicate changes which are judged desirable from the perspective of environmental benefits and maximizing agricultural production. T1 indicates the present time period; T2 indicates a future time period after which farmers may have changed certain practices.

Because scientific analyses have shown that substitution-based measures alone cannot enable a 50 percent overall pesticide reduction, phasing out glyphosate in an EU policy context focused on reducing overall pesticide use is fundamentally different from implementing past pesticide bans. Contrary to technology-focused approaches in which problematic pesticides can be substituted with less toxic ones, phasing out glyphosate and other chemical herbicides to reverse biodiversity loss necessitates changes in farming *systems* and agricultural land use towards crops with lower per-hectare pesticide use intensities. Even short-term, non-chemical alternatives are likely to comprise mechanical substitution strategies which do not fundamentally change land use patterns and may also run counter to some of the EU's broader environmental goals for the agricultural sector — such as preventing climate mitigation — through additional carbon emissions from tractors. Although farmers who switch to non-chemical alternatives in the short term may be able to redesign their farming systems in the longer-term, the short-term transition may require additional farm investments which further lock farmers into a monoculture-based, pesticide-intensive production system, hindering deeper transitions.

6.2 Alternative approaches: management and economic instruments

Conceptualizing pesticides as part of a larger sociotechnical system points to the necessity to switch from command-and-control towards other instruments to ensure the long-term effectiveness of policies with the goal of phasing out glyphosate. Such options include management and planning approaches and/or economic instruments.

Management and planning approaches themselves comprise a wide range of instruments, from phase-out timelines and associated targets to comprehensive plans which include measures to address the potential negative social, political, and economic effects of transitions on those affected (Trencher, Rinscheid, Rosenbloom, Koppenborg, et al. 2022). Policy and academic discussions on "transitional assistance policies" — currently mainly addressed in the context of decarbonization — may yield important insights for the agricultural sector (Green and Gambhir 2020). For example, transitional assistance policies are intended to address adversely affected stakeholders who may strongly oppose transitions; these range from consumers fearing higher prices to workers needing to change jobs. Policies can include both economic levers and/or aid of a non-financial nature, such as training for farmers (Green and Gambhir 2020).

In the case of glyphosate, a variety of economic compensation or transitional assistance instruments have been proposed to enable farmers to remain economically stable (Interviews, 2, 3, 4, 9, 16). NGOs and academic experts have proposed concrete changes to current national spending which would enable transitions away from intensive pesticide use, such as the devotion of significant portions of the 1st pillar CAP spending to payments for ecosystem services, changes to current agri-environmental schemes, and funding for local projects (Faraldo et al. 2021a). In France, agri-environmental compensation measures have been proposed by experts commissioned by the government to advise on pesticide policies since 2005 (Aubertot et al. 2005; Butault et al. 2010; CGEDD, IGAS, and CGAAER 2017). In Bavaria, compensation measures have been introduced for farmers implementing environmental measures as part of the "Save the Bees" referendum (Interview 16).

7) Conclusion

Due to the constitutive role of the state in subsidizing and shaping agricultural production, reforming public policies is critical to shifting the conditions of production which underly economic lock-in for farmers. Reforms to agricultural and trade policy are essential financial levers for destabilization and for addressing farmers' economic lock-in to enable a successful phase-out of glyphosate (as well as other herbicides) and to reduce overall pesticide use. The CAP in particular plays a critical role in incentivizing the use of specific technologies and upholding the incumbent regime. Although the 2023-2027 CAP reform does not sufficiently address environmental issues, member states have considerable spending discrepancy, for which they are required to develop CAP National Strategic Plans. Moreover, national financing instruments can also play a crucial role: in France, over half of agri-food financing is national, while 47 percent originates from the EU CAP budget (Faraldo et al. 2021a, 33).

Because systemic change is likely to take time, yet substances and technologies targeted by phase-outs require action in the short term, policy mixes are likely necessary for reconciling these needs (Kivimaa and Kern 2016). Current structural incentives for agricultural production prevent regulatory instruments *alone* from stimulating a glyphosate phase-out which would also enable overall decreases in pesticide use of 50 percent. Given the economic and political lock-ins facing pesticide use reduction, changing regime rules and reducing support for dominant regime technologies is critical to creating a new environment to disincentivize pesticides usage. Such changes to regime rules are a form of “deliberate destabilization” which intentionally weaken the incumbent regime to enable the expansion of alternatives (Frank and Schanz 2022; van Oers et al. 2021). Such attempts at destabilization require an integrated approach to agricultural and trade policies which centers sustainability and which could enable a restructuring of actor networks, institutions, and power relations throughout national and EU food systems.

Appendix A
List of interviews

Number	Institution	Description of instit	Date	Number of interviewees	Language
1	Vivea	Mutualized insurance fund for farmers' training	19.10.20	1	FR
2	French Ministry of Agriculture	Federal ministry	30.04.21	1	FR
3	INRAE	National research institute	28.04.21	1	FR
4	INRAE	National research institute	01.06.21	1	FR
5	Arvalis	Agricultural technical institute	27.10.21	1	FR
6	Terres Inovia	Agricultural technical institute	29.10.21	1	FR
7	Bayer	Pesticide manufacturer	29.04.21	1	EN
8	Pesticide Action Network UK	Non-governmental organization	23.04.21	1	EN
9	French Ministry of the Environment	Federal ministry	02.12.21	2	FR
10	French Ministry of Research	Federal ministry	03.12.21	1	FR
11	ANSES	Federal regulatory agency	14.12.21	1	FR
12	French Ministry of Agriculture	Federal ministry	16.12.21	1	FR
13	ITAB (Institut de l'agriculture et l'alimentation biologiques)	Agricultural technical institute	02.02.22	1	FR
14	Terrena	Farmers' cooperative	13.04.18	1	FR
15	Pesticide Action Network Germany	Non-governmental organization	04.21.2021	1	EN
16	Hessen Ministry for the Environment, Climate, Agriculture and Consumer Protection	State-level ministry	04.08.20	1	EN
17	Umweltinstitut München	Non-governmental organization	16.04.21	1	EN
18	Die Linke (Left Party)	German political party	04.07.18	1	DE
19	Die Grüne (Green Party)	German political party	06.06.18	1	EN
20	WWF Germany	Non-governmental organization	02.05.18	1	EN
21	Umweltbundesamt	Federal government agency	07.09.22	1	EN

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[i] It is noteworthy that glyphosate is not used on genetically modified organisms (GMOs) in France and Germany, where GMOs have been banned since 2015, while the cultivation of these crops is a main driver of its use in some of the world's largest glyphosate-using countries, such as Brazil and Argentina.

[ii] The EU vote to renew the authorization of glyphosate (which was initially set to expire December 15, 2022) has been pushed back due to a delay of EFSA's delivery of its report on the peer review of the glyphosate risk assessment which, as of December 2022, is expected in July 2023. Glyphosate's use authorization has been temporarily extended to December 15, 2023.

[iii] IARC's membership included 27 countries in 2022: its founding States, Germany, France, Italy, the United Kingdom, and the United States of America, along with Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, Hungary, India, Iran, Ireland, Japan, Morocco, Norway, the Netherlands, Qatar, Republic of Korea, Russian Federation, Spain, Sweden, and Switzerland.

[iv] The vote took place in the Standing Committee on Plants, Animals, Rood and Feed (SCOPAFF) of the European Commission.

[v] Outside of the agricultural sector, ANSES also restricted the use of glyphosate for forestry based on an evaluation of alternatives.

[vi] This announced ban date marks the expiry of glyphosate's current approval, as glyphosate products will not disappear from the market until a year after a potential EU ban.

[vii] One interlocutor considered it necessary "to display something optimistic" in light of heavy NGO and public scrutiny (Interview 9).

Book Chapter I

Transformative biodiversity governance in agricultural landscapes: taking stock of biodiversity policy integration and looking forward

Yves Zinngrebe, Fiona Kinniburgh, Marjanneke Vijge, Sabina Khan & Hens Runhaar

13

Transformative Biodiversity Governance in Agricultural Landscapes: Taking Stock of Biodiversity Policy Integration and Looking Forward

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13.1 Introduction

Agricultural land systems, covering about 40 percent of the world's ice-free terrestrial surface, are the single largest contributor to biodiversity loss worldwide (Chapin et al., 2000; IPBES, 2018a; 2019). Agricultural practices have been linked to staggering losses in critical ecosystems such as tropical forests and ecologically functional species such as pollinators, raising concerns of losing biodiversity as both an intrinsic global value and as a central pillar of food security and ecosystem functions (IPBES, 2016; Laurance et al. 2014; Ramankutty et al., 2018). Conserving biodiversity in this sector is crucial beyond this intrinsic value (see Chapter 2), since biodiversity in agricultural landscapes supports ecosystem services that sustain human well-being through provisioning services such as food production, regulating services including flood and climate control or stabilization, and supporting services such as pollination and soil fertility (IPBES, 2016; 2018b; 2019; Scherr and McNeely, 2008; Tscharntke et al., 2012). There are a wide range of approaches proven to enhance synergies and reduce conflicts between biodiversity, food production and livelihood objectives, such as agroecology, permaculture, organic agriculture, agroforestry and "nature-inclusive" agriculture (Bouwma et al., 2019; Chapin et al., 2000; Chappell and LaValle, 2011; Runhaar, 2017; Scherr and McNeely, 2008). Climate change, the projected rise in global food demand and changing diets are projected to further increase pressures on food systems and land use (FAO, 2017a). The challenge for transformational policies is to disincentivize unsustainable practices while incentivizing biodiversity-friendly food production approaches. While healthy diets (Chapter 5) and animal welfare (Chapter 9) are also fundamental components of future food systems, this chapter focuses on governance of agricultural land use.

Conserving and enhancing biodiversity in agriculture is central to some of the most prominent international environmental agreements and conventions. The Convention on Biological Diversity (CBD) aims to ensure sustainable management and biodiversity conservation (Aichi Target 7 of the 2011–2020 Strategic Plan) and keep resource extraction within sustainable limits (Aichi Target 4). The impending Post-2020 CBD Global Biodiversity Framework (GBF), which is expected to be approved in 2022, is also expected to reflect the importance of sustainable agriculture. The importance of agricultural

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biodiversity has been reconfirmed by the 2015 United Nations Sustainable Development Goals (SDGs), particularly SDG15 (Life on Land), SDG2 (Zero Hunger) and SDG8 (Sustainable Production and Consumption). In 2017, the UN Framework Convention on Climate Change also initiated a work stream aiming to promote sustainable agricultural systems (UNFCCC, 2017).

Within these international conventions, as well as in national-level governance frameworks, an increasingly important way to promote biodiversity conservation in agricultural landscapes is through the *mainstreaming* of biodiversity[1] into public and private governance of the agricultural sector, a strategy that was specifically advocated in the CBD's 2011–2020 Strategic Plan. This chapter analyzes the progress in mainstreaming biodiversity into public and private sector agricultural policies worldwide by employing the concept of *biodiversity policy integration* (BPI). BPI analyzes the consideration of biodiversity in all sectors and levels of policymaking and implementation, providing a conceptual approach to identify leverage points for transformative change. In this chapter, we analyze BPI in agricultural landscapes, which adds to the toolbox of the transformative biodiversity governance framework. We review available literature on BPI in agricultural policies in developed countries (with a focus on the European Union [EU]) and developing countries (with a focus on tropical countries). Recognizing the important role of nonstate actors in biodiversity governance, we also include private sector governance in our analysis, defined here as rules and standards developed and monitored by firms or nongovernmental organizations (Grabs et al., 2020).

This chapter proceeds as follows. We first provide an overview of trends and threats to biodiversity, highlighting the necessity to integrate biodiversity in the governance and management of agricultural landscapes (Section 13.2). We then introduce our analytical approach (BPI) and how it relates to the broader literature on environmental policy integration and mainstreaming (Section 13.3), before analyzing to what extent and how biodiversity is integrated into agricultural governance in developed and developing countries (Section 13.4). Based on these analyses, we discuss four central leverage points for transformative biodiversity governance in agricultural landscapes and reflect them with the analytical dimensions of this book (Section 13.5), before concluding with key lessons (Section 13.6).

13.2 Current Trends and Key Threats to Biodiversity

This section focuses on two principal mechanisms through which agriculture impacts biodiversity: land use change for agricultural expansion and management choices on agricultural land – that is, intensification, specialization and enlargement of farms (Ramankutty et al., 2018). After introducing these issues within the broader contemporary debate, we discuss central arguments for segregated ("land-sparing") versus integrated ("land-sharing") approaches.

[1] Article 6b of the Convention on Biological Diversity (CBD) requires parties to "Integrate, as far as possible and as appropriate, the conservation and sustainable use of *biological diversity* into relevant sectoral or cross-sectoral plans, programmes and policies" (my emphasis).

13.2.1 Land Use Change

Land use change for the production of feed, fuel, biofuels and livestock is one of the major drivers of biodiversity loss (IPBES, 2019; MEA, 2005). Between 2000 and 2010, 80 percent of deforestation worldwide was directly attributable to the agricultural sector (Hosonuma et al., 2012). Agriculture currently occupies 38 percent of the world's terrestrial land surface, with about 12 percent devoted to crops and about 25 percent to livestock rearing and grazing (Foley et al., 2011). Of the area used for cereal production, 31 percent is devoted to animal feed (Mottet et al., 2017). Although land clearing has slowed since the 1950s relative to the previous century in temperate latitudes, it has shifted to tropical highly biodiverse forests in Latin America, Southeast Asia and Africa (IPBES, 2019; Ramankutty et al., 2018). In addition to loss of ecosystems and their intrinsic value, deforestation of biodiverse, tropical forests reduces carbon sinks, which are important for mitigating climate change (Bunker et al., 2005; IPCC, 2014).

The causes of agricultural expansion into intact ecosystems differ by region. In Africa, subsistence and small-scale farming drives the majority of expansion and deforestation (IPBES, 2019; Seymour and Harris, 2019). In contrast, deforestation in South America (particularly in the Amazon) and Southeast Asia is primarily driven by commercial agriculture supplying international markets, most notably since the 1990s (Hosonuma et al., 2012; IPBES, 2019; Seymour and Harris, 2019). Though the majority of agricultural commodities are consumed domestically, global trade of a select few agricultural commodities – notably soybeans (of which the majority is used for animal feed globally), beef and palm oil – is a major external driver of ecosystem loss (DeFries et al., 2013; Green et al., 2019; Henders et al., 2015; Meyfroidt et al., 2013). As a prominent example, oil palm plantations supplying global markets have been responsible for over 80 percent of agricultural land expansion in South Asia since the 1990s (Gibbs et al., 2010). Countries that consume these commodities are thus contributing to ecosystem and biodiversity loss, as recognized in recent attempts to reduce "imported deforestation" (Bager et al., 2021). The long-term effects of land use change are often underestimated as – particularly in biodiversity-rich regions – species continue to be lost even if the agricultural land has been abandoned (Gibson et al., 2011).

13.2.2 Management Choices

Agriculture has undergone significant structural changes since the Second World War. New farming practices falling under the paradigm of "industrial agriculture" were strongly subsidized by governments, particularly in developed countries and in some developing countries, as part of the "Green Revolution." This "agricultural modernization" relied heavily on mechanization, genetic alterations of crops (e.g. hybridization, genetically modified organisms) and the use of chemical inputs to increase productivity (Bosc and Belières, 2015; Duru et al., 2015). Three overarching and interrelated trends can be distinguished: intensification, specialization and scale enlargement (Aubert et al., 2019; Poux and Aubert, 2018).

Intensification refers to increasing productivity on a given parcel of land through the heavy use of inputs (such as pesticides and fertilizers). Though this may increase profits, and in some cases also food security, it generally drives biodiversity loss as it is currently practiced (Batáry et al., 2017; Hendershot et al., 2020; Rasmussen et al., 2018). Studies point to the detrimental impacts on biodiversity in general, and on soil biodiversity and insects in particular, especially through mechanization and pesticide use (see, for example, Orgiazzi et al., 2016; Sanchez-Bayo and Wyckhuys, 2019; Seibold et al., 2019; Tsiafouli et al., 2015). Globally, pesticide sales and use continue to increase, with hundreds of older generation pesticides that are highly toxic to vertebrates and invertebrates still being used in developing countries, although banned in many developed countries (Schreinemachers and Tipraqsa, 2012). Through run-off, pesticides and fertilizers also have biodiversity impacts reaching far beyond the farm (Beketov et al., 2013; Van Dijk et al., 2013; Yamamuro et al., 2019). Solutions related to increasing efficiency, such as precision agriculture, can contribute to sustainability and food security through the reduction of inputs (IPCC, 2019). However, recent work shows that implementation remains a problem (Lindblom et al., 2017). Moreover, such solutions do not address many of the underlying problems of conventional intensification, including the need for energy-intensive inputs (Kremen, 2015).

Secondly, *specialization* describes a shift away from diversified crop production to monocultures and a separation of crops and livestock systems. At the macro level, specialization is driven by the logic of economies of scale and the creation of regional or national comparative advantages in trade (Abson, 2019). As a prominent example, Brazil has developed a significant comparative advantage in soybean production by using soybeans as a "flex crop" with multiple processing pathways that differentiate the product into a food grain, livestock feed or fuel (Oliveira, 2016). However, these regional advantages come at a cost – extreme specialization of food and agriculture is a major driver of the decline in biodiversity at genetic, species and ecosystem levels (FAO, 2019; IPBES, 2019). While agronomic research and technical expertise have focused on the production of a few key staple crops (wheat, corn and rice initially, now followed by oilseeds, e.g. soybeans and rapeseed), technical knowledge on other crops remains low (FAO, 2019; Magrini et al., 2016). Furthermore, specialization conflicts with the idea of multifunctional production and its potential for contributing to food security (Bommarco et al., 2018; Misselhorn et al., 2012), climate-smart landscapes (Scherr et al., 2012) and viable farming income, despite potential trade-offs in efficiency (Lakner et al., 2018).

Lastly, *scale* enlargement entails a trend toward fewer but larger farms. Although there is still a wide variety of farm types and sizes around the world, a productivist ideology has led farms to increase in size overall in order to benefit from economies of scale, which enables cost reductions and helps farmers remain competitive (Duffy, 2009). This strategy is capital- and input-intensive, requiring high investments in machinery and chemical inputs that are only considered worthwhile if farm output is high, lowering costs per unit of production (McIntyre et al., 2009). Concentration across the agri-food industry, and the resulting control exerted by a small number of companies on farmers, has further encouraged a consolidation and enlargement trend (Folke et al., 2019; IPES-Food, 2017). Scale enlargement contributes to biodiversity loss principally through the destruction of semi-natural landscape features, such as hedges, field margins and permanent prairies, which maintain heterogeneity and connectivity of habitats at the landscape level (Poux and Aubert, 2018; Tscharntke et al., 2012).

13.2.3 Land-Sharing and Land-Sparing in a Telecoupled World

For many decades, the dominant global discourse on food security has resulted in the notion that there is direct competition for land between biodiversity conservation and agricultural production and that the two are incompatible (Butler et al., 2007; Henle et al., 2008; Steffan-Dewenter et al., 2007; Tscharntke et al., 2012). This has led to a simplified framing in which "land-sparing" (segregating intensive agriculture from conservation lands) and "land-sharing" (more extensive agriculture that contributes to conservation) are viewed as a dichotomy, though neither of them singularly has the full potential to address the challenge of sustainable agriculture (Kremen, 2015). Instead, we argue that a combined approach of both large, protected regions *and* wildlife-friendly farming areas is critical to conserving biodiversity (Kremen, 2015; Kremen and Merenlender, 2018).

The land-sparing logic argues that effective biodiversity conservation on nonagricultural land (see Chapter 11) depends on the separation of agricultural land from protected areas, necessitating the intensification of production on agricultural land to "free up" land for conservation. However, since the effectiveness of protected areas correlates with the pressures from its surroundings (Kremen and Merenlender, 2018; Watson et al., 2014), conservation in these designated areas will still depend on the management of external or internal pressures. Therefore, the idea of completely separating the interactions between biodiversity conservation and agricultural production areas is conceptually flawed, as landscape structures are shaped by cultural dynamics and human–nature interactions, as well as geographical and climate conditions, making ecological and productive systems mutually interdependent (Fischer et al., 2011; 2014). In addition to localized detrimental impacts of intensive farming, the land-sparing approach can also have far-reaching impacts on biodiversity: Land-sparing in one area can have spill-over effects that drive relocation and expansion of production in other regions, rather than leading to an overall reduction of biodiversity threats (Meyfroidt, 2018; Meyfroidt et al., 2013; Rudel et al., 2009). Even in regions where the extension of agricultural land use remains relatively constant (such as within the EU), the "imported land" needed to satisfy consumer demand continues to grow (Asici and Acar, 2016, Teixidó-Figueras and Duro, 2014; Yu et al., 2013). This shows that consumption decisions and agricultural management in a globalizing world are "telecoupled" (Friies et al. 2016; Sun et al., 2017). Therefore, while protected areas remain crucial to maintaining biodiversity, the land-sparing approach requires policy integration.

In contrast, land-sharing recognizes agriculture as "both the greatest cause of biodiversity loss *and the greatest opportunity for conservation*" (Hendershot et al, 2020: 393, emphasis added). Land-sharing approaches recognize the need and potential for agricultural land to help protect biodiversity through a range of practices, as agricultural expansion and its (inadequate) management drive biodiversity loss. While this is a good idea in theory, the above-described trajectories show that land conversion and management choices continue to invade important ecosystems and fail to produce sound ecological structures. At the same time, the separation of sufficiently large areas seems necessary for the conservation of certain ecosystem values and habitats (Kremen and Merenlender, 2018; Watson et al., 2014).

Hence, while a conceptual separation of land-sparing and land-sharing can help to identify socio-ecological trade-offs, it has largely failed in identifying solutions for addressing them (Fischer et al., 2014). We argue that in transformative biodiversity governance, area-based (land-sparing) *and* integrated (land-sharing) approaches offer a complementary toolkit to address direct and indirect drivers of biodiversity loss in agricultural landscapes, and that biodiversity policy integration is crucial in both of these approaches.

13.3 Conceptual Framework for Biodiversity Policy Integration

Biodiversity policy integration (BPI) is an analytical tool derived from the broader literature of environmental policy integration (EPI) (Zinngrebe, 2018). EPI can be defined as "the incorporation of environmental objectives in non-environmental policy sectors such as agriculture, energy and transport" and can be considered transformative because of its "aim to target the underlying driving forces, rather than merely symptoms, of environmental degradation" (Persson et al., 2018: 113). Governance elements and processes that support EPI have been widely studied, particularly in European and OECD countries (see e.g. Jordan and Lenschow, 2010; OECD, 2018; Persson et al., 2018; Runhaar, 2016; Runhaar et al., 2014; 2018; 2020, Visseren-Hamakers, 2015). This literature shows that no single instrument can realize policy integration, but rather, EPI needs a suite of complementary instruments and mechanisms (Persson and Runhaar, 2018; Runhaar et al., 2020).

In this chapter, we use BPI as an analytical tool deriving from EPI literature, with a focus on biodiversity (Zinngrebe, 2018). To date, empirical analyses of policy integration between agriculture and biodiversity are scarce. A Web of Science search for the terms "agriculture" AND "policy integration" AND "biodiversity" resulted in six articles, all of which are included in the analysis in this chapter (Karlsson-Vinkhuyzen et al., 2017; 2018; Söderberg and Eckerberg, 2013; Somorin et al., 2016; Zinngrebe, 2018, Zinngrebe et al., 2017). Other combinations of search terms were also explored: "biodiversity" OR "mainstreaming biodiversity" AND "production landscapes," "agricultural policy," "coherence," "inclusion," "social capital" and "capacity." These also returned few hits of direct relevance that included concrete examples. Redford et al. (2015) note that publications by practitioners involved in public and private biodiversity mainstreaming programs and projects are severely deficient in the peer-reviewed literature, particularly those focused on developing countries. Therefore, to capture relevant gray literature, we also applied the following Google searches. "mainstreaming biodiversity" AND "production landscapes" (yields sixty-seven results) and "mainstreaming biodiversity" AND "agricultural policy" (yields ninety results). Titles and abstracts were screened to select relevant publications.

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In order to analyze the extent to which biodiversity considerations have been incorporated in agricultural policies, we distinguish five dimensions of BPI (see Figure 13.1) (Zinngrebe et al., 2018; for similar approaches see Kivimaa and Mickwitz, 2006 and Uittenbroek et al., 2013):

1. ***Inclusion*****:** the extent to which the objective of biodiversity conservation is included in political sectors. This is measured by the extent to which a sector has reframed a biodiversity objective into sector-specific targets and specific biodiversity indicators.
2. ***Operationalization*****:** the extent to which a sector has adopted or adjusted policy instruments and monitoring and enforcement mechanisms to implement biodiversity objectives (see also Runhaar, 2016), and the uptake of biodiversity values in internal evaluation processes.
3. ***Coherence*****:** the extent to which objectives and policy instruments within a sector complement rather than contradict each other. This is measured by the extent to which policies within a sector are internally consistent and direct sector activities toward biodiversity objectives.
4. ***Capacity*****:** the level of institutional development, available resources and political mechanisms that ensure the implementation of instruments identified in the "operationalization" dimension, as well as the extent to which other actors are supported by their organization ("social capital") (Zinngrebe et al., 2020).
5. ***Weighting*****:** the importance given to biodiversity objectives in relation to other political objectives. Weighting further analyzes whether biodiversity, as natural capital, is regarded as substitutable by other forms of capital and whether ecological limits are recognized.

In the next section, we use this analytical framework to analyze the current state of BPI in agricultural governance along the five dimensions. However, we note that while the BPI framework assesses the level of integration at a specific point in time, transformative governance is adaptive, requiring dynamic policy design and institutional reconfigurations to iteratively improve BPI performance. In Section 5, we draw on our BPI analysis to reflect on enabling factors and barriers and discuss them in relation to the transformative governance analytical framework of this book.

13.4 Taking Stock: Assessing the Level of Biodiversity Policy Integration in Agricultural Governance

13.4.1 Inclusion

In many developing countries with available studies, biodiversity is not an explicit target in agricultural policies (Zinngrebe, 2018; Zinngrebe et al., 2020). While most Parties to the CBD identify the need for both ex-situ and in-situ biodiversity conservation, only 3 percent have mainstreamed biodiversity in their agricultural policies, plans and programs (Lapena et al., 2016). Among the exceptions is Kenya, where the Ministry of Agriculture in Busia County has set a performance target for establishing a biodiversity policy (Hunter et al.,

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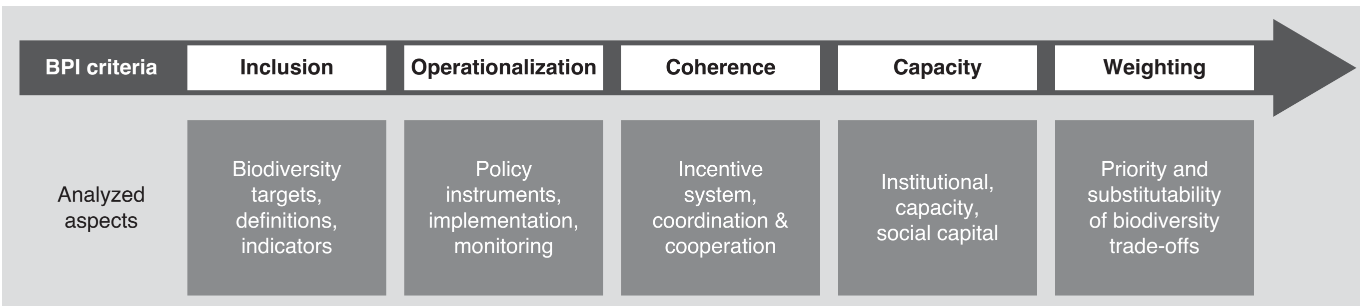

Figure 13.1 Five dimensions of biodiversity policy integration (reprinted from Zinngrebe, 2018).

2018). Similarly, Costa Rica has a biodiversity law setting general standards (although in rather generic terms) to also be considered in agricultural landscapes, which has been regarded as "one of the most comprehensive efforts to implement . . . the Convention on Biological Diversity" (Miller, 2006: 359). Despite few government-led policy initiatives to advance BPI in developing countries, international organizations have been active in pushing for integrated instruments and planning procedures, which we include in the following sections.

In the EU, various policies have aimed to integrate biodiversity objectives into the agricultural sector to differing degrees. Most recently, the European Green Deal includes a "Farm to Fork" strategy that explicitly aims to reverse biodiversity loss by aiming for a "neutral or positive impact" within agri-food systems (EC, 2019; 2020a). As an additional element, the EU Biodiversity Strategy for 2030 includes area-based targets aimed at protecting 30 percent of its terrestrial area, with "at least 10 percent of utilized agricultural area under high diversity landscapes," and a life-cycle assessment assuming responsibility for outsourced environmental impacts as well as a reduction of the overall EU's global footprint (EC, 2020b, section 2.2.2). The key legal instruments underpinning the EU's conservation policies date back several decades: the Birds and Habitats Directives established the Natura 2000 network, which covers almost 18 percent of the EU's terrestrial surface area (Bouwma et al., 2019). Almost 90 percent of all Natura 2000 sites are subject to agriculture or forestry activities, making BPI highly relevant (Tsiafouli et al., 2013). The Habitats and Birds Directives do not, however, include targets or indicators related to land use systems or ecosystem services. Instead, they have the objective of maintaining healthy habitats for selected species (Bouwma et al., 2019). Similarly, the European Common Agricultural Policy (CAP) speaks more generally of "sustainable management of natural resources and climate action" in the 2013–2020 period and uses a farmland bird index and High Nature Value farmland index as proxies for biodiversity (EC, 2013). Since 2018, a proposal by the European Commission that includes a strategic objective on the protection of biodiversity, enhancement of ecosystem services and preservation of habitats and landscapes (Target F, EC, 2018) has been negotiated by EU institutions. While this proposal takes a comprehensive approach to envisioning sustainability in agriculture, the proposed indicators target farm management and land use in general and have been assessed as insufficient for monitoring biodiversity (Pe'er et al., 2020).

Overall, countries face challenges in translating international biodiversity targets into nationally determined targets (Chandra and Idrisova, 2011; Velázquez Gomar, 2014). In an analysis of 144 national biodiversity strategies and action plans (NBSAPs) developed by countries that signed the CBD, 72 percent of developing countries and 58 percent of developed countries acknowledge agriculture explicitly as a threat to biodiversity conservation (Whitehorn et al., 2019). Despite this, only 23 percent of the developing and 33 percent of the developed countries address the question of trade-offs between agriculture and conservation (Whitehorn et al., 2019). More tellingly, almost no national agricultural plan cross-references the countries' NBSAPs (Pe'er et al., 2019; Zinngrebe, 2018). This means that although these NBSAPs may be well developed by environmental ministries and include agriculture-related targets, these goals do not reach the actors they need to engage, such as agricultural ministries and the network of actors in the agricultural sector. In some agricultural policies, the need for considering "sustainability," the "environment" or certain land use practices are mentioned, but without linking it to specific ecological criteria or policy instruments (Zinngrebe, 2018).

13.4.2 Operationalization

The operationalization of biodiversity-related objectives into policies differs strongly between developing and developed countries. In many developing countries, operationalization of policy instruments is poorly executed (e.g. Carew-Reid, 2002; Huntley, 2014); regulatory frameworks are weak, poorly implemented or nonexistent (Huntley, 2014) and some countries have started to develop their environmental governance framework only in the past decade (e.g. Vijge, 2018). Nevertheless, some advancement in operationalization is visible, particularly in Latin America, including Costa Rica, Mexico, South Africa, Australia and Brazil (Harvey et al., 2008; Huntley, 2014; Somarriba et al., 2012).

Costa Rica made significant advancements in the institutionalization of payment for ecosystem services schemes, aimed at enhancing forest biodiversity on agricultural land (Sanchez-Azofeifa et al., 2007). However, these payment schemes are regarded as insufficiently funded in the long-term and to complement but not substitute regulatory interventions by governments (Schomers and Matzdorf, 2013; Wunder et al., 2008). In South Africa, the national Biodiversity Act sets bioregional plans, biodiversity assessments and biodiversity action plans as legal instruments for BPI operationalization at the regional spatial scale (Botts et al., 2020). Additionally, "conservation farming" is supported by stringent regulation, involvement of nongovernmental organizations and farmer communities, effective communication with farmers and scientific and technical support for farmers (Donaldson, 2012). In Brazil, operationalization focuses on specific tools such as national plans promoting agroecology and organic production (Biodiversity International 2016), an "agrobiodiversity index" assessing private sector performance (Tutwiler et al., 2017) and a national school food program mandating 30 percent of federal funds toward procurement from family farms using agroecological production approaches (Johns et al., 2013).

In the private sector, producers and companies have started responding to the demand for deforestation-free commodities. Initiatives such as the Consumer Goods Forum, Tropical Forest Alliance, the New York Declaration on Forests, the Amsterdam Declaration Partnership, various beef and soy moratoriums and voluntary commitments under the Business for Nature coalition are, however, nonbinding and coexist with nonsustainable policies (Stabile et al., 2020).

In Europe, the main biodiversity-related instruments of the 2014–2020 CAP are direct subsidies to farmers conditioned on fulfilling "greening" obligations (Ecological Focus Areas) and cross compliance, as well as voluntary agri-environmental and climate measures (AECMs). These specific "deep green measures" have been found to produce strong local impacts (Batáry et al., 2015; Pe'er et al., 2017). However, the weak performance of "greening" (Pe'er et al., 2016) and the low allocation of funding to AECMs are central arguments for identifying the CAP's toolbox as weak "green architecture" (Pe'er et al., 2019). The new Post-2020 CAP proposal will continue to link direct payments to weak, unspecific targets (similar to cross compliance), while allowing for EU member states to use voluntary "eco-schemes" to support specific landscape features (Pe'er et al., 2020). Simultaneously, area-based instruments linked to the EU Birds and Habitats Directives are being used. However, evaluations of Natura 2000 indicate that only about a third of the sites have developed specific management plans for biodiversity conservation and only 4 percent show an improvement of habitats (Bouwma et al., 2019; EEA, 2015). Literature suggests that effective implementation of Natura 2000 sites depends on a joint implementation with policies such as agri-environmental measures (Bouwma et al., 2019; Lakner et al., 2020).

13.4.3 Coherence

Even in cases where conservation is included as one of the targets in agricultural policies, and when policies have been appropriately reconfigured to achieve those targets, they may still run counter to specific biodiversity conservation policies in the environmental sector. Often, decisions about trade-offs between productivity and conservation are avoided or not explicitly addressed, and a patchwork of incoherent policies result in a lack of incentives for biodiversity-friendly farming.

One barrier to coherent agri-environmental policies is a lack of horizontal coherence, notably, a lack of coordination between ministries and agencies at the national level. Insights from Indonesia, Uganda, Peru and Honduras show that while different regulatory processes for agricultural landscapes exist for the governmental sphere and for sustainability markets in the private sector, they are incoherent and generally favor conventional practices, rather than biodiversity-sound management systems such as agroforestry (Zinngrebe et al., 2020). Even in Costa Rica, which has relatively strong environmental laws and regulations, incoherent policies have been reported (Brockett and Gottfried, 2002; Lansing, 2014). One general issue is that ministries of finance and planning – which generally hold decision-making power on large-scale investment allocations – are often not in regular consultation with the ministries responsible for biodiversity governance (Swiderska, 2002).

Besides a lack of horizontal coherence (i.e. between sectoral policies at one level of governance) there is also often a lack of vertical coherence (i.e. between national and subnational biodiversity strategies). Vertical coherence is especially pertinent in developing countries, since many are in the process of decentralizing their governance systems (Carew-Reid, 2002; Hunter et al., 2016; Swiderska, 2002). The few existing studies indicate that vertical integration across political levels for the implementation, enforcement and monitoring of biodiversity conservation in agricultural landscapes is generally low (e.g. Zinngrebe, 2018). Nevertheless, the example of local stakeholder networks in Ethiopia illustrated that despite low coherence at the national level, local collaboration can lead to coherent management approaches (Jiren et al., 2018). In Rwanda, the successes of watershed management plans in enabling dialogue and policy coordination across ministries of agriculture, fisheries and rural and social development at both local and national levels are another promising exception (FAO, 2017b). Based on selected case studies from countries within Africa and Latin America, the FAO (2017b) highlights that management models that take an ecosystem-based approach can serve as a lever for coordination, integration and synergies, though this has not been sufficiently applied to improve coherence. In South Africa for instance, bioregional plans enhance both coherence in local land use planning and across core sectoral strategies at the national level (Botts et al., 2020). Deliberations in trade-off options between conservation and other goals is part of the planning process for this purpose (Redford et al., 2015). The international Biodiversity for Food and Nutrition Project, funded by the Global Environment Facility, shows how, in Brazil, Kenya, Turkey and Sri Lanka, a sound evidence-base on how biodiversity supports nutritional outcomes, and the establishment of multistakeholder and multisectoral steering committees, improves coherence across agriculture and food policies (Beltrame et al., 2016; 2019).

The EU is a strong advocate of policy coherence across sectors, as acknowledged in a large number of official EU documents. However, while most EU policies are coherent at the level of objectives, they provide incoherent incentives at the implementation stage, and therefore have not managed to effectively or efficiently reverse declining biodiversity trends (Pe'er et al., 2017). For example, while the EU Birds and Habitats Directives aim to conserve biodiversity, the CAP's fundamental targets, defined by the Treaty of Rome in 1957, direct agricultural policy toward increased productivity, low food prices and supporting farmers' incomes. Another example of incoherence in the CAP is the aforementioned Ecological Focus Areas, which obligates each farm of more than fifteen hectares to dedicate 5 percent of its land to conservation activities. In reality, this instrument primarily results in measures with a low contribution to biodiversity, such as catch crops and nitrogen-fixing crops (Cole et al., 2020; Pe'er et al., 2017). Watering down ecological standards in federal implementation processes, as well as misconceptions about farmers' motivations to engage in biodiversity conservation, reduce the CAP's potential to contribute to conservation (Brown et al., 2020). In the EU proposal for a post-2020 CAP (EC, 2018), direct payments will continue to dominate and low ecological targets continue to persist (Pe'er et al., 2020). Overall, studies show that despite the EU's rhetoric for policy coherence, large inconsistencies in the instruments and implementation of EU policies remain (De Schutter et al., 2020; Nilsson et al., 2012).

Within the EU, there are also strong calls for enhancing coherence of EU policies with non-aid policies that impact developing countries. These calls have grown since the 1990s, when Europe's need for agricultural biodiversity and production land substantially increased and was therefore transferred to other parts of the world. This policy blind-spot results in the EU's contribution to tropical deforestation and biodiversity loss in developing countries (Fuchs et al., 2020). However, while the EU and member states such as Denmark, the Netherlands, Sweden and the UK (which was an EU member at the time of analysis) have tested approaches for policy coherence for development, implementation performance has been weak (Carbone, 2008; see also Pendrill et al., 2019). Civil society actors have

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created a proposal to streamline EU policies into a "Common Food Policy" for Europe (De Schutter et al., 2020; IPES-Food, 2019). Blueprints describe an integrated food policy framework that promotes healthy diets and sustainable food systems through coherence across policy areas and governance levels, including by aiming to relocalize food production and to reduce dependence on global food imports (De Schutter et al., 2020; IPES-Food, 2019). It remains to be seen to what extent the integrated approach of the European Green Deal, and its "Farm to Fork" strategy, can translate such suggestions into practice.

13.4.4 Capacity

While there is generally higher institutional capacity in developed countries relative to developing countries, the aforementioned division between the institutional processes of the environmental and agricultural sectors undermines social capital for BPI in most countries.

In developing countries, the capacities to develop biodiversity (and other environmental) policies are limited to environmental ministries or departments. In Indonesia, Uganda, Honduras and Peru, social capital and capacities for training, financial support and regulation exist, but are not targeted at ecologically sound forms of production (Zinngrebe et al., 2020). The availability of institutional capacities is further undermined by unclear mandates between government agencies, high turnover among government officials resulting in discontinuous policy formulation and execution, and a lack of experienced biodiversity research institutions or centers of excellence (Zinngrebe, 2018; Zinngrebe et al. 2020). In the public policy arena, there is a lack of knowledge on and awareness of the linkages between biodiversity and agriculture or food security (Beltrame et al., 2016; Chandra and Idrisova, 2011). This is largely due to lack of training, funding, incentives for experts to work in the environmental field (Chandra and Idrisova, 2011), biodiversity-focused science–policy interfaces, and institutionalized mechanisms for the participation of Indigenous Peoples and local communities (which hold critical local ecological knowledge) in monitoring, reporting and verification initiatives (Vanhove et al., 2017). Mexico tackles these issues via multistakeholder roundtables, consisting of agricultural, rural development and research agencies, Secretaries of States, academia, NGOs and private actors, which coordinate sector activities, financing and science-policy mechanisms at the national and state level (Tutwiler et al., 2017). In Uganda, the agricultural ministry, under the direction of the Ministry of Finance, Planning and Economic Development, has to allocate a portion of their budget to conservation activities (IIED, UNEP-WCMC, 2015). Their staff receive training and a dedicated conservation expert from the environmental ministry to help prepare plans, while policy actors use learning lessons from the ground to inform the national macroeconomic framework (IIED, UNEP-WCMC, 2015). In South Africa, implementation of the Biodiversity Act is supported by pilot projects, regular monitoring and a national science-policy institute and multiagency committees, which align partnerships and cofinancing (Botts et al., 2020).

Within the EU, implementation of agricultural and biodiversity policies is supported by institutions at the European, national and subnational levels. However, lack and variance of capacity among different members states has also been identified as a barrier to implementation of agricultural policy proposals that contribute to environmental protection (Erjavec et al., 2018). Political decision-making and implementation processes of theoretically synergistic policies are designed and implemented by separated policy regimes (Pe'er et al., 2020), undermining social capital and potential synergies. Capacity problems are further enhanced by budgetary imbalances between agricultural and environmental instruments. Although the CAP is the EU policy with the highest budget (€58.4 billion in 2020), the majority of this is dedicated to direct income support. As a result, most of the budget in the 2015–2020 CAP (approximately €40 billion in 2017) was spent on direct payments that support land-intensive and biodiversity-threatening forms of farming, such as intensive animal breeding and monocultures (Pe'er et al., 2019). Furthermore, though Natura 2000 has demonstrated improvements in biodiversity within agricultural areas, funding per hectare is considerably lower than for greening or agri-environment climate measures (Pe'er et al. 2017), hardly compensating farmers for resulting costs from forgone incomes due to management restrictions and lower rents, and thus not providing sufficient incentive for adoption by farmers (Bouwma et al., 2019). Additionally, contradictory technical advice by agricultural extension services and administrative hurdles have hampered effective implementation of biodiversity measures (Zinngrebe et al., 2017).

13.4.5 Weighting

Even where biodiversity policy objectives are present and have been operationalized through concrete instruments with allocated capacity, political discourses are dominated by productivist narratives. The political framing in which food production must increase above all else provides little incentive to phase out agricultural subsidies that support the dominant model but are harmful to biodiversity (Bouwma et al., 2019; Fouilleux et al., 2017; Roche and Argent, 2015). In 2015, OECD countries provided $100 billion in direct and indirect subsidies that stimulated intensive agricultural production (OECD, 2019: 73). Although certification and other schemes are partly driving growth in organic and sustainable practices, the overwhelming policy bias and dominance of conventional agricultural methods gives these practices limited scope for truly scaling-up (Aubert et al., 2018).

In developing countries, both policies and politics also prioritize agricultural intensification and expansion (Wilson and Rigg, 2003; Zinngrebe et al., 2020). Biodiversity narratives in Peru show that even conservationists do not dare to talk about limits to production carrying-capacity. Adverse impacts on ecological functionality and related pollution and water-management issues remain untargeted key drivers for biodiversity loss (Zinngrebe, 2016a; 2016b). Another example is China, where, though the Law of Agriculture provides for wetlands conservation, the priority is placed on the draining and cultivation of wetlands for food security, resulting in lower priority and trade-offs for biodiversity (Ongley et al., 2010). Despite successful instruments for supporting agrobiodiversity and integrated natural resource management, agricultural expansion and intensification dominates decision-making considerations (Laurance et al., 2014).

Similarly, in the EU, the political discourse and resulting policies are oriented toward increasing productivity for human nutrition (Erjavec et al., 2009; Freibauer et al., 2011; IPES-Food, 2019). Despite the emergence of new discourse elements targeting multi-functionality and liberal markets, central policy elements support productivity (Alons and Zwaan, 2016; Erjavec and Erjavec, 2015). Following this policy design, even the implementation of conservation mechanisms, such as Ecological Focus Areas, is biased toward measures supporting increased productivity of agricultural lands (e.g. cash crops and nitrogen-fixing crops) (Pe'er et al., 2016). This is one of the stated reasons for why the CAP has not managed to reverse biodiversity loss (Pe'er et al., 2017). Some argue that the CAP is also not likely to do so in the near future, considering the content of current proposals for a post-2020 CAP (Pe'er et al., 2019). This strongly conflicts with the European Green Deal, which explicitly aims to halt biodiversity loss due to agriculture (EC, 2019).

13.5 Looking Forward: Toward Transformative Biodiversity Governance in Agricultural Landscapes

The previous section highlighted the overall very modest advances of BPI in agricultural landscapes. Given that the majority of global and national biodiversity targets are vague and the agricultural sector is not held accountable for its biodiversity performance, there is little guidance for investments in operationalization and capacity-building. Likewise, biodiversity policies are mostly "added on" to regulations of agricultural landscapes, receiving a low share of support compared to that for conventional farming systems focused on productivity. Given the significant agri-food system lock-ins and incumbent power dynamics, more effective BPI will not be implemented spontaneously – rather, the required shifts will need leadership at various levels (Oliver et al., 2018; Runhaar et al., 2020). We argue that *political will* is required as a key driving force to overcome lock-ins and improve BPI performance (see Figure 13.2). In the following paragraphs, we present four central leverage points specifying the dimensions for the transformation of biodiversity governance for agricultural landscapes.

A first transformative factor is the creation of a coherent *sustainability vision based on inclusive biodiversity governance*, which will guide implementation and induce accountability among implementing agents. As we showed in the previous section, the BPI dimensions of *inclusion* and *coherence* suffer from a lack of clear orientation, and the *weighting* is geared toward specific production-oriented interests. Decisions on agricultural policy are often dominated by small but well-organized interest groups that marginalize values of biodiversity conservation and downplay societal mandates such as the biodiversity targets under the CBD (Brown et al., 2020, Pe'er et al., 2019). Stakeholder groups differ in the way they envision appropriate use of land and nature, leading to different, often disconnected, discourses that are not equally reflected in policy design and implementation processes (Velázquez Gomar, 2014; Zinngrebe, 2016a). Questions of accountability and legitimacy of planning will depend on the extent to which potentially conflicting values are acknowledged and diverse value systems and perceptions are reflected in democratic planning and participatory implementation processes

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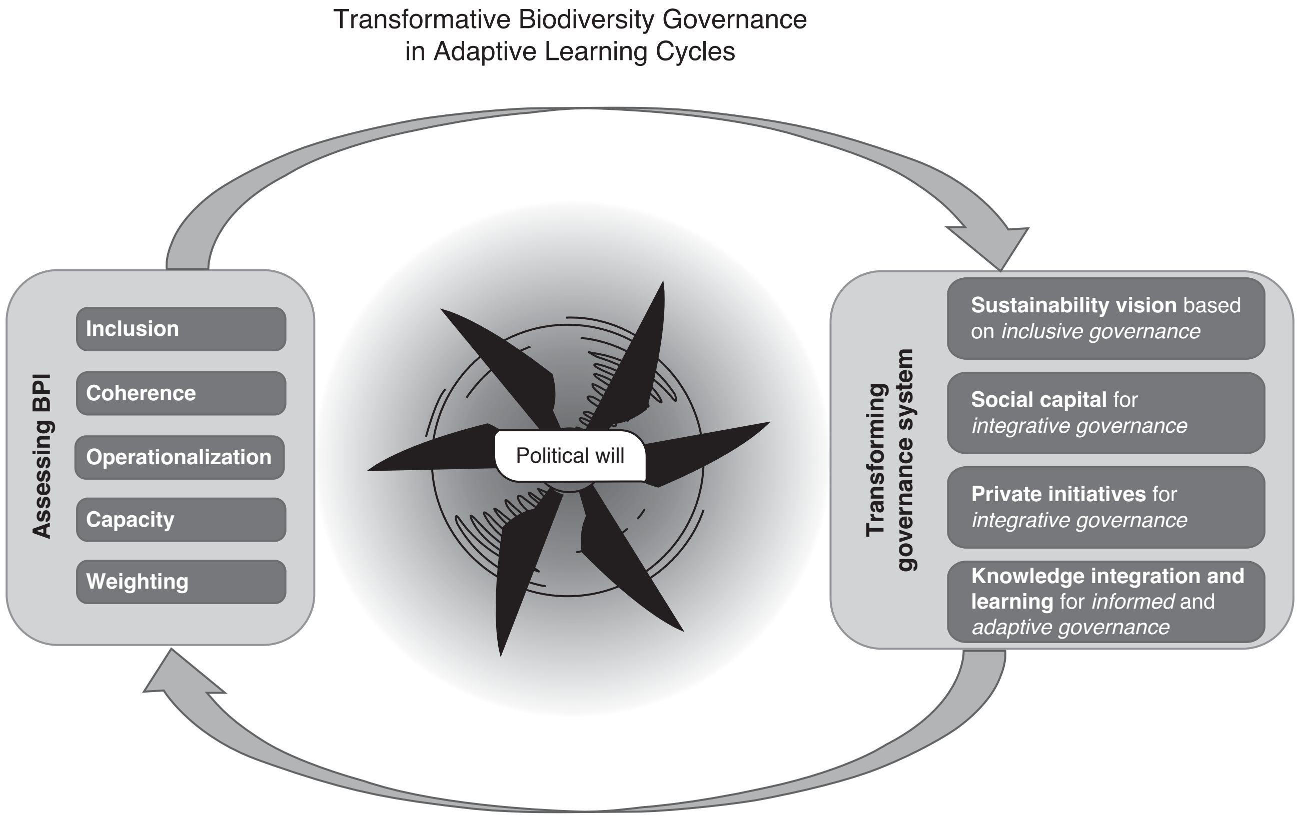

Figure 13.2 Improving the BPI level through transformative governance in adaptive learning circles.

(Díaz et al., 2018; Runhaar et al., 2020; Termeer et al., 2013; Zinngrebe, 2016b). Likewise, a positive perspective of what "sustainable agricultural landscapes" entail in a given context helps to orient the decisions and activities of political and nonpolitical actors. There are various alternatives to the dominant productivist model, including agroecology, sustainable intensification, agroforestry, and "nature-inclusive" agriculture (Brouder et al., 2015; IPCC, 2019; Loos et al., 2014; Perfecto and Vandermeer, 2010; Plieninger et al., 2020; Tscharntke et al., 2012; van Noordwijk, 2019; Zinngrebe et al., 2020). Agroforestry, as a specific example of an agroecological approach, has the potential to support ecosystem functions and biodiversity in both developed (Torralba et al., 2016) and developing countries (van Noordwijk, 2019). More concretely, objectives can be formulated around agroecological infrastructure such as hedges, trees and other seminatural habitats that protect multiple taxonomic groups and ecosystem services (Barrios et al., 2018; Fagerholm et al., 2016; Gonthier et al., 2014; Plieninger et al., 2019; 2020; Poux and Aubert, 2018; Torralba et al., 2018). Scenarios form an effective method for a participatory visioning process involving policymakers and other actors to deliberate options for land use and assess their implications for food security within a land-constrained world facing climate change (e.g. Aubert et al., 2019).

A second transformative factor that gives more weight to biodiversity in decision-making on trade-offs is *social capital for integrative governance*. Especially in developing countries, institutional *capacities* for implementing policies are severely lacking and often result in institutional gaps between policy integration "on paper" and the implementation of concrete policy instruments (Runhaar et al., 2020). Overlapping and unclear competences also create "responsibility gaps" in which no actor actually takes leadership in regulation or wider governance (Sarkki et al., 2016). Efforts to improve mainstreaming and fill these gaps have not resulted in institutional reconfigurations favoring effective implementation (Herkenrath, 2002; Prip and Pisupati, 2018). However, environmental impact assessments of large agricultural projects, or approval and monitoring of agroforestry concessions, can improve the operationalization of conservation objectives (Slootweg and Kolhoff, 2003; Zinngrebe, 2018). In Europe, both agricultural and environmental policies are well developed, but not institutionally connected in decision-making and implementation structures (Pe'er et al., 2019). Involving farmers in local implementation processes and partnerships with conservationists is an important strategy for improving biodiversity conservation leadership and outcomes in both developing (Harvey et al., 2008) and developed countries (Buizer et al., 2016; Pe'er et al., 2019; Persson et al., 2016). A collaborative process of aligning policy packages of information, regulation and finance can help overcome fragmentation between political actors and produce coherent incentive systems for conservation practices (Zinngrebe et al., 2020). Such a collaborative process should not only advance top-down implementation of (inter)national regulatory frameworks, but also cover a diverse range of locally based agricultural management practices. The IPBES Global Assessment (2019), for example, highlights a wide number of studies documenting the importance of small agricultural landholdings[2] in contributing to biodiversity conservation in different ecosystems (Batáry et al., 2017; Belfrage et al., 2015; Fischer et al., 2008).

[2] In this case, defined as under two hectares.

A third point of leverage is harnessing *private initiatives for integrative governance*. Private sector and market-based mechanisms can help with *operationalization*, provide new sources for institutional *capacity*, and increase *coherence* with farming interests (see Chapter 5). Engaging private actors is critical, particularly due to the rise and extent of private governance in the agricultural sector globally. Private actors can help incentivize biodiversity-friendly agriculture through various market opportunities, finance mechanisms, and public–private partnerships and other cooperative mechanisms. For example, numerous cases of the landscape approach have shown cooperation between governmental and private actors, such as co-funding from corporate actors in the maintenance of ecosystem services (Van Oosten, 2013). Private agricultural standards (including voluntary programs, such as various organic certifications) have become an integral part of agri-food chain governance (Henson and Reardon, 2005; Verbruggen and Havinga, 2017). Sustainability certifications (potentially) open new markets (FAO, 2017b) and provide opportunities for the scaling-up of environmental sustainability criteria, including for biodiversity (Runhaar et al., 2017). Particularly in countries that import large quantities of agricultural goods with high biodiversity impacts, government procurement of certified agricultural products can support and incentivize private sector actors in achieving biodiversity goals (Fransen, 2018). The use of economic instruments by firms, such as payment for ecosystem services, can also help provide financial incentives for other actors to engage in biodiversity-friendly farming and production processes (Donaldson, 2012; Harvey et al., 2008; Sanchez-Azofeifa et al., 2007).

However, to improve biodiversity outcomes, private initiatives need to be accompanied by political regulation and cooperation between private and public actors (Folke et al., 2019, Lambin et al., 2018; Runhaar et al., 2017; 2020). So far, land use change and management choices exercised by powerful transnational corporations have had a range of detrimental consequences for biodiversity (Folke et al., 2019). In the agri-food sector, consolidation is extremely high among corporations controlling fertilizers, agrochemicals and seeds, as well in the production of specific commodities such as coffee, bananas, soy, palm oil and cocoa (Folke et al., 2019). Private initiatives and certification schemes connecting consumer support for sustainable production systems have not yet proven effective in reversing detrimental environmental impacts (Dietz et al., 2019; Lambin et al., 2018; Pendrill et al., 2019). Experiences with green certification show that private standards need to be complemented with adequate regulatory frameworks to avoid deforestation and other detrimental effects to biodiversity, while simultaneously providing sufficient economic incentives for farmers (Dietz et al., 2019; Lambin et al., 2018).

Knowledge integration and learning for informed and adaptive governance is necessary to develop context-specific policy solutions for complex societal challenges. This can help in identifying suitable strategies for *operationalization* and (targeted) *capacity*-building. Experiences in participatory land use planning have shown how different knowledge systems can be integrated at the community level to build adaptive capacity and adopt more sustainable land use practices (Rodríguez et al., 2018). While the EU has a wide range of instruments for conservation in agricultural landscapes, it does not yet use all available knowledge to inform the improvement of these instruments from one funding period to the next (Pe’er et al., 2020). Social capital can facilitate the input and reflection of available knowledge (Zinngrebe et al., 2020). Policy learning based on available experiences has the potential for overcoming complete policy failure and fragmentation (Feindt, 2010; Zinngrebe, 2018). Feindt (2010) argues that stronger institutionalized support for policy integration, balanced representation and wider societal engagement is needed to hold back powerful actors from dominating the policy arena to defend the status quo. Certain levels of flexibility and a complementary structure of CAP support and Natura 2000 instruments have shown synergistic effects in increasing the willingness of farmers to adopt conservation measures (Lakner et al., 2020). In addition, the integration of local knowledge has been shown to improve both farmers' engagement in reflexive learning processes and policy performance, in the EU context on the CAP's agri-environmental measures (Goldman et al., 2007; Prager et al., 2012) and in developing countries, for example in the context of conservation farming in South Africa (Donaldson, 2012) or in Mesoamerican landscapes (Harvey et al., 2008).

13.6 Conclusion

Low levels of biodiversity policy integration in agricultural policy in both developing and developed countries is a determining factor in the continued biodiversity loss within agricultural landscapes and beyond. While land-sparing approaches have proven to be indispensable for the conservation of certain components of biodiversity (Le Saout et al., 2013; Watson et al., 2014), a more integrated land-sharing approach is necessary to enable a transformation of current trajectories toward sustainable farming, in order to bend the curve of biodiversity loss while also ensuring food security, climate resilience, enhanced animal welfare and improved rural livelihoods.

With the exception of EU policies, in most countries, specific biodiversity-related objectives are missing in agricultural policies. Worldwide, the underlying drivers of biodiversity loss from agriculture are not sufficiently addressed. In particular, the objective of phasing out policies supporting threats to biodiversity and a strongly productivist-oriented agricultural sector overpowers the idea of sustainable agriculture. Instead of coherent targets and complementary institutional structures, conservation has generally been treated as an add-on to business-as-usual agricultural policy. Trade-offs considering biodiversity and ecological limits are seldom explicitly recognized in agricultural policies, and no country expresses a long-term vision for the development of sustainable agricultural landscapes. Political discourses remain centered on prioritizing intensive food production, thereby marginalizing the potential functions of agricultural landscapes for biodiversity conservation. Based on our BPI analysis, we extract the following recommendations for transformative biodiversity governance:

1. Inclusive governance needs to genuinely incorporate multiple stakeholder views and perceptions, and negotiate and develop clear, coherent visions and definitions of sustainable agriculture to legitimate policies and decision-making.

2. Integrative governance can be improved by building social capital as a means to creating favorable actor constellations and institutional structures incentivizing and prioritizing biodiversity-sound practices.
3. Integrative governance can benefit from complementing public and private initiatives in coherent governance structures.
4. Informed and adaptive governance requires a continuous and participatory reflection of governance systems to guide institutional learning processes toward sustainable agricultural landscapes.

We argue that the Post-2020 Global Biodiversity Framework should focus on the transformation of agricultural governance systems by concretely addressing key leverage points and providing specific guidance for member states to address country-specific drivers and potentials for sustainable innovation through biodiversity policy integration. Eventually, however, the dynamic of this transformative process will be conditioned by political will and active leadership at all levels.

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IV. CONCLUSION

4.1 Cross-cutting discussion

This section provides a cross-cutting discussion of the findings of the different chapters (5.1), a summary of each chapter's contributions to different literatures (5.2), a review of the policy implications of this research (5.3), and reflections on its limitations and avenues for future research (5.4).

The main contribution of this thesis is to show how the rise of private actors, the mobilization of different kinds of policy instruments, and the construction and use of new forms of scientific knowledge impact environmental governance in an era of transitions toward sustainability. It also contributes new empirical data and advances social science research on global, EU, and national pesticide governance (Bureau-Point et al. 2022; Helepciuc and Todor 2021; Möhring, Ingold, et al. 2020; Storck, Karpouzas, and Martin-Laurent 2017). By synthesizing findings from four publications, this section answers the three initial research questions relating to environmental governance raised in section 1.3 and concludes with a general discussion of issues specific to the case of pesticides.

The first research question probes how the rise of private actors in environmental governance affects policymaking. Examining the impacts of the rise of private agricultural standards on multilateral decision-making processes, **Paper I** demonstrates that indirect interactions between public and private governance can result in unexpected counteracting feedback effects on environmental governance. Even in cases in which public and private actors have broadly aligned goals, private actors aiming for more stringent action can unintentionally impact public decision-making processes. In this case, we show how private agricultural standard-setting bodies indirectly affect the decision-making processes of the Rotterdam Convention, altering the Convention's intended role and impeding efforts to add substances to the treaty by influencing the interests of some parties to the Convention. Thus, a confounding interaction can occur when private actors seeking to gain legitimacy by adopting certain components of public governance inadvertently affect treaty-based decision-making processes. Given the growing importance of private governance in a wide range of sectors, similar confounding interactions are likely to arise elsewhere as private actors seek to build upon the legitimacy of public governance. The case also shows the importance of differentiating between different types of private actors within environmental governance and their varied and potentially opposing intentions and interests, as demonstrated in previous research (Lambin and Thorlakson 2018; Verbruggen and Havinga 2017b).

The second research question focuses on the (political) role of new forms of scientific knowledge in guiding transitions toward sustainability. **Paper II** shows how the production of specific forms of knowledge for policymaking can affect the division of political responsibilities and allocations of power among different actors and institutions. This highlights the critical role of science-policy interfaces and their implications for governance and for legitimizing specific divisions of political responsibilities. In this particular case, through successive stages of boundary work, the French government has come to define the political "solution space" to address the glyphosate problem by steering both the production of reports by INRAE on the costs of alternatives to glyphosate and ANSES' subsequent translation of the findings into regulations. The close collaboration between the French government and appointed experts ultimately created a new type of policy-relevant knowledge intended to be used specifically as an input for a new regulatory process for pesticides which uses the availability and costs of alternatives as a basis for restricting the use of glyphosate. This process limited the framing of glyphosate alternatives to practices considered economically and practically feasible by selected experts and excluded more systemic alternatives from policy debate and instrumentation. The adoption of this regulatory instrument reflects specific institutional contexts, power differentials between governmental ministries, and the hidden political influence of a powerful agricultural sector and agrochemical industry.

The third research question concerns the role of different types of policy instruments in governing transitions toward sustainability. **Paper II** shows how, at the national level, the development of novel command-and-control regulatory instruments designed to improve sustainability outcomes may do so in a marginal way while simultaneously closing down political pathways towards policy instruments which could enable more systemic transformations. **Paper III** then demonstrates why command-and-control instruments alone are likely to prevent enabling systemic change in a given sector. The paper situates glyphosate within a broader sociotechnical system and identifies the mutually reinforcing economic, political, and regulatory lock-ins which challenge a glyphosate phase-out and hinder sustainability transitions. Because substitution-based measures alone cannot enable a 50 percent overall pesticide reduction, phasing out glyphosate in an EU policy context focused on strongly reducing overall pesticide use is fundamentally different from implementing past pesticide bans. The paper shows how conceptualizing pesticides as part of a larger sociotechnical system points to the need to switch from command-and-control towards a mix of management-based instruments to ensure the long-term effectiveness of policies that aim to fully phase out glyphosate. Contrary to technology-focused approaches in which problematic pesticides can be substituted with less toxic ones, phasing out glyphosate and other chemical herbicides to reverse biodiversity loss necessitates changes in farming *systems* and agricultural land use towards crops with lower per-hectare pesticide use intensities.

Due to the constitutive role of the state in subsidizing and shaping agricultural production, reforming public policies is critical to shifting the conditions of production which underly economic lock-in for farmers. A phase-out which will not enhance dependency on other chemical pesticides instead requires an integrated approach to agricultural and trade policies which centers sustainability and which could enable a restructuring of actor networks, institutions, and power relations throughout national and EU food systems. The case of glyphosate explored in **Papers II** and **III** crystallizes tensions likely to arise with attempted phase-outs in a wide range of sectors, notably regarding the temporality and the integration of different policy instruments in sustainability transitions. The governance of systemic change is a long-term process, whereas phase-outs require short-term action targeting specific substances and technologies. This case demonstrates that policy mixes are likely necessary for reconciling these needs, as similarly demonstrated by research in other areas of sustainability (Kivimaa and Kern 2016).

Broadening beyond pesticides and focusing on biodiversity impacts of the agricultural sector, **Book Chapter I** further illustrates that no single instrument can enable transformative biodiversity governance. Rather, environmental policy integration requires a suite of complementary instruments and mechanisms. Both developed and developing countries currently exhibit low levels of biodiversity policy integration in agricultural policy. Instead, we find that biodiversity policies are predominantly 'add-on' and neither directly address biodiversity-threatening agricultural practices, nor specifically support more 'nature-inclusive' agriculture. Thus, existing knowledge on biodiversity-sound agriculture is not reflected in dominant agricultural policies and practices. Political will is required as a key driving force to improve the integration of biodiversity across sectors. To this end, biodiversity governance can target the following leverage points to transform existing governance structures: (a) working towards a coherent sustainability vision based on inclusive governance principles; (b) building social capital; (c) integrating private sector initiatives such that they can complement public governance structures; and (d) better integrating knowledge and learning into policy development and implementation. Thus, existing sectoral policy instruments can provide a useful basis for the governance of transitions toward sustainability, but leveraging these will require political will to overcome system lock-ins and to enable mainstreaming in sectoral policies.

This thesis emphasizes the importance of context-specific factors and multi-actor and -level interactions. It is therefore critical to unpack the ways in which the theoretical contributions may be appropriately generalized and to distinguish these from context-specific empirical findings to identify the ways in which the theoretical contributions may be appropriately generalized and policy lessons drawn.

Regarding the role of scientific knowledge in sustainability transitions, **Paper II** shows how, in the French case, the state continues to have tight relationships with various institutions which have mandated roles in policymaking processes. This demonstrates the public recognition of the legitimacy of science for decision-making (Maxim 2022). In the case of glyphosate alternatives, the French government played a strong role in framing the issue and in requesting the production of specific inputs for policymaking, using boundary work to enable a division of responsibilities between different institutions that enabled the perceived autonomy of scientific expertise to stay intact. This tight relationship presents opportunities and risks: on one hand, it can enable governments to quickly and fluidly mobilize expertise in support of transitions "in good faith," while, on the other, it can also enable a depoliticization of critical issues and delegation of decision-making to experts rather than citizens or democratically elected representatives. Public expertise also faces the risks of all public institutions, namely the drawbacks of their political economies. As Demortain (2018b) explains, the tightening of public budgets in France and across Europe is causing a privatization of institutions mobilized for public policymaking, creating risks of conflicts of interest. The French government is committed to maintaining public scientific institutions which support policymaking, but is a particular case for which findings may not be generalizable to other countries, such as those which do not have such centralized or strongly institutionalized relationships with knowledge-producing and -brokering institutions. In such cases, the cognitive and sociopolitical boundary work involved in producing knowledge for policymaking will depend strongly on the specific institutional contexts in question.

Across all the publications in this thesis and in the specific case of pesticides, it is critical to bring attention to a conceptual demarcation within governance studies that distinguishes *de jure* from *de facto* steering mechanisms. Examining the case of geoengineering, Gupta and Möller (2019) define *de jure* mechanisms as targeted interventions intended to govern, in contrast with *de facto* mechanisms which have a steering effect that is not mandated nor openly pursued. This distinction highlights the importance of studying steering mechanisms which are not conventionally considered as falling within the boundaries of "pesticide governance." In all cases examined in this thesis, actors involved in governing the reduction of pesticide use are institutionally separate from those involved in designing other forms of governance which influence pesticide use in the agricultural sector. This is most clear at the national level, where regulatory agencies, environmental agencies, and select directorates within agricultural ministries are involved in designing mechanisms to decrease pesticide use and risks, while other — typically more powerful — directorates within agricultural ministries are responsible for allocating agricultural subsidies and formulating overarching productive strategies for the sector.

As this thesis shows, agricultural policy is itself a form of *de facto* pesticide governance. So, too, are expert assessments which influence the questions of why and how actors govern, ultimately influencing who is responsible for governing. The strong focus on strategies, such as the National Action Plans for pesticides required by the EU, as well as pesticide regulations, demonstrates that *de jure* pesticide governance is an add-on layer of damage control which aims to target sectors already operating with their own logics across established networks of actors. As seen in **Book Chapter I**, "biodiversity governance" suffers from a similar problem, where *de jure* biodiversity governance, such as the National Biodiversity Strategies and Action Plans required by the Convention on Biological Diversity, generally do not target the *de facto* governance mechanisms which influence biodiversity loss.

This distinction between *de facto* and *de jure* forms of pesticide governance can be applied to environmental governance more broadly. As discussed in **Book Chapter I**, scholars have brought attention to how various domains of environmental governance suffer from a lack of integration into existing policies, leading to a lack of coherence. Such a lack of policy integration is often not coincidental; rather, this is in many instances linked to power differentials between actors and institutions. Attempts to change institutions can therefore lead to institutional layering, in cases where institutional challengers lack the capacity to change existing rules yet manage to add new rules (Mahoney and Thelen 2010).

Shifting attention to reforming *de facto* pesticide governance (i.e. the variety of sectoral structures which drive pesticide use), two key challenges arise: first, how "old" and "new" instruments and institutions can be integrated to enable transformations in specific contexts; second, how to undertake policy integration which may shift existing power structures in favor of reforms toward sustainability. **Paper III** and **Book Chapter I** grapple with these questions. **Paper III** suggests that policy reform is necessary in specific agricultural and trade policies within France and the EU. **Book Chapter I** argues that political will is critical to driving a transformative agenda through effective leadership at different levels.

Due to the stability of incumbent structures and institutions within the agricultural sector, **Paper III** aligns with other work suggesting that "deliberate destabilization" or steering from the state may be necessary to accelerate change (Rosenbloom and Rinscheid 2020). It also supports the notion that governance for sustainability transformations "entails a dual focus on high-level, longer-term transformation combined with an honest recognition of the realities of near-term incrementalism at the same time" (Patterson et al. 2017, 4). Stimulating innovation to increase the availability and competitiveness of alternatives to dominant technologies is critical to transitions, but not sufficient given the power of incumbent actors in many sectors. The state therefore has the potential to play a unique role by reforming subsidies and sectoral policies which sustain current regimes that are incompatible with sustainability. The state can also provide transitional assistance for sectoral reforms, as has been most notably been used for designing policies to phase out coal (F. Green and Gambhir 2020). In this approach, developing long-term "pathways" with short-term milestones can play a key role in maintaining political accountability within the timeframe of political mandates.

4.2 Contributions

Through the different theoretical approaches and empirical cases examined across the four publications, this thesis makes several contributions to the literatures discussed in section 1.2.

First, this thesis contributes to regulatory governance literature by expanding our understanding of the rapidly evolving pesticide governance landscape at the international level and the potential impacts of new configurations of actors and interactions. Examining the effects of changing interactions between public and private actors, **Paper I** makes theoretical and empirical contributions. Theoretically, the findings have implications for theorizing interactions between public and private actors in international governance. Adding to the *complementary*, *competitive*, and *coexistent* interaction types defined by Cashore et al. (2021), this thesis uses the term *confounding* to describe a new, fourth type of interaction in which indirect interactions between public and private actors with broadly aligned goals result in unexpected counteracting feedback effects. This theoretical contribution extends beyond pesticide governance alone: similar dynamics of confounding interactions whereby private actors aiming for more stringent action unintentionally impact public decision-making processes could also exist in other sustainability areas.

Empirically, these results are relevant for understanding important dynamics in Rotterdam Convention negotiations and for understanding private standard-setting processes. Recent negotiation blockages under the Rotterdam Convention are partially explained by concerns of several parties opposing new listings of pesticides on the PIC list that such a listing would automatically result in a use ban of listed pesticides by private standard-setting actors. Although private actors' adoption of the PIC list as a ban may be considered favorably by actors advocating for more stringent global pesticide controls, it contradicts one of the foundational principles which allowed the Rotterdam Convention to come into existence. Regarding private standard-setting processes, our findings call attention to the ways in which private standards' own legitimating strategies are often intertwined with state-based decision-making. This suggests that, in order to avoid interactive effects, standard-setting bodies with leeway to incorporate independent scientific expertise may have the potential to ratchet up ambition on pesticide restrictions independently of multilateral processes.

Paper II contributes to the study of agency perspectives in sustainability transitions through the integration of STS concepts and to a growing literature devoted to rethinking of the role of ideas and scientific knowledge in influencing political responsibility and allocations of power. Drawing attention to formally non-political realms, it shows how sub-politics in the production of knowledge and adoption of a new policy instrument for glyphosate reflected specific institutional contexts, power differentials between governmental ministries, and the hidden political influence of a powerful agricultural sector and agrochemical ministry. The production of a specific type of knowledge and policies for governing glyphosate is not purely technical, but rather reflects specific social and political value judgements made by selected experts who ultimately define the realm of what is "possible." The case also suggests that while governments' mobilization of public expertise can be used to perpetuate existing power relations, it could potentially guide and legitimize new forms of knowledge production for transitions and engage a broader range of actors in the translation of boundary objects.

Paper III makes both theoretical and empirical contributions. Theoretically, its findings have implications for understanding how single-technology phase-out policies relate to transitions governance and can be incorporated into broader agendas targeting systemic sectoral change. The paper proposes an analytical framework for state-led governance of discontinuation which integrates concepts from sustainability transitions, political economy, and multi-level governance literatures. Empirically, these results are relevant for understanding policy retrenchment dynamics in pesticide governance in France and Germany, which can inform ongoing policy debates on pesticide governance across the EU.

The main empirical contribution of **Book Chapter I** is the assessment of biodiversity policy integration in agricultural policy worldwide, surveying both developed and developing countries. By identifying four specific leverage points within existing sectoral governance structures, it contributes to conceptualizing transformative biodiversity governance for the agricultural sector and suggests concrete ways to operationalize it.

4.3 Policy implications

This thesis also speaks to ongoing policy debates and provides insights for policymakers and practitioners. This section outlines general policy implications from the four publications and discusses them within today's rapidly evolving political context.

This thesis research was undertaken during a period of profound social and political change during which several shocks affected citizens around the world and reshaped the global geopolitical landscape, namely the Covid-19 pandemic and Russia's invasion of Ukraine. Such events are likely to become more frequent, marking a new "turbulent era" in which global, system-wide turbulence fundamentally changes the context of environmental governance (Shipton and Dauvergne 2022). Through the lens of transition studies, these events can be interpreted as landscape level changes, or exogenous factors, which may provide windows of opportunity for change if combined with simultaneous changes from the niche and regime levels. During the Covid-19 pandemic, production and consumption habits changed profoundly, with certain changes which persisted once the world started to come back to "normal" modes of operation. Profound change, too, has marked the EU's approach toward governing the energy sector and the permissible political rhetoric regarding energy savings and the difficult political choices which may be necessary when the block faces profoundly challenging collective choices. In both cases, crises gave state-led governance stronger legitimacy within neoliberal democracies than it has had for decades, as citizens and policymakers recognized the need for swift, coordinated action and investment in existing solutions and in promising future technologies. This time of profound change provides some inroads into rethinking possibilities for the governance of pesticides, agri-food transitions, and pollutants more generally.

The deepening environmental crises and rising global consciousness of their effects on people's well-being have driven stronger support for environmental policies worldwide. Public concern regarding chemicals specifically has increased in recent years, particularly in the EU. In 2020, it was found that a vast majority, 84 percent, of Europeans, "worry about the impact of chemicals present in everyday products on their health"; at the same time, 90 percent "worry about their impact on the environment" (European Commission 2020a, 2). Prompted and reinforced by the growing body of scientific literature regarding the risks of chemicals, this increased public awareness has put pressure on policymakers.

As shown in **Paper III**, a first step towards transformative governance of pesticides is to shift the framing of pesticide pollution away from a focus on singular substances to a systemic understanding in which pesticides are part of a broader pesticide-intensive sociotechnical regime. Similarly to the "post-fossil fuel" future being discussed by a growing number of actors, discourse on pesticides also appears to be shifting. "'The time for pesticides is over,'" the European Commissioner for Health and Food Safety, Stella Kyriakides, said after the European Commission presented its proposal for a Sustainable Use Regulation (Foucart and Mandard 2022). A growing coalition of actors is supporting a governance approach which encompasses entire agri-food systems, as shown by the holistic approach displayed in the EU's Farm to Fork Strategy. A similar broadening of discourse beyond farmer-centric narratives of agricultural productivity was also notable during the 2021 UN Food Systems Summit (Montenegro de Wit et al. 2021). However, the adoption of such discourses does not reveal a true shift in underlying power dynamics or recognition of the need to tackle power asymmetries between actors in order to catalyze more holistic approaches.

Although the EU has been the first to adopt an official Green Deal, proposals for similar overarching political projects have been circulating in countries around the world, including the United States. Resistance to transitions and transformations from incumbent industries and affected workers is strong, and perhaps intensifying and driving the rise of populist parties, casting doubt on the possibility for political progress on deep structural reforms. **Book Chapter I** argues that political will is critical to driving transformative policy change in the agricultural sector. Despite political resistance, there continue be emergent signs of political ambition at various levels to govern transformative change. Although political promises and discourses of transformative change may be used as a fig leaf to fend off social pressure, growing scientific evidence of environmental risks paired with increasing social pressure may create the political conditions in which maintaining the status quo is no longer viable. On the basis that political will to address environmental issues is increasing, this thesis suggests both broad and specific suggestions for policymakers and practitioners.

This thesis has demonstrated the need to enlarge the concept of pesticide governance — and the governance of pollution more broadly — beyond *de jure* pesticide governance mechanisms which have been designed under an overarching risk reduction paradigm and to shift attention to reforming *de facto* forms of pesticide governance in line with broader visions of systemic change towards sustainability. *De jure* pesticide governance mechanisms (including pesticide regulations at the national level and the pesticide treaties at the international level, along with a wide variety of other pesticide control instruments) play an important role in protecting human health and the environment and will continue to do so as many actors push for deeper structural reforms. Yet these "traditional" pesticide governance instruments form only a small part of the broader picture of the *de facto* mechanisms impacting pesticide use.

Engaging with both *de facto* and *de jure* forms of pesticide governance will require stronger environmental policy integration in different sectors and policy spheres. Various approaches and concepts have been proposed to conceptualize more integrated and effective approaches to policymaking for issues which span across multiple siloed realms of policy, notably "mainstreaming" (Karlsson-Vinkhuyzen et al. 2017). Mainstreaming has gained traction in climate change policy, which is now more widely recognized as a transversal issue which requires action from all sectors and an "all-of-government" approach (Karlsson-Vinkhuyzen et al. 2018). This has led to reforms such as the integration of climate considerations throughout strategies of different actors and sectors, notably financial institutions (European Investment Bank 2022). In the case of biodiversity, mainstreaming has entered policy discourse and is present in many countries' National Biodiversity Strategies and Action Plans (NBSAPs). However, mainstreaming largely remains aspirational, without concrete institutional and legal measures planned or in place to enable integration (Cardona Santos et al. 2023; UNEP 2018).

Rather than constantly starting anew with new forms of governance and instruments, it is essential for policymakers and practitioners to consider mobilizing, reforming, and adapting existing policy instruments to fulfill multiple overlapping sustainability goals. Such reforms will inherently be highly specific to the governance level and context, as demonstrated by an example. At the international level, a new Global Biodiversity Framework was established in 2022 and there are ongoing reforms to the chemicals post-2020 framework. During this period of reform and agenda-setting, it may be fruitful for policymakers to consider collaboration between the chemicals and biodiversity clusters to enhance synergies between their respective agendas. Four potential ways to mobilize the chemicals conventions for biodiversity would be to: i) expand the list of pesticides included in the Stockholm and Rotterdam Convention annexes; ii) reinforce institutional collaborations between biodiversity and other clusters, for example by developing joint programs, such as the strategic initiative on pollinators developed by the CBD and FAO which recommends measures on pesticides; iii) enhance non-state and multi-stakeholder cooperation between biodiversity and chemicals actors through platforms like SAICM or partnerships under the different multilateral environmental agreements; and iv) build collaboration at the level of national instruments and actors (Kinniburgh and Rankovic 2019). At the national level, an example of adapting existing policy instruments would be to reform the CAP and national spending on agricultural subsidies according to the recommendations of various NGOs and researchers. This could include reallocating significant portions of the 1st pillar CAP spending to payments for ecosystem services, changing current agri-environmental schemes, and funding local projects (Faraldo et al. 2021).

The findings of this thesis also highlight the need for closer attention to and scrutiny of science-policy interfaces and the ways knowledge which is used as a basis for policy is produced and translated into action. The increasing concentration and power of a small number of multi-national companies in the agri-food sector presents the danger of capture of environmental science by competing political actors aiming to shape policy. Previous work has shown that scientists can become "agents of corporate power on public policy" by being engaged as one component of broader lobbying strategies developed by corporations to shape policies and discourses (Demortain 2018a).

There is a critical need to promote innovation in the production of scientific knowledge and evaluation methods related to environmental governance and transitions. In agri-food research, a critical appraisal of the role of private actors involved in producing new forms of policy-relevant knowledge is also required. The politics surrounding the EU's proposed Sustainable Use Regulation for pesticides provide a useful example. At the time of writing of this thesis, a number of EU member state governments and members of the European Parliament have called for its delay and/or a watering down of its main components (Foote 2022). Although the EU has already carried out an impact assessment of this proposal (Barreiro-Hurle et al. 2021), member states are currently asking for another impact assessment in light of the new conditions facing global food chains as a result of Russia's invasion of Ukraine. At the same time, current modes of impact assessment have been criticized for being maladapted for adequately assessing food system transitions (J. Candel 2022; Schiavo et al. 2021).

Impact assessments for pesticides reflect broader trends in environmental research, which often neglect accounting for complex interactions, in particular with regard to societal factors (N. E. Selin 2021). The Farm to Fork impact assessments are a case in point, demonstrating limitations in scoping, conceptual assumptions, and methodologies (J. Candel 2022). In contrast with the Farm to Fork Strategy's primary objectives of reducing environmental, climate, and public health impacts of food systems and ensuring fair economic returns, the majority of the impact studies focused exclusively on market, income, and food security effects without examining positive impacts of proposed measures. Moreover, these studies do not compare the costs of action to the largely unknown potential costs of *inaction* under a business-as-usual scenario, nor take into account the positive effects that increased biodiversity or the uptake of new technologies may have on production in the long run (European Commission 2022b). They also falsely portray the EU as a contributor to worldwide food security, though the EU is currently a net importer of calories and mainly a major agro-exporter of high-value commodities (such as alcohol, cheese, and processed foods) which do not relate to food security (Schiavo et al. 2021). The main Farm to Fork impact studies focus only on farm-level policies, despite the potential for other measures at the supply chain- and consumer- levels to offset the impacts of possible production decreases on farm incomes, food prices, and trade (J. Candel 2022). Examples of measures at the level of food supply chains include policies to improve farmers' position in food supply chains and to prevent food loss and waste along supply chains, and the modification of EU import standards and tariffs to prevent trade distortions. The ongoing politics of these debates reflect the need to closely examine the actors involved in the production of knowledge: one of the impact assessments which points to strong reductions in agricultural production and increases in prices has been linked to strong conflicts of interest since it was commissioned by Croplife International, one of the major international pesticide lobbying firms (J. Candel 2022).

As this example shows, the strong influence of corporate actors in knowledge production on pesticides — and chemicals more broadly — as well as deficiencies in risk and impact assessment methodologies pose challenges for policymaking. It also suggests that institutional reforms are critical both for increasing policy effectiveness and for regaining public trust which has deteriorated in recent years (Zeitlin et al. 2022). In the context of ongoing global discussions to negotiate a science-policy panel on chemicals, it is critical for policymakers to keep in mind the imbalances in knowledge production on chemicals and the diffuse means through which corporate actors influence knowledge production and public policies. Building a science-policy body in which environmental and public health interests are properly represented will in part depend on reforms and learning from past experiences in other institutions, such as national and EU regulatory bodies, as well as the IPCC and IPBES (Beck et al. 2014; Hulme et al. 2011; Turnhout et al. 2021).

Many of these suggestions for reforming policies and institutions are strongly dependent on political leadership. The challenges of effective environmental governance have shown that breaking various socio-political lock-ins requires action through different political mechanisms at different levels of governance using different means (Bernstein 2018). Changing norms, building capacity, and building coalitions in support of multi-goal sustainability transitions will be critical to ensuring their long-term success. Yet recent rapid shifts in the social and political landscape suggest that non-linear changes may be possible and that transformative policy agendas — if considered legitimate by a wide range of actors — may be politically feasible.

4.4 Limitations and future research

This section addresses empirical, methodological, and conceptual limitations of this dissertation and highlights various avenues for future research.

A main limitation of this research is the empirical, methodological, and conceptual challenge of multi-level, multi-scale research which aims to connect governance interventions with impacts and environmental outcomes. Throughout the thesis, environmental outcomes are discussed relative to secondary scientific literature assessing impacts in specific conditions and at specific scales. Future interdisciplinary research is required to further develop approaches and frameworks which link sociopolitical and socioecological factors to help identify the most relevant scales for governance.

This thesis has also highlighted the situated and context-dependent nature of environmental governance by highlighting the specific actors, instruments, and knowledge which shape the dynamics of each case. The majority of the thesis was therefore case-based, focusing on specific countries and pesticides. The empirical scope of research on the politics of pesticide use as a case of environmental governance would therefore benefit from future research examining a larger number of cases and potential comparative analysis among them. For example, the findings in **Papers II** and **III** focusing on glyphosate in the EU may not be generalizable to other cases, such as Latin American countries where glyphosate is extremely prevalent but is used for other commodities in different agro-climatic conditions, influenced by very different constellations of actors than those in EU countries.

Paper I points to a need for further research into the impacts of interactions between public and private actors on sustainability outcomes. Future research could examine the potential for confounding interactions at other levels of pesticide governance and in international or national environmental issue areas outside of pesticide governance. Additional empirically based analyses of interactions between private standard-setting bodies and multilateral decisionmaking under specific treaties or in other international fora could help to further clarify and expand upon interaction types and mechanisms theorized in the governance literature and to inform public policy debates on the potential role(s) of private standards in advancing sustainability. Better understanding the heterogeneity and motivations of private actors as well as power dynamics relative to the public sector is also critical to help inform discussions on bolstering sustainability outcomes more broadly.

Papers II and **III** point to a need to further examine mechanisms of resistance from incumbent regimes through knowledge production as well as through framings and the dominance of discourses around the meaning of sustainability. Addressing underlying issues in the governance of pollutants requires further research on the paradigms of toxicity and risk that underpin regulatory frameworks around the world and the logics and conditions which underpin pesticide regulations and regulations-in-the-making. It also requires further examination of the political economy of pesticide research and corporate investments which aim to influence scientific researchers, research agendas or expert agencies. This is an area of research which remains sparse due to difficulties in accessing data, but which is critical to complementing research on the politics and political economy of the pesticide industry, its restructuring, and its ongoing efforts to influence regulatory politics (e.g. Clapp 2021a, 2021c).

Third, **Book Chapter I** points to the need for future research to unpack the notion of "political will," the factors motivating the political adoption of transformative sustainability agendas, and the interactions between strong political willingness to govern change and other factors, such as political economy issues. This thesis, and other works, contend that strong political will can drive transformational change by setting a variety of governance mechanisms in motion which together can influence sociotechnical change. Yet the deep entanglement between different levels of governance in a highly globalized economy raise questions regarding the agency of states and the limitations which may be caused by binding legal mechanisms and agreements such as the WTO, along with possible pathways for reform (Cahill et al. 2021).

Future research should also aim to contribute to policy objectives for pesticide reduction and food system reform at different levels. More research is required on effective strategies to engage diverse actors in agri-food transitions and the equity and justice impacts of different reforms within countries and between the Global North and the Global South. As highlighted by Candel (2022), new methodologies are required for better assessing policy options for food transformation, taking into account the multifaceted nature of sustainability. Lastly, and most specifically, research is urgently needed regarding a possible global science-policy interface for chemicals to inform ongoing international discussions from a social science perspective (Brack et al. 2022; Wang et al. 2019, 2021). Such research should address key questions of institutional design (such as how expert committees are composed and issues of representation from different regions and scientific disciplines) which have been examined during the development and design of other global expert bodies including the IPCC and IPBES (Kohler 2019b). Such research must take the political nature of the governance of expertise as a starting point and aim for reflexivity, acknowledging that the models adopted for the IPCC and IPBES cannot be directly replicated in the case of chemicals (Beck et al. 2014).

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