TYPE Original Research
PUBLISHED 17 November 2022
DOI 10.3389/fsufs.2022.1027583

The social costs of pesticide use in France

Christophe Alliot[1], Delphine Mc Adams-Marin[1], Diana Borniotto[2] and Philippe V. Baret[2]*

[1]BASIC—Bureau d'Analyse Sociétale d'Intérêt Collectif, Paris, France, [2]SYTRA—Earth and Life Institute-Agronomy, Université catholique de Louvain (UCLouvain), Louvain-la-Neuve, Belgium

Check for updates

OPEN ACCESS

EDITED BY
Johann G. Zaller,
University of Natural Resources and Life Sciences Vienna, Austria

REVIEWED BY
Nicolas Lampkin,
Johann Heinrich von Thünen Institute, Germany
Susan Kegley,
Pesticide Research Institute, United States

*CORRESPONDENCE
Philippe V. Baret
philippe.baret@uclouvain.be

SPECIALTY SECTION
This article was submitted to Agroecology and Ecosystem Services, a section of the journal Frontiers in Sustainable Food Systems

RECEIVED 25 August 2022
ACCEPTED 24 October 2022
PUBLISHED 17 November 2022

CITATION
Alliot C, Mc Adams-Marin D, Borniotto D and Baret PV (2022) The social costs of pesticide use in France. *Front. Sustain. Food Syst.* 6:1027583. doi: 10.3389/fsufs.2022.1027583

The modern agricultural production system relies heavily on the use of synthetic pesticides, but over the course of recent decades various concerns have been raised on the associated negative externalities touching a variety of dimensions, such as human health and the environment. Yet, the magnitude of those effects is still unclear and data availability is scattered and heterogenous across dimensions, regions, and time. The public sector is called upon to develop and implement strategies to face those externalities and their associated social costs. This study aims to provide an assessment of social costs of pesticides in France in the prospect of an integration to the public budget spending, helping public authorities to identify financial flows of public funding with an impact perspective, within a methodological framework based on the social norms at the core of the public system. The results show that the social costs attributable to synthetic pesticide use in France amounted to 372 million euros, of which environmental costs are estimated at least at 291.5 million euros, health costs at least at 48.5 million euros, regulation at least at 31.9 million euros and public financial support to the sector at least at 0.4 million euros. For comparison, this total value of social costs represents more than 10% of the annual budget in 2017 of the French Ministry of Agriculture and Food (3,587 million euros). The analysis can be used as a monitoring indicator for the implementation of public policies in the context of the growing social and environmental issues they face.

KEYWORDS

pesticide use, social cost accounting, externalities, public budget accounting, sustainability assessment, health impact of pesticides

Introduction

Since the middle of the twentieth century, the use of synthetic pesticides, combined with the use of synthetic fertilizers, varietal improvement and mechanization, has allowed unprecedented productivity gains and enabled agricultural production to grow faster than the world's population (Benton et al., 2021). Over the decades, however, societal concerns about the impacts and associated societal costs, such as public health and environmental effects, have emerged and grown as knowledge and evidence has been gathered by academic and other research institutions (Benton et al., 2021).

Yet, assessments of social costs rely on methods that mainly account for theoretical costs and less frequently on real costs that the actors have faced (or will face). For example, while looking at social costs linked to health impacts, a possible assessment of its value can be done by estimating the willingness to pay for health treatment (i.e., theoretical costs) (Robinson et al., 2017). Another option, related to "Real" costs, would be to account for the actual net health expenditure in the public (and private) sector.

The environmental impact of pesticides is well documented: active substances are not only found in treated fields but also in the surrounding environment. At the European level, it is estimated that 6.5% of groundwater and 7.3% of surface water fail to achieve a "good chemical status" (as defined by the European Union) because of a high concentration of pesticides (European Commission, Directorate General for Agriculture and Rural Development, and EEIG Alliance Environnement, 2020). The environmental presence of pesticides generates adverse effects on biodiversity and on natural habitat (Köhler and Triebskorn, 2013; Matthews, 2015; Medarova-Bergstrom, 2015; Carvalho, 2017). The exact magnitude of the impact of pesticides on biodiversity is uncertain, since biodiversity loss is multifactorial and the contribution of pesticides to this process is not yet clear. At national level, France is, after Spain, the biggest buyer of pesticides in EU, with an average across the period 2011-2020 of almost 69 million kg of pesticides. As data on consumption is very scattered and inconsistent across year and regions, sales of pesticides is used as proxy for assessing the magnitude of pesticides consumption in a country (Wagner et al., 2010).

In terms of human health too, pesticides have significant documented impacts, first of all on agricultural workers. Although personal protection equipment is the main tool for occupational safety, its effectiveness in working conditions may be over-estimated, and instructions to wear such equipment are inapplicable in many situations (Garrigou et al., 2020). Several cohort studies have been conducted on farmers to better understand disease risks associated with different hazards, including pesticides, in populations of agricultural workers (Leon et al., 2011). Literature reviews have established lists of diseases with a presumed link to pesticides (Baldi et al., 2013; Scala, 2021), albeit with difficulties in differentiating between the impacts of banned pesticides from those of pesticides still authorized and in use. Some of these diseases have been recognized as occupational diseases for farmers in some countries, for instance Parkinson's disease and non-Hodgkin lymphoma in France (Deprost et al., 2018). More broadly, the health impacts of pesticides on people living in the vicinity of farmlands, and more generally on consumers, are also being investigated (Dereumeaux et al., 2020).

Neoclassical economic theory has recognized that such undesired impacts are in fact associated with inefficiencies that constitute a form of "market failure" externalities (Ayres and Kneese, 1969). Externalities arise whenever the actions of one economic agent make another economic agent worse or better off, yet the first agent neither bears the costs (e.g., social and environmental costs) nor receives the benefits (e.g., social and environmental benefits) of doing so (Cannan, 1921). In the context of pesticides use, what can occur is that private market-based decision-making fails to yield efficient outcomes from a social welfare perspective. Neoclassical economists provide a set of measures—defined as internalization strategies—to reduce those externalities, on the one hand to prevent those externalities to occur and on the other hand for rebalancing the benefits (and costs) across economic agents. Internalization strategies are usually associated with market driven solutions (e.g., taxes), but can occur also through "command and control" solutions (e.g., governmental regulations) (Klaassen and Opschoor, 1991) or the actions of self-governing institutions (Gupta and Prakash, 1993). The three main strategies adopted in the context of pesticides are the following: price regulation, quantity regulation, and allocation of rights (Cannan, 1921; Coase, 2013), where the first two are market driven solutions, and the latter a "command and control" solution. Examples can be found at both EU and Member State level, were respectively the European Commission Directive on Pesticides (Directive 2009/128/EC) and National Action Plans are formulated and implemented. France has imposed taxes on pesticides sales in France since 2014. In April 2018, the EU Regulatory Committee banned outdoor usage of three neonicotinoids, namely imidacloprid, clothianidin, and thiamethoxam. Nevertheless, since then, EU countries have repeatedly granted emergency authorizations to their usage (in other words allocating rights to their usage), specifically for sugar beets. In November 2020, EFSA published its evaluation, concluding that all emergency authorizations were justified (EFSA, 2021).

Two fundamental factors influence the applicability of different internalization strategies, namely (i) the nature of the social cost and (ii) the context in which such cost arises. For the first, the underlying reason is that, even if the triggering activity of the occurring social cost is the same (i.e., pesticide use), each type of social cost occurs in a different setting, therefore internalization strategies could be significantly different. For example, strategies to best internalize health impacts related to pesticides use might not be the same as strategies to internalize the associated environmental impacts. For the second, internalization strategies might not be effective for some activities but could be appropriate for others. For example, in the context of pesticides, regulating the use of some herbicides could mean a substitutional effect with others or a change of practices that could be applicable for some crop management practices but not necessarily for others.

In 2020 the European court of auditors underlined several issues concerning the implementation of the EC Directive on Pesticides (Directive 2009/128/EC) at national and regional level. It points out limited progress in measuring and reducing pesticides (Special Report 15/2020, 2020). So far, national plans have not yet tackled all issues, and actions to internalize social costs are not able to meet all EU and national objectives. For example, in France the legal framework regulating pesticides relies on main three strategies: national restrictions for the usage of pesticides outside agricultural activities and in the private sector (Loi Labbé, 2014), and incentives set to promote the transition to alternative plant protection schemes (e.g., Integrated Pest Management), along with investments on research and innovation (i.e., Écophyto plan II+, 2018). Yet, the main target of reducing by 50% the usage of pesticides (measured in quantity of active substances), that has been a main priority since Écophyto 2018 and has been kept in Écophyto 2025, is far from being achieved. Similar target is set for the EU "Farm to Fork" Strategy, which aims to reduce by 50% the use and risk of chemical pesticides and the use of the more hazardous pesticides by 2030.

Materials and methods

Theoretical framework

Effective public pesticide policy to internalize externalities is made difficult by a variety of characteristics of those externalities, including the multidimensionality and temporal and spatial heterogeneity of damage; the diffuse and non-point source nature of pesticide pollution; information asymmetries; and monitoring costs (Sexton, 2007). An essential requirement for the efficiency of any internalization measure (either within or outside the market) is that social costs, along with benefits, have to be known. This follows the economic theory for which efficient use of pesticides occurs until the benefit of the last application is equal to its cost (Sexton, 2007). But it is often claimed that a complete record and monetary assessment of social costs (and benefits) is very hard to implement (Girardin and Bockstaller, 2000).

Both academia and private sector have recently invested in developing methodologies to assess the (negative) impacts of the production system within the agri-food sector, and various authors have underlined the complexity of assessing related impacts (Independent Evaluation Group, 2011). On this subject, methodologies to assess environmental impacts are mainly developed around the Life Cycle Assessment (LCA) approach, which involves a thorough inventory of the energy and materials that are required across the industry value chain of a product, process or service, and calculates the corresponding emissions to the environment [Scientific Applications International Corporation (SAIC) et al., 2006]. After this inventory, the methodologies set midpoints, endpoints and eventually define the monetization phase. Midpoint indicators focus on single environmental problems, for example contribution to climate change or soil pollution. Endpoint indicators show the environmental impact on higher aggregation levels, being for example—in the context of pesticides—the effect on human health, biodiversity, or resource scarcity (e.g., ReCiPe model). The final phase of monetization allows for comparability across categories of impacts. Both the assessment of endpoints and the value of monetization factors vary quite substantially across authors.

The definition of the composing elements of both midpoints and endpoints indicators strongly varies depending on the (i) type of impact assessed (e.g., soil pollution, water pollution) and (ii) the methodology (and related characterization factors) chosen (e.g., ReCiPe model, WHO method). Moreover, the costs (and benefits) identified by such indicators are, to some extent, theoretical as it is hard to attribute them to real financial flows that have occurred (or are to be expected).

The methodologies developed so far, even if they provide a systematic way to account for externalities, do not clearly distinguish between those theoretical and real costs. This means they have some limitations in supporting the development of internalization strategies, especially if looking at related governmental regulation measures. Following the taxed-based approach (Cannan, 1921) and command and control approach (i.e., Coase, 2013), social costs are perceived as inevitable and, while occurring, they are framed within the theory of externalization and market failure. The theory sees them therefore as exclusively related to market dynamics, and solutions have to be found in market regulation practices. But some economists, such as K. W. Kapp and K. Polanyi, proposed a different approach to overcome limitations of market-based solutions. The starting assumption here is that social costs are, to a large extent, a non-market phenomenon because the relations between production, the environment and the individual are not voluntary market relations, but involuntary one-sided relationships forced upon the individual (Kapp, 2000). The authors claim that market dynamics fail to a large extent to provide solutions for the redistributions of social benefits and costs as the foundation of the market is heavily driven by financial balance rather than ecological balance (Berger, 2008). According to Kapp, societal costs may be seen as part of the "natural" course of productive activities where the harmful effect is shifted to third persons or the community at large, but are, simultaneously, defined as always avoidable (Kapp, 2000). The role that governments plays in such a setting is key, and public budgetary accounting of social costs could be a valuable asset in defining best strategies to internalize externalities to reduce the impacts of pesticides.

The present study aims to operationalize those key concepts in the context of pesticide usage in France, and to provide valuable information for choosing best strategies to reduce impacts of pesticides, such as internalization practices, either market-driven or as regulatory frameworks. The study will focus on providing an assessment of social costs of pesticides in France, as evidence for design, allocation and evaluation public budget spending. The approach for the assessment is done as follow:

1. Identify social costs: a preliminary step identifying public norms, regulations, and policies associated with synthetic pesticides (national as well as international) serving as a reference point to identify the costs which are deflected on society
2. Account of social costs—the assessment of social costs is done through defining two main types of public budget expenses:

    a. "Defensive" costs comprise (i) the costs incurred because of negative externalities created during production (e.g., the public expenses engaged to fight an industrial accident), (ii) the costs linked to mitigate the effects of these externalities, to adapt to them, to repair for the damage—when possible—or to compensate for it (e.g., public subsidies to clean up a polluted area)
    b. "Abatement" costs comprise (iii) the costs incurred to prevent externalities ex-ante, through measures that enable to remove and/or reduce below commonly agreed public norms (e.g., public investments in renewable energy).

Identify social costs

Throughout the years while assessing impacts and associated social costs of pesticides, various attempts have been made to identify them, covering a vast number of regions. On this, Bourguet and Guillermaud published in 2016 a meta-study which comprehensively reviewed 61 scientific papers on the subject published between 1981 and 2014 (Bourguet and Guillemaud, 2016). Only external costs of pesticides are analyzed in this meta-study. These costs can be regrouped in three categories:

1. The regulatory costs paid by private or public actors, due to regulation measures (associated to the norms mentioned above) implemented to reduce the impacts of pesticide or the use of pesticides. These types of costs are considered in 24 articles only.
2. The human health costs due to acute or chronic pesticide poisoning (considered as external costs in this study even if there is a debate whether some of these costs are internal or external). These types of costs are considered in 57 articles. In addition, defensive expenditures paid by farmers or society to prevent pesticide exposure are also considered, but in 13 articles only.
3. The environmental costs due to damage on animals, plants, and other organisms. These types of costs are considered in 26 articles.

An approach to identify social costs is related to public norms (Kapp, 2000). Social costs are taken into account if they are acknowledged by the regulation framework. Following this reasoning, a list of public norms that are related either to pesticide use directly or to pesticides' impacts is used to identify the types of social costs. For example, an important regulation framework is the European directive that imposes a low concentration of pesticides on water because of the pollution induced by these toxic substances. These regulation frameworks are often drafted as a response to scientific research that shows negative impacts of pesticides on various aspects such as health, biodiversity, water resource, soil quality. Based on this, we included the three aforementioned categories (i.e., regulatory, human health, and environmental) and added a fourth category that relates to public financial support to the sector. Considering the environmental and social impacts of synthetic pesticides, supporting the sector can be viewed as a social cost for society since it enables a sector to make profit, either by directly financing the manufacturers or by helping consumers.

Accounting for social costs

The first step to estimate the social costs is to identify the real expenses paid by public actors because of pesticide use in France. Those costs can be expenditures to finance actions entirely related to pesticides (i.e., National Action Plan on pesticides) or actions partially related to pesticides (i.e., public health expenditures for cure of diseases caused by many factors including pesticides). For the latter, scientific research may have already linked some actions with specific factors (i.e., number of cases of occupational diseases due to pesticides for farmers). An attribution factor is computed if literature cannot provide a scientific reference to that specific social cost. The methodological framework hereby developed lists all relevant type of social costs but, in case of missing robust data, does not compute them. A conservative approach is therefore adopted, to guarantee overall robustness of results.

Regulation costs

The first category of social costs corresponds to regulation costs, i.e., costs incurred by pesticide regulatory authorities that are covered by public budgets.

As described in Table 1, the regulation costs that we have been able to identify can take three forms:

- public budget of regulation authorities,
- budget of the National Action Plan on pesticides,
- budget of public research on the health and environmental risks of pesticides.

TABLE 1 Forms and description of the regulation costs associated with the use of synthetic pesticides in France.

Component of social costs	Forms of social costs associated with the use of synthetic pesticides	Description of the methodology used to estimate the social costs	Attribution factor
Regulation costs	Public budget of regulation authorities	Total budget of regulation authorities prorated to France's activity (i.e French pesticide use)	Share of the activity linked to pesticides
	Budget of the National Action Plan on Pesticides	Total budget of the plan	*100%*
	Budget of public research on the health and environmental risk of synthetic pesticides	Not measured for lack of robust data	

We first investigated the budget of regulatory agencies. The national agency ANSES deals with the implementation in France of European regulation pertaining to food safety, chemical substances registration, evaluation, authorization, and restriction (REACH). Its activity linked to pesticide regulation is entirely funded by taxes paid by pesticides manufacturers, therefore we cannot consider its budget as a social cost related to pesticide use in France. In contrast, at the European Union level, the European Food and Safety Authority agency (EFSA) is entirely financed by public funds from Member States and the European Union. In addition, part of EFSA's activities directly benefit the pesticide sector by giving independent scientific advice on risk assessments of pesticides' active substances, which is a compulsory step before the European Commission can approve their commercialization on the market. As a result, we can consider that the share of the EFSA budget of 79.95 million euros dedicated to pesticides work is a social cost. The question is then how to evaluate the attribution factor, that is to say the share of the EFSA budget linked to activities related to pesticides. On top of that, the share of this budget needs to be reduced to French use of pesticides only (and not the European one).

Although we were unable to find information on the breakdown of the EFSA budget for the functional units related to pesticides, we found public information on the EFSA budget per strategic objective (SO), as well as the number of questions closed for each of these objectives (i.e., in the first SO "Prioritize public and stakeholder engagement in the process of scientific assessment," one of the questions closed concerns the application of regulation on maximum pesticide residues). In the absence of further available information, we thus considered the attribution factor as the share of questions closed concerning pesticides in the related objective of EFSA (published in the 2019 annual report of the agency).

In order to estimate the share of this dedicated budget that is related to pesticide use in France only, we multiplied the previously obtained result by the ratio of total pesticide purchases of French farms to the total pesticide purchases of EU farms recorded in the Farm Accountancy Data Network (FADN) public database. Indeed, the regulation costs linked to pesticide use in France are not directly related to the share of the financing of the EFSA agency by the French government, but rather to the share of pesticides authorized at the EU level that are used in France by farms, regardless of which Member State financed the EFSA budget.

The mathematical formula used to estimate the social costs linked to the public financing of the EFSA agency dedicated to synthetic pesticide use in France is as follows:

$$\begin{aligned}&\textit{Costs of pesticides regulation}\\&= \sum_{\textit{Per strategic objective}} \left[\textit{EFSA annual budget} \times \frac{\textit{Number of questions closed concerning pesticides}}{\textit{Total number of questions closed}}\right]\\&\times \frac{\textit{Total annual expenditure of French farms on synthetic pesticides}}{\textit{Total annual expenditure of EU farms on synthetic pesticides}}\end{aligned}$$

The second form of social cost linked to public regulation in France corresponds to the annual financing of the French National Action Plan on Pesticides, Ecophyto. As this plan is partly funded by taxes paid by pesticides manufacturers to the French Water Agencies, only the share of the plan financed annually by public funds was accounted for a social cost, as reported in the French government's budget law. There is no need for an attribution factor, since the plan is totally linked to pesticides (that is to say we consider the attribution factor as 100%).

There are social costs which should be in the scope but which could not be estimated at all because of the current lack of data. This is the case of the French budgets for public research projects investigating the health and environmental risks of synthetic pesticides, their impacts, and their alternatives. We were unable to find public data or estimates on the total amount of the public financing for these projects.

Environmental costs

The second category of social costs relates to environmental costs, defined as expenses paid by public authorities in order

TABLE 2 Forms and description of the environmental costs associated with the use of synthetic pesticides in France.

Components of social costs	Forms of social costs associated with the use of synthetic pesticides	Description of the methodology used to estimate the social costs	Attribution factor
Climate change	Public expenditures related to greenhouse gas emissions	Price of emissions due to manufacture of pesticides in France	100%
Water resource	Public expenditures for water treatment to ensure drinkable water fulfills maximum levels for pesticides	Excess cost of water treatment due to the presence of pesticides	100%
	Public expenditures related to palliative measures of water treatment	Expenses for palliative measures	Could not be computed (absence of data on the share of the measures due to the presence of pesticides)
Biodiversity	Public expenditures related to biodiversity protection (National Action Plans on pollinators, etc.)	Expenses related to biodiversity protection in public accounting	Could not be computed (absence of data on the share of biodiversity erosion linked to pesticides)
Waste management	Public expenditures due to incineration of pesticides waste	Not measured for lack of data	

to ensure the fulfillment of environmental regulations (beyond pesticide regulation) and to implement environmental public policies, as well as the damage, adaptation, or reparation costs incurred by public authorities and third parties when these public regulations are not respected.

As described in Table 2, the environmental costs that we have been able to identify can take the following forms:

- in relations to climate change:
  - public expenditures related to greenhouse gas emissions,
- in relations to water resources:
  - public expenditures for water treatment to ensure drinkable water fulfills maximum levels for pesticides,
  - public expenditures related to palliative measures of water treatment
- in relations to biodiversity:
  - public expenditures related to biodiversity protection
  - excess costs generated because of the degradation of ecosystem services provided by pollinators,
- in relations to waste management:
  - public expenditures due to incineration of pesticides waste.

Other impacts of pesticides are important to mention, such as contamination of aquatic resources such as fish and shellfish due to high concentration of pesticides in water sources. However, there are no public policies identified specifically related to these contaminations, only biodiversity plans at large or water treatment for human consumption. Therefore, no social costs can be estimated based on real expenses related to public policies or actions financed by national or regional institutions.

A first form of social cost is related to climate change and corresponds to the expenditures incurred by public authorities so as to limit the greenhouse gas emissions during the manufacturing of pesticides. We estimated these emissions based on data on the quantities of active substances bought in France, multiplied by the average amount of CO_2 equivalent tons emitted by the manufacturing of synthetic pesticides (the latter as measured through life cycle assessment and computed by the "Base Carbone" database of the French Environmental agency ADEME). In order to estimate the related social costs, several methods exist: the monetary value of each ton of greenhouse gas emitted can either be estimated using the $CO\text{-}_2$ price linked to the European Emissions Trading System, or using the mean value of academic research on the social costs of carbon computed by the IPCC (Environmental Protection Agency, 2016), or the reference shadow price of carbon instituted by the European Union. The two first methods are not fully in line with the theoretical framework adopted in the study, as they result from market dynamics (for the first one) or academic modeling (for the second). However, the third method appears fully in line with the theoretical framework, which requires a direct link with public norms fixing collective limits and objectives. Indeed, the reference shadow price of carbon is intended to be used by public authorities (national and local) to make decisions on investments and policies intended to cap global temperature increase at 1.5°C, as defined in the Paris Agreement signed in 2015. In practice, we used for our calculations the reference shadow price of carbon in 2017 defined by the European Commission which is applicable throughout the EU (Quinet, 2019). The value given by the report is the one in 2018 deflated to correspond to value in 2017.

The mathematical formula used to estimate the social costs linked to the greenhouse gas emissions of synthetic pesticides manufacturing in France is as follows:

$$\textit{Costs of carbon emissions} = \textit{Greenhouse gas emissions per ton of synthetic pesticides manufactured} \times \textit{Quantities of pesticides consumed by French farmers} \times \textit{Reference shadow price of carbon defined by the European Commission in } 2018$$

The second form of social costs relates to the preservation of water resources.

In this domain, one of the main costs we were able to estimate corresponds to the excess expenses incurred by public authorities for water treatment due to the trespassing of synthetic pesticide regulation thresholds in drinking water. When the concentration of pesticides in water is too high, the water must be treated to remove them; thus, the additional cost of treating drinking water can be considered as a social cost of pesticides. In France, the General Commission for Sustainable Development of the French Ministry of Ecology (CGDD) has been able to estimate the costs of agricultural pollution in water resources (Bommelaer and Devaux, 2011). These costs correspond to the additional expenses for households and public authorities compared to a situation without pollution. Among these costs, only the excess expenses of water treatment to obtain drinking water fulfilling public technical norms can be attributed entirely to synthetic pesticides. All other costs (agricultural pollution control, cleaning of water catchments, wastewater treatment, water mixing, cleaning of coastline, etc.) cannot be considered as social costs of synthetic pesticides, because they are either (i) attributable to both nitrogen fertilizers and pesticides without the possibility of identifying the share attributable only to synthetic pesticides, or (ii) attributable only to nitrogen fertilizers. The contribution of pesticide manufacturers to covering these costs through their payments to French Water Basin Agencies has already been taken into account in regulation costs as they are fully targeted at financing the French National Action Plan on Pesticides, Ecophyto, discussed above.

Beyond these treatment costs to ensure drinkable water fulfills public technical norms, the water contamination caused by pesticides is also the cause of additional palliative measures of water treatment: for instance, catching water from further away because the surrounding water catchments are too contaminated, mixing waters from cleaner plants in order to reduce pesticides concentration of the more contaminated ones, treating water to protect biodiversity, etc. As previously described, the French study conducted by the Ministry of Ecology (Bommelaer and Devaux, 2011) estimated the costs of these palliative measures. However, the study does not enable computation of an attribution factor, that is to say isolate the share of responsibility of synthetic pesticides in these palliative measures as opposed to that of other sources of pollution, in particular nitrogen fertilizers.

A third form of social costs is related to the decline of biodiversity, of which synthetic pesticides are a documented cause (Scholes et al., 2018). To address this issue and support the protection of biodiversity, the European Union as well as Member States all have put in place special public funds (Hart, 2015). However, the exact share of responsibility of pesticides in the decline of biodiversity is not known, and the public expenditures linked to biodiversity protection cannot be prorated to them.

Finally, the last form of social cost relates to the management of pesticide waste; it corresponds to the public expenditure engaged to limit or remediate the consequences of the greenhouse gases and toxic substances emitted during the waste incineration of pesticides. In this case too, we were unable to find data on the quantities of synthetic pesticide waste incinerated in France or in the European Union. Therefore, we were not able to estimate the associated environmental and public health costs.

Public health costs

The third category of social costs corresponds to the public health costs of pesticides, that is, the expenses linked to the treatment of diseases provoked by pesticide manufacturing or use.

As detailed above in Table 3, the public health costs that we have been able to identify can take 3 forms:

- public expenditures for the treatment of occupational diseases due to pesticides,
- public expenditures for the treatment of diseases in the general population attributable to pesticide exposure,
- excess costs generated because of farmers' intoxications (public allowances, families' expenses, etc.).

The only diseases that can directly be attributed to synthetic pesticide use and for which we have enough data for the estimation are the ones recognized as occupational diseases for farmers in French legislation (Parkinson's disease and hematologic malignancies—non-Hodgkin lymphoma and multiple myeloma).

The number of cases of illness due to pesticides among farmers and other agricultural workers was estimated in France by Deprost et al. (2018), based on the study of the AGRICAN cohort. We computed an average number of cases per year in the following way: for Parkinson's disease, we divided the number of cases by the number of years after which the population of ill farmers is renewed (10 years) and for lymphomas, we divided the number of cases by the number of years during which the survey was conducted (7 years). The annual figure we obtained corresponds to the number of cases among farmers of

TABLE 3 Forms and description of the public health costs associated with the use of synthetic pesticides in France.

Component of social costs	Forms of social costs associated with the use of synthetic pesticides	Description of the social costs that can be measured and attributed to synthetic pesticide use in France	Attribution factor
Public health costs	Public expenditures for the treatment of occupational diseases due to pesticides	Number of cases of diseases recognized by authorities as due to pesticides (Parkinson's, non-Hodgkin lymphoma) * annual cost of treatment A	100%
	Public expenditures for the treatment of diseases in the general population attributable to pesticide exposure	Annual costs of treatment of these diseases for France (Parkinson's, non-Hodgkin lymphoma)	Could not be computed (absence of data on the share of the cases due to pesticides)
	Excess costs generated because of farmers' intoxications (public allowances, families' expenses)	Not measured for lack of robust data	

Parkinson's caused by pesticide use, and to the excess risk (also called the "population attributable risk") of having non-Hodgkin lymphomas and multiple myeloma because of pesticide use.

We then proceeded to estimate the cost of medical treatment of these excess cases of Parkinson's disease and non-Hodgkin lymphoma attributable to pesticide exposure. The medical cost of treatment of Parkinson's has been estimated by Gustavsson et al. (2011). The medical cost of lymphomas has been assessed by Mounié et al. (2020). For lymphomas, we had trouble estimating the cost because there are many types of non-Hodgkin lymphomas with different types of treatments and different costs for each. On top of that, costs are not estimated for each type of lymphomas. Therefore, we computed a weighted average of the costs of two types of non-Hodgkin lymphomas of other types, which are treated in a similar way but for which we do not have data. As a result, we assume that for a similar treatment, the cost is also similar.

Finally, in order to estimate the social costs linked to health issues, we multiplied the average cost of treatment per year by the mean life expectancy post-diagnosis for Parkinson's disease. For lymphomas, no data was found on the mean life expectancy post-diagnosis. However, we did find data making it possible to approximate the median number of years lived post-diagnosis: after 5 years, the survival rate post-diagnosis is 54% for men and 56% for women (Gisselbrecht, 2009). We assumed that five years is a median number of years lived after the diagnosis and used this figure for our calculations. The mathematical formulae used to estimate the social costs linked to both diseases is as follows:

$$\begin{aligned}&\textit{Costs of treatment of Parkinson's occupational diseases attributed to synthetic pesticides use}\\&= \frac{\textit{Number of occupational cases of Parkinson's diseases attributed to synthetic pesticides over } 10 \textit{ years}}{10}\\&\times \textit{Costs of annual treatment of Parkinson's diseases} \times \textit{Mean life expectancy post diagnosis}\end{aligned}$$

$$\begin{aligned}&\textit{Costs of treatment of occupational cases of lymphomas}\\&\textit{attributed to synthetic pesticides use}\\&= \frac{\textit{Number of occupational cases of over} - \textit{risk of lymphomas attributed to synthetic pesticides over } 7 \textit{ years}}{7}\\&\times \Big[\textit{Costs of treatment of DLBCL lymphomas}\\&\times \frac{\textit{Frequency of DLBCL lymphomas (and similar types)}}{\textit{Frequency of DLBCL and follicular lymphomas (and similar types of both lymphomas)}}\\&+ \textit{Costs of treatment of follicular lymphomas}\\&\times \frac{\textit{Frequency of follicular lymphomas (and similar types)}}{\textit{Frequency of DLBCL and follicular lymphomas (and similar types of both lymphomas)}}\Big]\\&\times \textit{Mean life expectancy post diagnosis}\end{aligned}$$

(DLBCL and follicular), which are the most frequent and for which we have the most data. We weighted each type based on the relative frequencies of each with regards to the frequencies

More broadly, these same diseases are present in the whole population, not just farmers, and are likely to be caused in part by pesticides amongst other factors. The literature review we have conducted enabled us to estimate the orders of magnitude of the health costs of treatment for some of these diseases (Gustavsson et al., 2011; Burns et al., 2013; Luengo-Fernandez et al., 2013). As data is only available at the EU level, we could have multiplied them by the share of the French population in the EU, assuming that the costs and prevalence of these diseases was similar in France as in the wider European Union. However, these costs cannot entirely be attributed to synthetic pesticides and, due to the lack of the current knowledge and data, their exact share of responsibility is not known.

Finally, there are also excess costs generated because of farmers' intoxications due to synthetic pesticides: social security allowances, sick leaves, private costs incurred by farmers' families (remaining health costs at their expense), etc. Unfortunately, data for France is not available, neither any evaluation on the subject. On top of that, there is no public policies that compensate for the loss of quality of life, and thus no real costs for society that can be estimated.

Public financial support to pesticide manufacturing and use

The last category of social costs relates to financial aid granted to support pesticide manufacturing and use by public authorities at different levels (European, national, local). These public financial supports are considered a cost, in line with the public norms approach used to identify social costs.

As detailed above in Table 4, the public financial support that we were able to identify can take three forms:

- public subsidies to pesticides manufacturers,
- public subsidies to farmers that use pesticides,
- reduced rate on Value Added Tax (VAT) for pesticides.

A direct form of public financial support consists of public subsidies directly awarded to pesticide manufacturers. Information on such subsidies is quite fragmented and often not transparent within the European Union. We were unable to find information on subsidies from the French government, but we managed to find data on subsidies from EU institutions to European pesticide manufacturers on the transparency register of the European Commission. As these public subsidies are granted at the EU level, there is a need to estimate the share that is attributable to the use of pesticides in France only. To do so, we used a similar approach as before for regulation costs, i.e., multiplying the total reported subsidies by the ratio between total pesticide purchases of French farms and the total pesticide purchases of EU farms recorded in the Farm Accountancy Data Network (FADN) public database.

Another more indirect form of public financial support consists of public aids provided to farmers who are the main buyers of synthetic pesticides. A major part of this support is linked to the Common Agricultural Policy (CAP), which is the main tool to subsidize farmers across the EU. The CAP is complemented by public financial support provided by national and local public authorities. In addition, national governments, including French authorities, also grant reductions in taxes and social security contributions which directly benefit farmers and can be almost as significant as CAP subsidies (BASIC, 2021). Altogether, these public financial supports (CAP, national and local subsidies, tax and social security reductions) represent a large part of the income of farmers in the European Union. Since the prevalent agricultural systems in the European Union and more specifically in France imply the use of synthetic pesticides, these subsidies can be considered as an indirect public support to maintain pesticide use.

It is possible thanks to French FADN database to estimate the share of public subsidies and fiscal reductions perceived by the group of farmers that use most of pesticides (BASIC, 2021). This group of farmers represent 9% of farms and also 9% of public subsidies and 17% of reductions of taxes. Since only the financial support taken into account here is the one perceived by the main buyer of pesticides, financial supports to organic farming (200 million euros, partly paid by French Water Agencies) are de facto excluded from the perimeter.

We could not establish an attribution factor for these subsidies, that is to say the share of the subsidies directly supporting pesticides purchases.

Finally, the reduction in VAT on pesticides is another important form of public financial support to the pesticide sector. This tool is used by seven EU Member States (Belgium, Cyprus, Poland, Portugal, Romania, Slovenia and Spain) according to the European Commission data on VAT, but not by the French government, which applies the standard VAT rate to pesticide products.

Results

An overview of the results is provided in Tables 5, 6, listing all social costs generated by the use of synthetic pesticides in French agriculture, and providing information on monetary assessment, where applicable. Total value of social costs can be assessed in two steps:

- the baseline value of all social costs attributable to synthetic pesticide use in France amounted to 372 million euros in 2017, as a result of all costs that could be identified and accounted for, and for which both robust data and attribution factor are available
- a complete assessment of all social costs attributable to synthetic pesticide use in France, that we assume to be higher up to 8,205 million euros. This value equals the sum of the social costs linked to pesticides but with some of which an attribution factor could not be computed.

TABLE 4 Forms and description of the public financial support to the sector of synthetic pesticides in France.

Component of social costs	Forms of social costs associated with the use of synthetic pesticides	Description of the methodology used to estimate the social costs	Attribution factor
Public financial support to the sector	Public subsidies to pesticide manufacturers	Total subsidies received by manufacturers at EU-level prorated to French use only	100%
	Public subsidies to farmers that use pesticides	Financial help received by farmers (deducting helps that are directly linked to pesticides use reduction)	Could not be computed (absence of data on the share of the help used to buy pesticides)
	Reduced rate on Value Added Tax (VAT) for pesticides	Not relevant for France	

We estimated regulation costs of pesticides as at least 31.9 million euros in 2017. It can be split in two computable and attributable costs: 1.9 million euros for the budget of pesticides' related activities of European regulation authorities prorated to French activities, and 30 million euros for the National Action Plan Ecophyto. A third cost which should be added but could not be computed is the cost of scientific research on synthetic pesticides and their risks.

We estimated environmental costs of synthetic pesticides as at least 291.5 million euros in 2017. It is composed of two computable and attributable costs: The excess expenses of water treatment due to the presence of pesticides reached between 260 and 360 million euros (we decided to use the lower value of 260 million euros in the analysis). We estimated the greenhouse gas emissions of pesticide manufacturing for French consumption at 31.5 million euros. Two other computable costs were identified but could not be attributed only to pesticides: the palliative measures of water treatment which can be estimated between 40 million euros (20 million euros for mixing waters and 20 million euros for using water from plants further away) and 100 million euros (40 million and 60 million respectively). The expenditures for biodiversity protection amounted to 1,723 million in 2017. One last cost was identified but could not be computed at all: the public expenditures due to the incineration of pesticides waste. As a result, we estimate environmental costs to lie between 291.5 and 2,054.5 million euros.

We estimated health costs of synthetic pesticide use as at least 48.5 million euros, based on the only computable and attributable costs related to occupational diseases: 46.7 million euros for Parkinson's disease and 1.8 million euros for non-Hodgkin lymphoma. The same diseases in the general population and some other diseases are known to be caused by pesticides, but attribution factors could not be computed: we estimated the annual health costs of treatment for diseases partly caused by synthetic pesticides at 1,262 million euros for Parkinson's diseases, 1,101 million euros for prostate cancer, and 2,090 million euros for non-Hodgkin lymphoma and other blood cancers, which correspond to a total of 4,453 million euros per year in health costs. Another cost could not be computed—the excess costs generated because of farmer's intoxication. As a result, we can estimate public health costs to lie between 48.5 and 4,501.5 million euros.

Finally, we estimated the public financial support to the sector at least at 0.4 million euros. Bayer received 0.60 million euros and BASF 1.25 million euros. The other two major actors of the sector did not receive any financial help according to the official EU registry, hence the total amount of public subsidies awarded to the main actors of the sector was 1.85 million euros, of which we can attribute to France 0.4 million euros in 2017. We also estimated the public financial support provided to French farmers who are the main buyers of pesticides (including tax reductions) at 1,600 million euros but could not attribute it to pesticides use only. As a result, we can estimate public financial support to the sector to lie between 0.4 and 2,600.4 million euros.

Discussion

The results show that the overall value of social costs due to synthetic pesticides use in France is at least 372 million euros in 2017 and spans a range of estimates between 372 million and 8,205 million euros. As a comparison, the baseline value of this estimate represents more than the 10% of the 2017 annual budget of the French Ministry of Agriculture and Food (3,587 million euros). To mention, 10 out of 13 types of costs were computed thanks to scientific research or details in public budget. For 6 of them we were able to attribute them to pesticides (for 5 entirely and for the other one, we were able to estimate the share attributable to pesticides). The study aims at pointing out the value of an assessment of social costs related to real public expenditure, as these could be extremely useful as a monitoring indicator for public institutions. Moreover, following the trends of such social costs across time, we could assess the efficiency of public policies targeting these impacts. However, in such

TABLE 5 Summary of the quantified estimates obtained for the social costs associated with synthetic pesticide use in France.

Components of social costs	Forms of social costs associated with pesticide use	Total measured social costs (million euros)	Attribution factor	Social costs attributed to pesticide use (million euros)
Regulation costs	Public budget of regulation authorities prorated to French activity	19.2 = 79.9 x 0.24 total EFSA Budget based on annual report : 79.9 Share of French use based on Eurostat data: 24%	10% based on EFSA annual report	1.9
	Budget of National Action Plans on Pesticides	30 based on ECOPHYTO reports	100%	30
	Budget of public research on the health and environmental risk of synthetic pesticides	*Not computable*		
	Total of regulation costs	**49.2**		**31.9**
Environmental costs	Public expenditures for water treatment because of the presence of pesticides	260 based on French Ministry of Ecology data (Bommelaer and Devaux, 2011)	100%	260
	Public expenditures related to other palliative measures of water treatment	*40* based on French Ministry of Ecology data (Bommelaer and Devaux, 2011)	*Not computable*	
	Public expenditures related to biodiversity protection	*1,723* *based on Eurostat data*	*Not computable*	
	Public expenditures related to greenhouse gas emissions due to manufacturing of pesticides used in France	31.5 French pesticides use (Eurostat) (cf Table 6) emissions per types of pesticides (Base Carbone) (cf Table 6) GWP per types of emissions (IPCC, 2013) (cf Table 6) shadow price of carbon based on EU Commission (Quinet, 2019): 54 € per tCO2e	100%	31.5
	Public expenditures due to incineration of pesticides waste	*Not computable*		
	Total of environmental costs	**2,054.5**		**291.5**
Public health costs	Public expenditures for the treatment of occupational diseases caused by pesticides	48.5 number of Parkinson's cases per year (Deprost et al., 2018): 1000 number of lymphoma's cases per year (Deprost et al., 2018): 328 total medical cost of Parkinson's diseases per year in France (Gustavsson et al., 2011): 3,595.64€ total medical cost of lymphomas per year in France (Mounié et al., 2020): 5,550.24 € (estimate average cost based on weighting the different types of lymphomas) life expectancy after diagnosis (Gisselbrecht, 2009): 13 relative survival rate: 56% for men and 54% for women (Gisselbrecht, 2009)	100%	48.5

(Continued)

TABLE 5 (Continued)

Components of social costs	Forms of social costs associated with pesticide use	Total measured social costs (million euros)	Attribution factor	Social costs attributed to pesticide use (million euros)
	Public expenditures for the treatment of consumers' diseases caused by pesticides	*4,453* cost of Parkinson's diseases for France (Gustavsson et al., 2011) : 1,262 cost of prostate cancer for Europe (Luengo-Fernandez et al., 2013) :8,430 cost of lymphomas and blood cancer for Europe (Burns et al., 2013) : 16,000 share of French population compared to Europe: 13%	*Not computable*	
	Excess costs generated because of farmers' intoxications (public allowances, families' expenses)	*Not computable*		
	Total of public health costs	**4,501.5**		**48.5**
Public financial support to the sector	Public subsidies for pesticide manufacturers prorated to French activity	0.4 total EU: 1.8 share of French use based on Eurostat data: 24%	100% (ratio of French use: 23%)	0.4
	public subsidies for farmers that use pesticides	*1,600* total amount of financial support for French farmers (BASIC, 2021) : 17,000 share of supports perceived by main buyer of pesticides (BASIC, 2021) : 0.096	Not computable	
	Total of public financial support	**2,600.4**		**0.4**
	Total of social costs	**8,205.4**		**372.3**

TABLE 6 Summary of the quantified estimates obtained for the social costs associated with synthetic pesticide use in France.

	Fungicides	Herbicides	Insecticides	Molluscicides	Plant growth regulator
French use of active substance in kg (Eurostat data)	29,769,882	30,230,424	3,773,304	712,253	3,462,443
Kg CO_2/kg active substance (Base Carbone—ADEME)	5.54	8.33	23.7	8.06	7.86
Kg N_2O/kg active substance (Base Carbone—ADEME) * relative GWP (IPCC, 2013)	= 0.00015 * 265	= 0.00022 * 265	= 0.00063 * 265	= 0.000222 * 265	= 0.00021 * 265
Kg CH_4/kg active substance (Base Carbone—ADEME) * relative GWP (IPCC, 2013)	= 0.01855 * 28	= 0.02548 * 28	= 0.00543 * 28	= 0.0285 * 28	= 0.0241 * 28

perspective a level of consistency should be pursued, as bias in magnitude could occur due to an increase in knowledge on the subject (e.g., availability of new, robust data; development of new attribution factors…). In fact, to be able to include such indicators as a monitoring KPI for public authorities, the former computations need to be updated in the event of knowledge on new perimeters and data availability. The study provides a list of topics and indicators that need to be explored, as the issue of pesticides is very timely and research only provides a partial panorama on the assessment of related impacts.

The methodology provided by this study could serve as a basis for an assessment of social costs of the use of synthetic pesticides in other Member States and third countries. This would result in a broader tool to monitor EU public policies on the subject. Nevertheless, a first effort should be invested in exploring impacts related to EU exported pesticides. In fact, the

EU is the first exporter of pesticides in the world (amounting to 1/3 of worldwide annual production) and European legislation does not ban the export of products which go beyond the toxicity level authorized within its Member States.

Beyond pesticides, this methodology could also be applied to other topics. For example, an assessment of social costs related to the use of synthetic fertilizers, mechanization, and seeds could provide complementary assessment, provided that sufficient data availability and attribution factors can be identified for such topics. If such assessment is compiled, it would make it possible to draft an overview of the impacts of the main pillars of modern agricultural production systems that could mean a major step forward to enable public authorities to design efficient internalization strategies. Nevertheless, it should be noted (and accounted for) that there is an interdependency across pillars, meaning that strategies implemented to reduce the impacts of one pillar might affect the impacts generated by the others. For example, a tax on pesticide manufacturers might result in an increase of sales prices and consequent social externalities faced by farmers, who in return might review their business plan and redistribute financial resources invested in mechanization practices or seeding strategies.

Broadly speaking, the norm-based approach used to identify social costs provides a valuable approach to the internalization of externalities in the context of pesticides. As claimed by William Kapp in its "Social costs of business enterprise" (Kapp, 2000), general neoclassical theory on externalities find its basis on the concept of social optimum. This relates to the idea according to which it is possible to identify (or at least approximate) an equilibrium point of the market where social welfare is maximized. The social optimum is used as reference in designing internalization strategies, such as the Pigouvian tax. In fact, without the identification of a social optimum, it would be impossible to define the optimal amount of tax for internalizing the externalities. On this point, Kapp reflects on the non-operationality of the social optimum, as he claims its foundational concept of present value of future revenues is not predictable (Kapp, 2000). In other words, essential factors influencing social optimum (e.g., institutional behavior patterns, future demand, future technical improvements) are by definition unpredictable; therefore assessing its optimal level is unrealistic. He instead proposes another tool for designing environmental policy (and related internalization strategies): the social minima. As opposed to social optimum, the social minima sets not policy objectives, but benchmarks which enable policy makers to appraise private practices and public policies and help trace the effect of different institutional arrangements and predicting general direction of social processes (Kapp, 2000). This study presents an approach very much in line with the idea of policy benchmarking, as the methodology is developed from the identification of social costs according to public norms that, in many cases, are there to protect society and ensure a threshold of minimum social welfare after which loss for society are against the social values defined by the society itself.

To conclude, this paper provides a methodology to compute real costs paid by public institutions due to pesticide use in France. The results help public authorities to identify financial flows of public funding with an impact perspective. In particular, it helps in assessing the relation between public budgeting and the social costs faced to mitigate the impacts generated by the use of synthetic pesticides, within a methodological framework based on the social norms that are at the core of the public system. For this reason, the results, along with the methodology, could serve as a key monitoring indicator for the implementation of public policies in the context of the growing social and environmental issues public authorities face. The methodology would require some efforts to consolidate and enrich this first attempt at implementation. Moreover, such a framework could be applied outside the issue of pesticides on other subjects linked to agricultural systems, such as fertilizers and potentially mechanization and seeds.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CA and DM conceived the paper. DM performed the quantitative assessment of the different social cost in collaboration with CA. DB, DM, CA, and PB defined the conceptual framework and contributed to the introduction and to the discussion. DB edited the manuscript. All authors discussed results, contributed to reviewing the manuscript, and approved the submitted version.

Acknowledgments

We thank the two reviewers and the editor for their helpful comments. We also thank Manon Ferdinand and Océane Duluins for their help in the preparation of the manuscript. We are grateful to CCFD-Terre Solidaire et Pollinis for the funding of seminal studies that enabled us to collect the initial data used in this paper.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ayres, R. U., and Kneese, A. V. (1969). Production, consumption, and externalities. *Am. Econ. Rev.* 59, 282–297.

Baldi, I., Cordier, S., Coumoul, X., Elbaz, A., Gamet-Payrastre, L., Lebailly, P., et al. (2013). *Pesticides: Effets sur la santé*.

BASIC (2021). *Analyse de la création de valeur et des coûts cachés des pesticides de synthèse*. Available online at: https://lebasic.com/wp-content/uploads/2021/11/BASIC_Etude-Creation-de-Valeur-et-Couts-Societaux-Pesticides_20211125.pdf

Benton, T. G., Bieg, C., Harwatt, H., Pudasaini, R., and Wellesley, L. (2021). *Food System Impacts on Biodiversity Loss. Three Levers for Food System Transformation in Support of Nature.* Chatham House, London.

Berger, S. (2008). *K.* William Kapp's theory of social costs and environmental policy: Towards political ecological economics. *Ecologic. Econ.* 67, 244–252. doi: 10.1016/j.ecolecon.2008.05.012

Bommelaer, O., and Devaux, J. (2011). Coûts des principales pollutions agricoles de l'eau. *Études et Documents* 52, 28.

Bourguet, D., and Guillemaud, T. (2016). The hidden and external costs of pesticide use. *Sustain. Agricult. Rev.* 16, 35–120. doi: 10.1007/978-3-319-26777-7_2

Burns, C. J., McIntosh, L. J., Mink, P. J., Jurek, A. M., and Li, A. A. (2013). Pesticide exposure and neurodevelopmental outcomes: review of the epidemiologic and animal studies. *J. Toxicol. Environ. Health, Part B* 16, 127–283. doi: 10.1080/10937404.2013.783383

Cannan, E. (1921). A. C. Pigou. the economics of welfare. *Econ. J.* 31, 206–213. doi: 10.2307/2222816

Carvalho, F. P. (2017). Pesticides, environment, and food safety. *Food Energy Secur.* 6, 48–60. doi: 10.1002/fes3.108

Coase, R. H. (2013). The problem of social cost. *J. Law Econ.* 56, 837–877. doi: 10.1086/674872

Deprost, P., Castet, J.-B., Esclous, L., and Toussaint, X. (2018). *La création d'un fonds d'aide aux victimes de produits phytopharmaceutiques. Report* 285.

Dereumeaux, C., Fillol, C., Quenel, P., and Denys, S. (2020). Pesticide exposures for residents living close to agricultural lands: a review. *Environ. Int.* 134, 105210. doi: 10.1016/j.envint.2019.105210

Directive 2009/128/EC *of the European parliament and of the Council of 21 October 2009 establishing a framework for community action to achieve the sustainable use of pesticidestext with EEA relevance*. (2009). p. 16.

EFSA (2021). *Neonicotinoids: EFSA assesses emergency uses on sugar beet in 2020/21*. Available online at: https://www.efsa.europa.eu/en/news/neonicotinoids-efsa-assesses-emergency-uses-sugar-beet-202021 (accessed August 10, 2021).

Environmental Protection Agency (2016). *Factsheet: Social Cost of Carbon*. Available online at: https://www.epa.gov/sites/default/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf

European Commission, Directorate General for Agriculture and Rural Development, and EEIG Alliance Environnement. (2020). *Evaluation of the impact of the CAP on water: Final report.* Publications Office. Available online at: https://data.europa.eu/doi/10.2762/63371 (accessed August 10, 2021).

Garrigou, A., Laurent, C., Berthet, A., Colosio, C., Jas, N., Daubas-Letourneux, V., et al. (2020). Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. *Safety Sci.* 123, 104527. doi: 10.1016/j.ssci.2019.104527

Girardin, P., and Bockstaller, C. (2000). Assessment of potential impacts of agricultural practices on the environment: The AGRO*ECO method. *jama* 13, 36. doi: 10.1016/S0195-9255(99)00036-0

Gisselbrecht, C. (2009). *Les lymphomes non hodgkiniens, Collection FMC de la revue Hématologie*. John Libbey Eurotext, p. 142.

Gupta, A. K., and Prakash, A. (1993). On Internalization of Externalities. *Working paper, Indian Institute of Management*, 26.

Gustavsson, A., Svensson, M., Jacobi, F., Allgulander, C., Alonso, J., Beghi, E., et al. (2011). Cost of disorders of the brain in Europe 2010. *Euro. Neuropsychopharmacol.* 21, 718–779. doi: 10.1016/j.euroneuro.2011.08.008

Hart, K. (2015). *Green Direct Payments: Implementation Choices of Nine Member States and their Environmental Implications*. IEEP, London.

Independent Evaluation Group (2011). *Impact Evaluations in Agriculture: An Assessment of the Evidence*. World Bank. Available online at: https://openknowledge.worldbank.org/handle/10986/27794 (accessed August 10, 2021).

IPCC (2013). Climate Change 2013: The Physical Science Basis. *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Chapter 8: Anthropogenic and Natural Radiative Forcing.

Kapp, K. W. (2000). *The Social Costs of Business Enterprise*. Spokesman.

Klaassen, G. A., and Opschoor, J. B. (1991). Economics of sustainability or the sustainability of economics: different paradigms. *Ecol. Econ.* 4, 93–115.

Köhler, H.-R., and Triebskorn, R. (2013). Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? *Science* 341, 759–765. doi: 10.1126/science.1237591

Leon, M. E., Freeman, L. E. B., Douwes, J., Hoppin, J. A., Kromhout, H., Lebailly, P., et al. (2011). AGRICOH: a consortium of agricultural cohorts. *Int. J. Environ. Res. Public Health* 8, 1341–1357. doi: 10.3390/ijerph8051341

Loi Labbé (2014). n°*2014-110 du 6 février 2014 visant à mieux encadrer l'utilisation des produits phytosanitaires sur le territoire national*, 2014-110.

Luengo-Fernandez, R., Leal, J., Gray, A., and Sullivan, R. (2013). Economic burden of cancer across the European Union: a population-based cost analysis. *Lancet Oncol.* 14, 1165–1174. doi: 10.1016/S1470-2045(13)70442-X

Matthews, G. (2015). *Pesticides: Health, Safety and the Environment*. New York, NY: John Wiley and Sons.

Medarova-Bergstrom, K. (2015). *Tracking Biodiversity Expenditure in the EU Budget, Part 1-Guidance on definition and criteria for biodiversity expenditure in the EU budget*.

Mounié, M., Costa, N., Conte, C., Petiot, D., Fabre, D., Despas, F., et al. (2020). Real-world costs of illness of Hodgkin and the main B-Cell Non-Hodgkin lymphomas in France. *J. Med. Econ.* 23, 235–242. doi: 10.1080/13696998.2019.1702990

Quinet, A. (2019). *The Value for Climate Action A Shadow Price of Carbon for Evaluation of Investments and Public Policies Report by the Commission Chaired by Paris*.

Robinson, L. A., Hammitt, J. K., Chang, A. Y., and Resch, S. (2017). Understanding and improving the one and three times GDP per capita cost-effectiveness thresholds. *Health Policy Plann.* 32, 141–145. doi: 10.1093/heapol/czw096

Scala, B. (2021). *Pesticides: Et maintenant que fait-on?* Inserm Le Magazine.

Scholes, R. J., Montanarella, L., Brainich, E., Barger, N., Ten Brink, B., Cantele, M., et al. (2018). *IPBES (2018): Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*.

Scientific Applications International Corporation (SAIC), Curran, M. A., National Risk Management Research Laboratory (US), and Office of Research and Development, E. P. A., United States. (2006). *Life-cycle Assessment: Principles and Practice*.

Sexton, S. E. (2007). The economics of pesticides and pest control. *Int. Rev. Environ. Resour. Econ.* 1, 271–326. doi: 10.1561/101.00000007

Special Report 15/2020 (2020). *Protection of wild pollinators in the, E. U. —, Commission initiatives have not borne fruit. European Court of Editors*, 61.

Wagner, S., Fantke, P., Theloke, J., and Friedrich, R. (2010). Quantification of pesticides used in agriculture in the EU-27. *Geophysic. Res. Abstr.* 12, EGU2010-12273.