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Assessment of policy instruments for pesticide use reduction in Europe; Learning from a systematic literature review

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ABSTRACT

Intensive and worldwide usage of conventional pesticides on arable land has led to varying problems for the environment and human health. Consequently, many governments and several private actors actively stimulate reduction of pesticide use. This paper focuses on the effectiveness of public and private policy instruments in terms of reducing pesticide use by farmers via a systematic literature review of 78 articles published between 1967 and 2017. The geographical focus area was Europe. The review determined that no specific instrument is guaranteed to reduce pesticide use. Instead, characteristics comprising an instrument were confirmed to be beneficial to reducing pesticide use. In particular, mixes of instruments, with varying degrees of authoritative force, applied at multiple scales with stakeholder collaboration were identified as beneficial to reducing farmer pesticide use. It is implied within the literature that instruments comprised of such characteristics aid reducing pesticide use due to facilitating consideration of heterogeneous farm and farmer characteristics.

1. Introduction

In the last 50 years, the problems and risks that conventional pesticide usage has posed to the environment via soil and water contamination and the presence of carcinogenic chemicals has led to global steps to reduce and regulate their use (Skevas et al., 2013; Barzman et al., 2015; Handford et al., 2015; Damalas, 2016; Lamichhane et al., 2016a; Kim et al., 2017). Alternative forms of more sustainable crop protection have been developed to guarantee food security whilst reducing negative impacts on health and environment - among other things by promoting biological controls, technologies such as precision agriculture, or more holistic approaches such as Integrated Pest Management (IPM) (Karuppuchamy and Venugopal, 2016; Lamichhane et al., 2016a, 2017a; Lamichhane, 2017). Despite the development and promotion of alternative methods, barriers to reducing conventional pesticide use persist, including a lack of knowledge of alternative methods, a lack of funds, labour, time and tools and concerns over crop yield productivity and profitability (Van Eerdt et al., 2014; Lefebvre et al., 2015; Birch et al., 2016; Lamichhane et al., 2016b; Doonan, 2017). As a consequence, pesticide use reduction will not emerge spontaneously.

To stimulate farmers to reduce conventional pesticide use, governments have employed a variety of public policy instruments such as legal prescriptions (maximum doses or even bans of particular chemicals), taxes and subsidies. Private actors (food processors, retailers etc.) have employed a variety of private policy instruments such as premiums, knowledge transfer, technical assistance. This paper focuses on public and private policy instruments, which in this context are defined as the set of techniques by which behavioural change among a particular target group, in this case farmers, is pursued (cf. Mickwitz, 2003; Bemelmans-Videc et al., 2011; Salazar-Morales, 2017; Giomi et al., 2018).

Research on policies for promoting reduction of pesticide use has been conducted for over 25 years (e.g. Falconer, 1998; Oskam et al., 1997), often focusing on economic based instruments such as incentives and taxation (e.g. Brewer and Goodell, 2012; Böcker and Finger, 2016; Finger et al., 2017). While providing valuable insights, these studies neither provide much insight into the relative effectiveness between the variety of different instruments, nor into which combinations of instruments are more likely to reduce pesticide use. Whilst the benefits of

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some instrument characteristics are well established, others are debated. For example, instrument mixes, incentivising instruments (carrots) and a clear instrument aim and target have been established in aiding achievement of a desired policy goal (Howlett, 2004, 2009; Bemelmans-Videc et al., 2011; Kohoutek, 2014).

Debate is still identified in areas including the level at which an instrument is applied and those who are involved in an instruments' application. Whilst instruments applied at national level are argued to encompass larger pesticide usage, it has been questioned whether they adequately consider differences in farmer attitude, topography or climate which impact pesticide usage (Skevas et al., 2013; Liefferink et al., 2014).

Recent literary attention has focused on the importance of interactive and self-governance arrangements with the inclusion of private actors for altering pesticide use due to farmer reliance on markets and the increase of accountability (Howlett, 2009; Mayer and Gereffi, 2010; Barzman et al., 2015). However, Lamicchane and Messéan (2016) question whether retailers are a constraint to promoting alternative approaches to conventional pesticide use due to their high standards. Other scholars maintain the essential nature of public actors in centralised arrangements to prevent disorganisation found in the interplay of multiple actors and the absence of an environmental focus in the profit maximising nature of private actors (Thorlakson et al., 2018; Hellström and Jacob, 2017).

This paper aims to contribute to the above knowledge gaps by providing an overview, via a systematic literature review, of a variety of different instruments which may aid pesticide use reduction in arable land (by comparison to a determined benchmark) and ascertaining the benefits of certain instrument characteristics to this. The geographical scope was limited to Europe to account for the influence of state of development on pesticide use (see e.g. Sugavanam, 1996) as well as potential influences of European food quality standards and the use of pesticides in food exporting countries from other continents (Okello and Okello, 2010; Lechenet et al., 2017), both of which can influence the effectiveness of instruments that promote reduction of pesticide use. Furthermore, it considers the varying national scale policy initiatives and corresponding instruments within EU countries' national action plans to reduce pesticide reliance (e.g. French and Danish policy efforts) (Falconer, 1998; Liebman et al., 2016; Hossard et al., 2017; Lechenet et al., 2017). Arable land is defined as that utilised to grow crops, including glasshouse horticulture, tree and flower cultivation and open-air horticulture (Eurostat, 2017).

2. Theoretical framework

2.1. Dependent variable

In the current study, we position effectiveness as the dependent variable. We conceptualise effectiveness as the capability of a policy instrument to achieve the outcome of a degree of farm reduction of conventional pesticide use, whether or not due to the utilisation of alternative methods to protect their crops from pests and diseases (e.g. crop rotation, hygiene, biological measures) (Barzman et al., 2015; Giomi et al., 2018). Conventional pesticides are those synthesised by agrochemical companies (Lamichhane et al., 2016a).

Merely studying pesticide use is sometimes critiqued for not being a guarantee of lessening the risks of eventual environmental impact (Peshin et al., 2009; Barzman and Dachbrodt-Saaydeh, 2011; Möhring et al., 2019). Reduction can be further specified according to volume, treatment frequency index or toxicity but these go beyond the purpose of our paper (Oskam et al., 1997; Möhring et al., 2019; Lechenet et al., 2017). In this instance, reduction is utilised to indicate the general progression to effectiveness and in order to have a measure that can be used to compare studies in a relatively unambiguous way (Peshin et al., 2009; Skevas et al., 2012; Barzman et al., 2015; Giomi et al., 2018).

2.2. Independent variable

Public and private policy instruments and their combinations form the independent variable in the literature review conducted here. To achieve effectiveness, instruments should be intentionally selected and designed for the situation in which they are applied (Schneider and Sidney, 2009; Chindarkar et al., 2017).

There is a rich body of literature on policy instruments. In policy scientific literature, usually a distinction is made between three types of policy instruments: legal or regulatory instruments, economic instruments, and communicative or informational instruments (e.g. Hood, 1983; Vedung, 1998; Brukas and Sallnäs, 2012). As Mees et al. (2014: 2) explain, "*Each type is based on a different rationale regarding the way actors are steered: by restricting or allowing behavioural options (legal instruments), by changing the cost-to-benefit ratios of these options (economic instruments), or by informing about options (communication instruments)*". This categorisation of policy instruments also applies to private policy instruments (Runhaar, 2016).

In this paper we employ a more detailed categorisation and characterisation of policy instrument in order to know more about 'what works' (cf. Runhaar, 2016). Based on the literature, we identify five characteristics that comprise an instrument and that can facilitate or hinder their effectiveness (based on Schneider and Ingram, 1997; Howlett, 2014). The first characteristic regards an instruments' aim: clear aims enhance effectiveness (Howlett, 2009; Stallman and James, 2017).

The second characteristic is the spatial orientation of an instrument – i.e. country, spatial scale and/or farm specific (Tey et al., 2014; Stallman and James, 2017). The broader the geographical coverage of an instruments' application, the greater the scale of pesticide use targeted (Liefferink et al., 2014). Similarly, an instrument must also achieve wider social acceptance across potentially heterogeneous landscapes to generate behaviour change (Waterfield and Zilberman, 2012; Lefebvre et al., 2015).

The third characteristic is who (which actors) are involved in an instrument. This refers to: (i) who is targeted; (ii) who is leading the application of the instrument; (iii) the governance arrangement utilised. Potential actors include governmental, market and civil society representatives, interacting in different ways (hierarchical, on an even basis or rather independent) (Driessen et al., 2012; Runhaar, 2016). Actor configurations often have a set of preferred instruments (Howlett, 2009; Driessen et al., 2012).

A fourth characteristic is what key strategy is used: what resources are employed to promote behavioural change? Strategies commonly identified within environmental governance literature are regulatory, organisational, economic and informative strategies (Hood, 2007). Regulatory resources utilise authority from government legal power and other obligatory mechanisms to restrict or permit certain behaviours (Weber et al., 2011). Organisational resources utilise structural change via government staff and organisations to alter existing procedures of agricultural sectors (Howlett, 2009; Runhaar, 2016). Economic resources influence actions through provision of incentives or disincentives (Borrás and Edquist, 2013). Information resources use communicative or knowledge tools to influence voluntary action. (Hood, 2007; Howlett, 2009).

The last characteristic refers to how an instrument is applied. This relates to whether the instrument is applied singularly, in conjunction with another instrument and the time frame for which it is applied. Single instrument application is perceived to generate fewer effective outcomes than those operating in a reinforcing mix (Howlett, 2009; Kohoutek, 2014). Some instruments are more effective in the short term than others (e.g. bans as opposed to taxes) (Skevas et al., 2013).

2.3. Situational and contextual factors influencing effectiveness

The effectiveness of policy instruments depends on a variety of

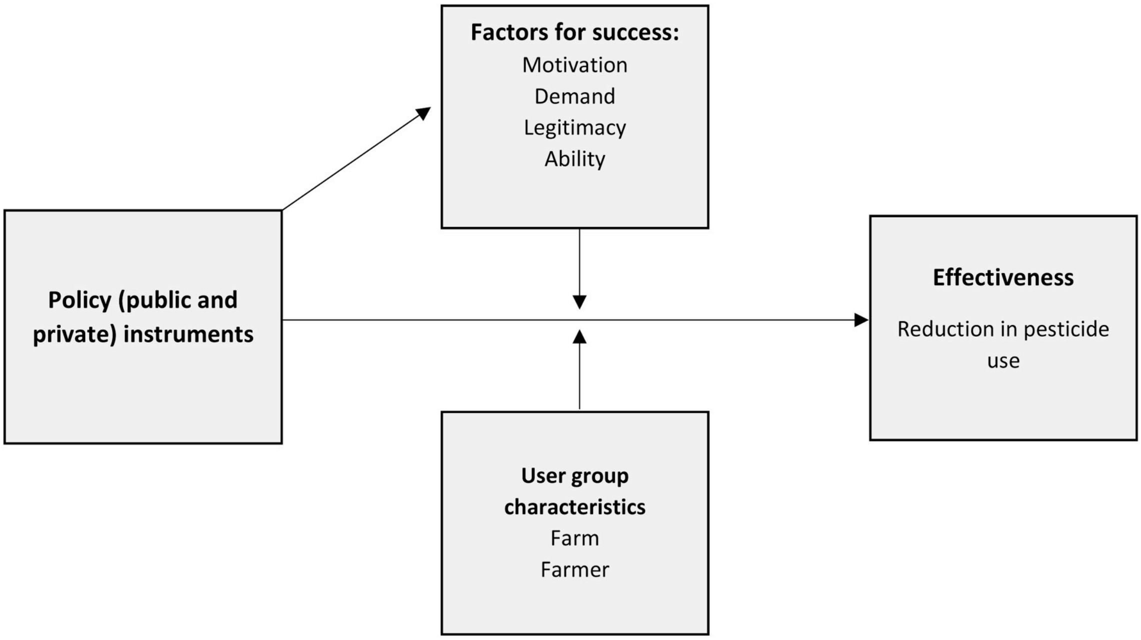

Fig. 1. Relationship between research variables – not all relationships are measured in this paper.

factors that influence or mediate the ways in, and extent to which instruments affect pesticide use. According to Runhaar et al. (2017), behavioural change by farmers depends on the extent to which farmers are (i) enabled, (ii) legitimised, (iii) demanded and (iv) motivated to change their behaviour towards the desired policy goals. The presence or absence of these four factors partly is a given, and partly can be provided by instruments. The first factor relates to ability, such as time, skills, information or resources farmers should possess to reduce their pesticide use aided by information or economic instruments (Timprasert et al., 2014; Tey et al., 2014; Wyckhuys et al., 2018; Runhaar et al., 2017). Employing alternative crop protection methods is more time, labour, information and knowledge intensive than conventional farming systems (Beckmann and Wesseler, 2003; Lefebvre et al., 2015).

The second factor relates to whether or not using or reducing pesticide use and its consequences is legitimised, supported or accepted by legal or social norms (Feola and Binder, 2010; Hall et al., 2015; Runhaar et al., 2017). Legitimacy can be enhanced by instruments such as covenants or interactive governance arrangements (Bouwma et al., 2015).

The third factor is whether or not farmers are directly or indirectly requested to reduce pesticide use, in a negative way (e.g. NGO campaigns) or in a positive way (e.g. a consumer demand for pesticide-free food). The greater the demand and coercion an instrument provides, the more actors must comply and reduce their pesticide use (Le Dang et al., 2014; Runhaar et al., 2017). In the instance of reducing pesticide use, demand can be influenced by formal requirements and regulations, consumer awareness and market pressure (Runhaar et al., 2017).

The fourth factor is willingness to change pesticide use and adopt alternative farming practices, which can originate from an intrinsic motivation or an extrinsic one (commercial opportunities for instance).

The four factors are interrelated. For example, the presence of ability can often enhance farmer motivation to reduce their pesticide use as seen in an example of types of land tenures (Runhaar et al., 2017). Farmers who are not in ownership of the farm are less likely and less able to switch to IPM (Wilson and Tisdell, 2001; Nave et al., 2013). Due to an absence of long term connection with the land, they are less willing and less able to invest long term in soil and plant health to enable IPM. Accordingly, changes in tenure periods or compensatory instruments such as subsides may be helpful to overcome this barrier (Wilson and Tisdell, 2001; Nave et al., 2013; Ahnström et al., 2009).

Other factors that influence the effectiveness of an instrument are user group characteristics, in this case farmer and farm characteristics (Howlett and Rayner, 2013; Böcker and Finger, 2016; Giomi et al., 2018). Farm aspects such as size and cultivation type may influence pesticide use. For example, farm types like monoculture or flower cultivation have little variation in resistance genes which makes these more susceptible to pest colonisation (Raseduzzaman and Jensen, 2017; Stenberg, 2017). Farmer aspects such as existing farmer attitude may also influence pesticide use. These attitudes may for example influence management styles – such as environmental stewards, production maximisers or network entrepreneurs (Brodt et al., 2006; Edward-Jones, 2006). Aspects such as farmer tenure, income reliance, existing knowledge and resources may further impact pesticide use (Wilson and Tisdell, 2001; Timprasert et al., 2014; Tey et al., 2014; Lamichhane et al., 2017b). For example; farmers who rely on their farms for 50% or less of their income may need greater regulatory or information-based instruments to stimulate use of IPM. Some authors suggest considering farm and farmer characteristics in an instruments' design in order to enhance its effectiveness (Manner and Gowdy, 2010). For instance, farmers with little knowledge about IPM and lack of resources may require information and economic based instruments such as training and subsidies to overcome this barrier (Tey et al., 2014).

Fig. 1 illustrates the relationship between the discussed factors.

3. Methodology

The research approach included a systematic literature review of scientific, peer reviewed papers that reported on the use of policy instruments surrounding pesticides with explicit mention of IPM as a sustainable crop protection practice. The sustainable protection practice of IPM was a necessary element due to the European focus of the paper and the mandatory implementation of the practice by all professional users of pesticides. The papers were selected with a geographical delineation of a European or developed country (due to higher likelihood of corresponding instruments and exogenous characteristics with Europe). Firstly, theoretical literature on pesticide use and environmental policy instruments was considered [step A]. This developed a framework for analysis of effective instruments and the influence of external factors [B]. This framework was applied via coding to 78

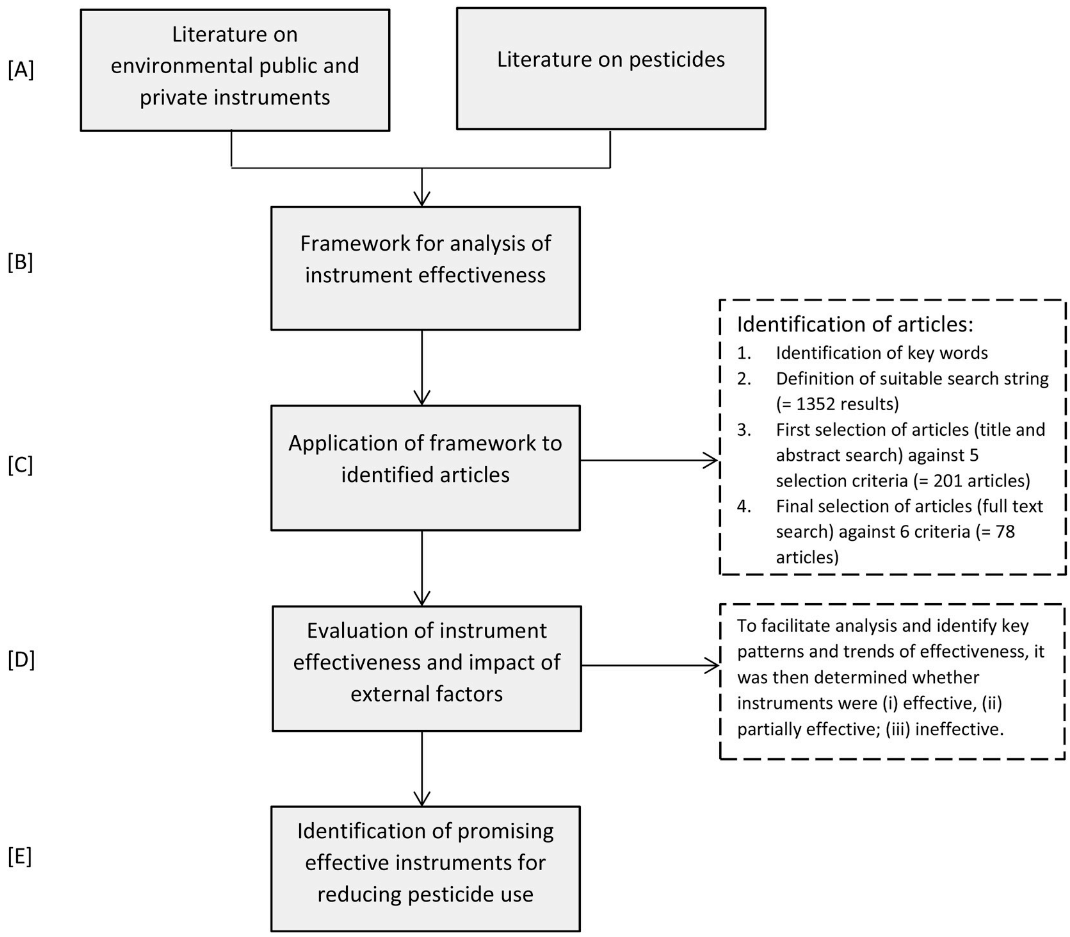

Fig. 2. Methodological framework.

selected papers with 235 reports of instruments [C]. These papers were identified through application of a devised search string and selection criteria from Scopus (1967–2017). The selected papers were carefully read and coded (see Annex 2) by the first author, in order to guarantee consistency in coding. From this, an evaluation of instruments for reducing pesticide use was conducted by identifying how these instruments addressed the factors influencing (in)-effectiveness [D]. This enabled identification of which instruments could stimulate pesticide use reduction [E]. Fig. 2 provides an overview of the research steps [A through E] taken. Annex 1 details the steps taken for compiling a literary database. Annex 2 gives the formation and application of the applied analytical framework.

The dependent variable – i.e. effectiveness – was coded as follows:

- Effective - an instrument achieved a degree of pesticide use reduction at farm level;
- Partially effective – whereby an instrument has prompted uptake of alternative forms of crop protection but has not led to pesticide use reduction at farm level (either because it could not be detected in the study for various reasons or because the need for pesticide use remained);
- Ineffective – pesticide use has not reduced at farm level.

Annex 2. provides some quotes that are illustrative of how reports were coded in terms of effectiveness.

4. Results

4.1. Overview of instruments reported in the literature

Over time, an increasing number of papers regarding instruments for reducing pesticide use have been published, particularly post 2009 (e.g. Trevisan et al., 2009; Skevas et al., 2012; Dong et al., 2017). Such a pattern could indicate increased concern surrounding pesticide use but may also reflect the introduction of the EU Directive on Sustainable Use of Pesticides 2009/128/EC in 2009 (EC, 2009). From the papers reviewed, countries with the greatest scholarly attention included the Netherlands (19%), the UK, France, and Denmark (all 12%) (e.g. Van der Vlist, 2007; Barzman and Dachbrodt-Saaydeh, 2011; Cross, 2013; Delière et al., 2015; Hossard et al., 2017).

Within the review, 235 policy instrument reports were identified. Table 1 provides an overview of the main characteristics identified for each instrument. Taxes (17%), prescriptions (15%), subsidies (14%) and advisory services (14%) were the most commonly identified instruments in the review.

4.2. Reported effectiveness

Below we present the results of our analysis of scientific, empirical evaluations of instruments that aim at reducing pesticide use, organised round the characteristics of instruments discussed in Section 2. We then report on factors beneficial to effectiveness.

Table 1
Main patterns in policy instrument characteristics. 'n/a' denotes an absence of information in the reviewed literature. Single/Mixed: standalone instrument of combined with other (mixed).

Which				How		Where		What		Who	
Governance resource	Policy Instrument	Description	Carrot/ Stick	Time frame	Single/ mixed	Targeted/ set level	Arable subsector	Aim	Targeted actor	Leading actor	No. of reports
Regulatory	Prescription	Laws authoritatively put forward (e.g. pesticide registration/setting of pesticide standard levels.	Stick	Long	Single	National	'n/a'	Environment	Farmers	National Govt.	35
	Covenants	Stakeholder gentlemen's agreement on agreed actions of pesticide use.	Carrot	Long	Mixed	National/ Farm	'n/a'	Environment	Farmers	National Govt./ Farmers	7
	Bans	Constraining the use of certain substances.	Stick	Long	Single	National	'n/a'	Environment	Farmers	National Govt.	21
	Zoning	Spatial division and restrictions on inputs depending on the surrounding environment (e.g. proximity to nature reserves).	Stick	'n/a'	Mixed	National	'n/a'	Environment	Farmers	National Govt.	4
	Monitoring	Enforced supervision to ensure appropriate actions are occurring.	Stick	Long	Mixed	National	'n/a'	Environment	Farmers	National Govt.	13
	Penalties	Financially penalized for breaking laws on pesticide use.	Stick	Long	Mixed	Sector specific	Open air	Environment	Farmers	National Govt.	3
Economic	Subsidies	Compensating an individual for actions relating to the reduction of pesticide use.	Carrot	Long	Mixed/ Single	National	'n/a'	Environment	Farmers	National Govt.	32
	Taxes	A financial charge on the purchase of pesticide units.	Stick	Long	Single	National	'n/a'	Environment	Farmers	National Govt.	41
Informative	Certification	Communication on chemical use for a product.	Carrot	Long	Single	National	'n/a'	Environment	Farmers/ Consumer	Private companies	17
	Training	Sharing and imparting of knowledge and practices to reduce pesticide use.	Carrot	Long	Mixed	National	'n/a'	Environment	Farmers	National Govt.	28
	Advisory Services	The voluntary sharing of information and support to aid and improve decisions on pesticide use.	Carrot	Long	Mixed	Farm	'n/a'	Environment	Farmers	Private companies	33
	Information campaign	The biased provision of information to change opinions on pesticide use.	Stick	'n/a'	Single	'n/a'	Vines	Social	Farmers	National Govt.	1

4.2.1. *Pesticide use reduction in relation to which instrument is applied*

Identification of single instrument application was reported 104 times. The instrument least employed singularly (penalties – one report) is relatively the most effective at achieving a pesticide use reduction. However, with an absence of consolidating reports, this result may not be representative of reality. Generally, information based instruments were indicated to achieve the largest relative proportion of effective outcomes, namely training or advisory services which achieved a degree of pesticide use reduction in 60% and 45% respectively of reviewed reports (Bruce, 2016; Trevisan et al., 2009; Barzman and Dachbrodt-Saaydeh, 2011). The comparative success was due to the provision of knowledge on alternative crop protection practices, preventing the exacerbation of application of alternative toxic substances (Zilberman and Millock, 1997; Davis et al., 2014; Pedersen et al., 2012). For example, in Australia chemicals such as metribuzin and S-metolachlor which are found to exhibit higher toxicities to freshwater species than those highly regulated substances such as atrazine for which they are substituting (Davis et al., 2014). This unintended effect of strict regulation was recently reiterated in a communication by Finger (2018).

In mixes of two instruments (84 reports), two particular resources combinations were indicated to be beneficial for effectiveness in terms of contributing to reduction of pesticide use.

For economic and regulatory resource based combinations, two mixes of instruments were identified as effective. Firstly, covenants and subsidies, mainly identified in France and Germany were reported to result in reduced pesticide use in 80% of reviewed reports (Kuhfuss et al., 2016; Heinz, 2002; Primdhal et al., 2003). Shared agreements were formulated according to agreed environmental practices. The subsequent provision of funds accounted for the barrier of perceived administrative burdens. Secondly, prescriptions and subsidies in Sweden, Switzerland – which achieved a reduction in pesticide use of 11.6% between 2000 and 2005 (Freier and Boller, 2009) – and Denmark were reported to result in reduced pesticide use in 100% of reviewed reports. The subsidies acted as incentive to comply to regulations. As seen in Denmark, they covered up to 80% of the incurred costs of the prescription requirements (Barzman and Dachbrodt-Saaydeh, 2011).

For regulatory and informative resource based combinations, the most effective instrument mix was reported as prescriptions and

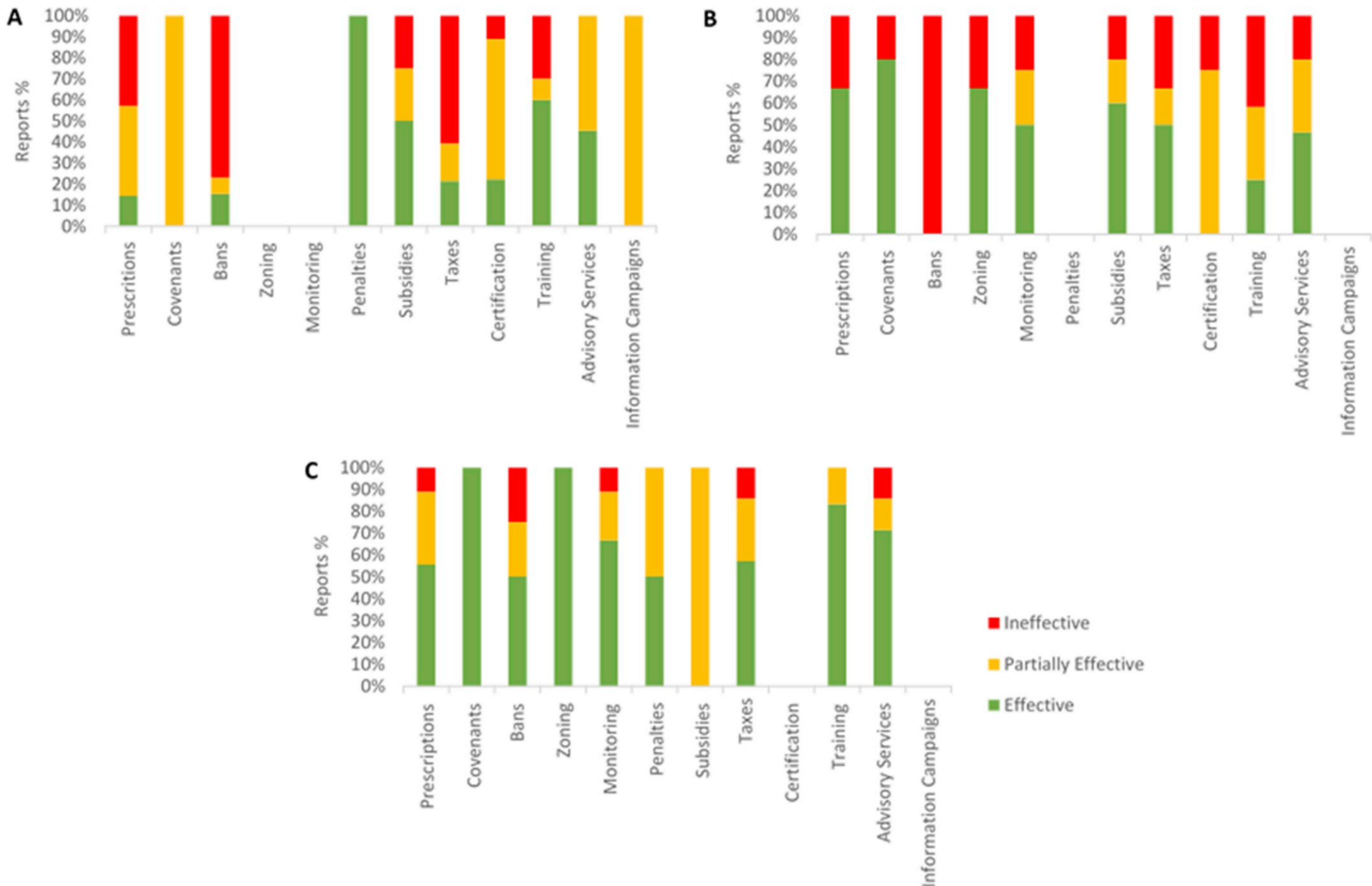

Fig. 3. Instrument outcomes according to how they were applied. A - single instrument application (104 reports); B - two instrument mix (84 reports); C - three or more instrument mix (47 reports).

advisory services (resulted in reduced pesticide use in 100% of reviewed reports) identified in the Netherlands, Germany, France and the UK (Barzman and Dachbrodt-Saaydeh, 2011; Peshin et al., 2009; Delière et al., 2015). The prescriptions could be reinforced through stakeholders co-constructing solutions through monitoring, advice and adjustments (Barzman and Dachbrodt-Saaydeh, 2011). Such advisory services can be identified as the "Mildium decision support system" in France or "Telen met Toekomst" in the Netherlands (Barzman and Dachbrodt-Saaydeh, 2011; Delière et al., 2015).

In mixes of three of more instruments (47 reports), a combination of economic, informative and regulatory resource based instruments was effective. This comprised of prescriptions, monitoring, taxes, training and advisory services (resulted in a reduced pesticide use in 100% of reviewed reports) applied in Denmark and Sweden (Peshin et al., 2009; Lefebvre et al., 2015; Liebman et al., 2016; Jacquet et al., 2011). The concept of the mix is taxation providing the funds for the cohesive application of the remaining instruments. By returning tax revenues to farmers through decreased land tax, the instrument maintained the economic viability of farming (Peshin et al., 2009; Liebman et al., 2016).

The identified effective mixes illustrates the necessity for both high and low degrees of authoritative force in instrument application. The benefit of including regulatory based instruments within a mix consolidates arguments of the importance of creating demand for farmer behaviour change (Saint-Ges and Bélis-Bergouignan, 2009; Stavins, 2003). Whilst 'carrots' are important for behaviour change, the 'sticks' should not be undervalued (Lefebvre et al., 2015; Peshin et al., 2009).

Whilst the results indicate the effectiveness of these instrument mixes, the impact of further characteristics, specific to the instruments should not be forgotten. Unfortunately, due to an absence of data in the literature, the impact of these characteristics such as subsidy quantity, tax rate, level of monitoring was difficult to determine and conclude. Its impact was observed, for example, in France, where the Ecophyto national action plan utilised a highly similar principle to that identified in Sweden and Denmark - taxation providing the funds for the cohesive application of the remaining instruments. A lower tax rate in France led to an ineffective outcome (Hossard et al., 2017).

4.2.2. *Pesticide use reduction in relation to how the instrument is applied*

A key message is the importance of applying an instrument mix for effective results. This is demonstrated by single instrument application resulting in 31%, a two-instrument mix resulting in 45% and a three plus instrument mix resulting in 64% of reviewed reports where a reduction of pesticide use was noted (Fig. 3). This consolidates the theoretical arguments of Howlett (2004), Feola and Binder (2010) and Skevas et al. (2013), who previously stated the importance of an instrument mix. Exceptions such as bans, subsidies and certification (seen in Fig. 3), where single instrument application is proportionally more effective than a mix can be explained in several ways. Firstly, the more instruments in a mix, the less data identified in the literature reviewed. Therefore, the more 'effective' results seen in single instrument application regarding these instruments may not always be representative. For example, subsidies were only identified once as part of a three or more instrument mix (Rudow, 2014). Secondly, when two or more instruments were applied in a mix, it was noted that if the instruments utilised the same resource, it was not always beneficial to pesticide use reduction due to the absence of certain characteristics. For example, instrument mixes of information based instruments of training and certification did not have the characteristics of both high and low degrees of authoritative force stated above as beneficial for creating farmer behaviour change (Lefebvre et al., 2015; Reus and Leendertse, 2000;

Dong et al., 2017).

With the exception of subsidies, the time frame of the instrument was not indicated to impact effectiveness. Due to subsidies' often short term nature, behaviour change was stated to be unsustainable (Papadaki-Klavdianou et al., 2000; Jansma et al., 1993). This partially corroborates arguments where behaviour change is more stable the longer an instruments' application (Lokhorst et al., 2011).

4.2.3. Pesticide use reduction in relation to who is involved in an instruments' application

Multi-stakeholder actor involvement in leading the application of an instrument seems beneficial to a reducing pesticide use (e.g. Heinz, 2002; Kuhfuss et al., 2016; Van Kasteren, 2012). In particular, stakeholders representing government, farmers, researchers and markets allowed the creation of targeted yet realistic instruments, contributing to effective outcomes (e.g. Brewer and Goodell, 2012; Barzman and Dachbrodt-Saaydeh, 2011; Delière et al., 2015). Interactive governance arrangements, to account for actors both in the public and private sphere, were frequently identified as beneficial to effective outcomes - particularly when the central state presented predetermined boundaries for the interaction (e.g. Barzman and Dachbrodt-Saaydeh, 2011; Jacquet et al., 2011; Slabe-Erker et al., 2017). Interactivity consolidates the arguments that public and private actors work best in tandem, not just singularly, with retained necessity of national governments (Chindarkar et al., 2017; Howlett, 2009).

Sole use of governmental actors and a centralised governance arrangement, frequently observed in single instrument application of bans, prescriptions and taxes was implied to lead to farmer exclusion and dissent with the policy process, alongside the inability to provide relevant instruments and/or targets (e.g. Papadaki-Klavdianou et al., 2000; Skevas et al., 2012; Archer and Shogren, 2001). Meanwhile, a self-governance arrangement and the use of autonomous private actors also contributed to absence of pesticide use reduction due to inadequate demand for farmers to alter their practices (e.g. Goldsworthy, 2007; Reus and Leendertse, 2000). This calls to question the previous arguments of Barzman et al. (2015) who argued for an increased role of private actors in leading an instrument application. It adds a new dimension to the argument of Lamichhane and Messéan (2016) who questioned whether private actor involvement was counter productive to pesticide use reduction.

4.2.4. Pesticide use reduction in relation to where an instrument is applied

The spatial scale in which an instrument is applied is indicated to impact effectiveness. A solely national level application, frequently observed in single economic and regulatory based instrument applications – appears linked to an absence of pesticide use reduction (e.g. Cross, 2013; Davis et al., 2014; Trevisan et al., 2009). A more localised, farm or regional level instrument application was employed more in information-based instruments, which achieved a relatively larger proportion of a reduction in pesticide use (e.g. Bruce, 2016; Levitan, 2000). Instrument application occurring at multiple and interacting levels is also conducive to success (e.g. Van den Berg and van Lamoen, 2008; Barzman and Dachbrodt-Saaydeh, 2011; Van Kasteren, 2012; Delière et al., 2015). It is indicated that whilst such local application allows the heterogeneity of farm and farmer characteristics to be considered to a greater extent, national level considers the necessity for behaviour change and pesticide use reduction at a broad scale.

The Netherlands, the UK and Denmark received the highest levels of reports of reducing pesticide use (e.g. Van der Vlist, 2007; Liebman et al., 2016; Lefebvre et al., 2015; Cross, 2013; Hillocks, 2012), potentially reflecting that regulatory based instruments or taxes more commonly applied here have a larger capability for effectiveness (e.g. Van Kasteren, 2012; Böcker and Finger, 2016). It could also reflect that these countries received some of the highest instances of literary attention.

The specification of arable land type in which the instruments were applied was rarely noted within the literature despite pesticide use differing per sector. In the reviewed studies, it is indicated that such specification of instruments according to farm type can achieve effective outcomes (e.g. Kuhfuss et al., 2016; Van der Vlist, 2007; Cross, 2013; Saint-Ges and Bélis Bergouignan, 2009).

4.2.5. Pesticide use reduction in relation to what an instruments' aim is

The coupling of social, environmental and economic aims within an instrument mix is viewed to be beneficial to reducing pesticide use (e.g. Falconer and Hodge, 2001; Archer and Shogren, 2001; Barzman and Dachbrodt-Saaydeh, 2011). A multiple aim may appropriately consider the varying reasons why farmers do not desire to alter their practices (e.g. Jacquet et al., 2011; Peshin et al., 2009; Van Kasteren, 2012).

4.3. The influence of situational and contextual factors on instrument effectiveness

In Section 2.3 we identified two (partly related) categories of factors that influence or mediate the extent to which instruments successfully contribute to pesticide use reduction. Firstly, the extent to which farmers are enabled, demanded, legitimised and motivated to change their behaviour. Secondly the extent to which user group characteristics are sufficiently addressed.

Regarding the first category of factors, we found that their presence or absence were reported to influence pesticide use reduction. In ineffective reports, these factors were either absent or few were present. In contrast, in reports of effective outcomes, the larger the presence of these factors for success. For instance, in the effective mixes of prescriptions and advisory services and prescriptions, monitoring, taxes, training and advisory services, all four factors for success were identified as present. Thus, the effectiveness of instruments and their mixes in terms of reducing pesticide use seems related to the extent to which farmers are enabled, demanded, legitimised and motivated to change their behaviour. Instruments and mixes can provide for these factors – for instance, advisory services can provide knowledge ('enable') and some social pressure ('demand') but also provide space for dialogue and mutual understanding ('legitimacy'). However, other literature has shown that farmers' ability to adopt more sustainable farming practices (including but not limited to pesticide use reduction) is substantially limited by outside factors and actors, including requirements set, and prices paid by, other companies in agri-food industry (Schoonhoven and Runhaar, 2018). This underlines that reducing pesticide use is not always a free choice and that multiple instruments, by public and private actors, will often be needed for effective steering towards pesticide use reductions.

Regarding the second category of factors, within the literature, the presence or absence of tailoring to farm or farmer characteristics and the subsequent impact on effectiveness was rarely made explicit.

The absence of consideration of farm characteristics was indicated to contribute to observed ineffective outcomes. For example, whilst flower farms were responsive to prescriptions, vegetable production based farms were not (Van der Vlist, 2007). Or, by not tailoring the instruments to farm size, only smaller farms would be inclined to reduce their pesticide use as a result of taxes (Skevas et al., 2012).

Tailoring to farmer characteristics was indicated to contribute to effectiveness. The failure of taxes to consider the dominance of production maximiser attitudes in farmers was a hindrance to the single application of taxes (Pedersen et al., 2012; Jansma et al., 1993; Hossard et al., 2017). In contrast, the presence of consideration to such an attitude in the use of subsidies contributed to effective outcomes (Kleijn and Sutherland, 2003; Kuhfuss et al., 2016). The absence of consideration of farmer knowledge was indicated to contribute to ineffective outcomes, particularly in the single application of bans and prescriptions (e.g. Zilberman and Millock, 1997; Davis et al., 2014; Papadaki-Klavdianou et al., 2000; Jansma et al., 1993).

Despite limited information, as the above results indicate, consideration of these external characteristics is important for effective outcomes. The presence of effective results in certain instrument and instrument mixes suggests that such characteristics are appropriately considered by the presence of the instrument characteristics confirmed as beneficial to effectiveness.

5. Discussion

5.1. Methodological reflections

Despite methodological attempts to minimise the bias of this study, two issues, regarding its reliability and validity can be identified as limitations to the conclusions reached. In terms of reliability (i.e. the extent to which results are replicable; Golafshani, 2003) a potential publication bias was present. The search for relevant papers in the systematic literature review was restricted to only peer-reviewed published papers in English from one database – Scopus. While this was a deliberate choice in order to secure a minimum level of scientific quality of the studies included in the analysis, it increased the likelihood that other relevant studies were omitted from the systematic literature review process which can impact the results observed (Bramer et al., 2017; Haddaway et al., 2015). Omission of potentially relevant articles also occurred as, despite being an ongoing research area, articles after 2017 are not included to maintain research consistency (e.g. Finger, 2018; Kudsk et al., 2018). Grey literature, which is also stated to impact observed outcomes, was not included (e.g. Leimu and Koricheva, 2005; Pullin and Stewart, 2006). In addition, our study is reliant on the reliability of the research design of others.

In terms of validity (i.e. the extent to which the measurements were accurate; Golafshani, 2003), we realise that in our coding of articles for effectiveness some interpretation bias is possible. By restricting ourselves to a simple operationalisation of effectiveness we hope to have avoided this as much as possible, allowing comparability between varying countries and timescales in our analysis. The flipside of the coin is that our analysis, by only studying outcomes, not impacts, does not allow for conclusions regarding the ecological or health effects of the instruments included in our analysis (Möhring et al., 2019). It is possible that, if effectiveness was defined in a different manner (i.e. volume or treatment frequency, see dependent variable), conclusions about effectiveness of policy instruments may shift. Utilising such an alternative definition could be interesting for future research.

Additionally, as a meta-analysis of previous studies, this paper does not contain a country or arable sub-sector specific perspective. Further research could be beneficial to explore in more detail what operationalisations of policy instruments contribute to their effectiveness, next to the resources we analysed. Suggested focus includes the Netherlands, UK, France and Denmark (whose scheme is currently undergoing evaluation) – countries which had the highest numbers of effective reports.

5.2. Theoretical implications

Following the work of Howlett (2009) on policy instruments, we expected to find organisation-based instruments in the literature studied - next to economic, informational and regulation-based policy instruments. However, in the literature reviewed here, we did not recognise organisation-based instruments. This could be a result of our methodological choices such as the exclusion of grey literature from analysis. It also might reflect that this type of policy instrument is rarely applied in practice or that this type of policy instrument is relatively under-explored in agricultural policy analyses. We therefore suggest that organisation-based instruments would benefit from more analytical attention. For example, by means of providing more characteristics how it can be identified and distinguished from the other types of policy instruments and by providing more empirical examples.

From our analysis we conclude that there is no definite answer to which instrument mix can achieve effective outcomes. This consolidates the work of Borrás and Edquist (2013), who determine that there are no optimal policy instruments or mixes for a purpose. From the analysis it is indicated that certain instrument characteristics are beneficial to effectiveness. Six beneficial characteristics, synthesised from the above discussion, can be formulated (Table 2). These are points previously made within the literature and are confirmed by this analysis. It should be stated that these are generally favourable – in specific situations obviously exceptions do exist because of the presence or absence of factors discussed in Section 4.3.

Table 2
Confirmation of beneficial instrument characteristics for reducing pesticide use derived from the literature review.

1.	Instruments applied in mix, comprised on instruments from regulatory, economic and informative governance resources are beneficial to reducing pesticide use.
2.	Instruments applied in mix, comprised of both incentivising and discouraging instruments (carrots and sticks), are beneficial to reducing pesticide use.
3.	Instruments led through a multi-stakeholder approach are beneficial to reducing pesticide use.
4.	Instruments applied in an interactive governance arrangement, within pre-determined boundaries, are beneficial to reducing pesticide use.
5.	Instruments applied at multiple and interacting levels (from national to farm) are beneficial to reducing pesticide use.
6.	Instruments with an environmental, social and economic aim are beneficial to reducing pesticide use.

In conclusion, four instrument mixes were reported from the review as beneficial to reducing pesticide use; covenants and subsides; prescriptions and subsidies; prescriptions and advisory services; prescriptions, monitoring, taxes, training and advisory services. Ineffective reports were frequently identified regarding the sole use of regulatory based instruments, namely bans and prescriptions. The effective outcome of reducing pesticide use in the identified mixes is implied in these results to have been aided by the presence of six beneficial instrument characteristics which clarifies the findings from previous research. The presence of these characteristics is indicated as considering the mediating situational and contextual factors which can also impact the outcome of pesticide use reduction. Therefore, the extent to which farmers are motivated, enabled, legitimised and motivated to change their behaviour alongside consideration of user group characteristics seems related to farmers altering their pesticide use. Despite policy instrument effectiveness being situation specific, general observations for the achievement of effective outcomes can be identified including the importance of instrument mixes as opposed to single instruments, the necessity of an interactive and multi-stakeholder approach and the ability for instruments to be applied at multiple levels.

For the future, the focus should not be on understanding how policy instruments target individuals or specific actor groups alone, as often targeted practices do not only depend on individual actions and decisions but are shaped by wider context (Schoonhoven and Runhaar, 2018). In the case of sustainable agriculture that would mean understanding how policy instrument mixes may engage with the context of agricultural practices. For example, understanding the economic context shaped by actors' groups from the value chain; understanding the social context shaped by social networks around farmers and discourse influencing groups such as green NGO's and interest groups; and understanding the innovation context largely shaped by the interaction with knowledge institutes.

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Appendix A. Supplementary data

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References

Ahnström, J., Höckert, J., Bergeå, H.L., Francis, C.A., Skelton, P., Hallgren, L., et al., 2009. Farmers and nature conservation: what is known about attitudes, context factors and actions affecting conservation? Renewable agriculture and food systems 24 (1), 38–47.

Archer, D.W., Shogren, J.F., 2001. Risk-indexed herbicide taxes to reduce ground and surface water pollution: an integrated ecological economics evaluation. Ecol. Econ. 38 (2), 227250.

Barzman, M., Dachbrodt-Saaydeh, S., 2011. Comparative analysis of pesticide action plans in five European countries. Pest Manag. Sci. 12 (67), 1481–1485.

Barzman, M., Bàrberi, P., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Hommel, B., Jensen, J.E., Kiss, J., Kudsk, P., Lamichhane, J.R., 2015. Eight principles of integrated pest management. Agron. Sustain. Dev. 35 (4), 1199–1215.

Beckmann, V., Wesseler, J., 2003. How labour organization may affect technology adoption: an analytical framework analysing the case of integrated pest management. Environ. Dev. Econ. 8 (3), 437–450.

Bemelmans-Videc, M.L., Rist, R.C., Vedung, E.O., 2011. Carrots, Sticks, and Sermons: Policy Instruments and Their Evaluation, vol. 1. Transaction Publishers.

Birch, A.N.E., Begg, G.S., Hawes, C., Squire, G.R., 2016. IPM research into practice; a long time coming. In: The Dundee Conference: Crop Protection in Northern Britain 2016, 23-24 February 2016, Dundee, UK. The Association for Crop Protection, Northern Britain, pp. 15–16.

Böcker, T., Finger, R., 2016. European pesticide tax schemes in comparison: an analysis of experiences and developments. Sustainability 8 (4), 378.

Borrás, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecast. Soc. Chang. 80 (8), 1513–1522.

Bouwma, I.M., Gerritsen, A.L., Kamphorst, D.A., Kistenkas, F.H., 2015. Policy Instruments and Modes of Governance in Environmental Policies of the European Union(No. 60). Statutory Research Tasks Unit for Nature & the Environment (WOT Natuur & Milieu).

Bramer, W.M., Rethlefsen, M.L., Kleijnen, J., Franco, O.H., et al., 2017. Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. Systematic reviews 6 (1), 245.

Brewer, M.J., Goodell, P.B., 2012. Approaches and incentives to implement integrated pest management that addresses regional and environmental issues. Annu. Rev. Entomol. 57.

Brodt, S., Klonsky, K., Tourte, L., 2006. Farmer goals and management styles: implications for advancing biologically based agriculture. Agric. Syst. 89 (1), 90–105.

Bruce, T.J., 2016. The CROPROTECT project and wider opportunities to improve farm productivity through web-based knowledge exchange. Food Energy Secur. 5 (2), 89–96.

Brukas, V., Sallnäs, O., 2012. Forest management plan as a policy instrument: carrot, stick or sermon? Land Use Policy 29 (3), 605–613.

Chindarkar, N., Ramesh, M., Howlett, M., 2017. Conceptualizing effective social policy design: design spaces and capacity challenges. Annu. Rev. Policy Des. 5 (1), 1–12.

Cross, P., 2013. Pesticide hazard trends in orchard fruit production in Great Britain from 1992 to 2008: a time-series analysis. Pest Manag. Sci. 69 (6), 768–774.

Damalas, C.A., 2016. Safe food production with minimum and judicious use of pesticides. In: Selamat, J., Iqbal, S. (Eds.), Food Safety. Springer, Cham, pp. 43–55.

Davis, A.M., Lewis, S.E., Brodie, J.E., Benson, A., 2014. The potential benefits of herbicide regulation: a cautionary note for the Great Barrier Reef catchment area. Sci. Total Environ. 490, 81–92.

Delière, L., Cartolaro, P., Léger, B., Naud, O., 2015. Field evaluation of an expertise-based formal decision system for fungicide management of grapevine downy and powdery mildews. Pest Manag. Sci. 71 (9), 1247–1257.

Dong, F., Mitchell, P.D., Davis, V.M., Recker, R., 2017. Impact of atrazine prohibition on the sustainability of weed management in Wisconsin maize production. Pest Manag. Sci. 73 (2), 425–434.

Doonan, H., 2017. Uptake of integrated pest management in the UK arable sector. Outlooks Pest Manag. 28 (1), 29–32.

Driessen, P.P., Dieperink, C., Laerhoven, F., Runhaar, H.A., Vermeulen, W.J., 2012. Towards a conceptual framework for the study of shifts in modes of environmental governance–experiences from The Netherlands. Environ. Policy Gov. 22 (3), 143–160.

EC [European Commission], 2009. 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 Pesticides.

Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. Anim. Sci. 82 (6), 783–790.

Eurostat, 2017. Glossary: arable land. Accessed online 13th March 2018 from. http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Arable_land.

Falconer, K.E., 1998. Managing diffuse environmental contamination from agricultural pesticides: an economic perspective on issues and policy options, with particular reference to Europe. Agric. Ecosyst. Environ. 69 (1), 37–54.

Falconer, K., Hodge, I., 2001. Pesticide taxation and multi-objective policy-making: farm modelling to evaluate profit/environment trade-offs. Ecol. Econ. 36 (2), 263–279.

Feola, G., Binder, C.R., 2010. Identifying and investigating pesticide application types to promote a more sustainable pesticide use. The case of smallholders in Boyacá, Colombia. Crop Protect. 29 (6), 612–622.

Finger, R., 2018. Take a holistic view when making pesticide policies stricter. Nature 556 (7700), 174–175.

Finger, R., Möhring, N., Dalhaus, T., Böcker, T., 2017. Revisiting pesticide taxation schemes. Ecol. Econ. 134, 263–266.

Freier, B., Boller, E.F., 2009. Integrated pest management in Europe–history, policy, achievements and implementation. In: Peshin, R., Dhawan, A.K. (Eds.), Integrated Pest Management: Dissemination and Impact, vol. 2. Springer, Dordrecht, pp. 435–454.

Giomi, T., Runhaar, P., Runhaar, H., 2018. Reducing agrochemical use for nature conservation by Italian olive farmers: an evaluation of public and private governance strategies. Int. J. Agric. Sustain. 1–12.

Golafshani, N., 2003. Understanding reliability and validity in qualitative research. The qualitative report 8 (4), 597–606.

Goldsworthy, P., 2007. Progress in environmental management through the voluntary initiative: partnership for best practice. J. R. Agric. Soc. Engl. 168.

Haddaway, N.R., Woodcock, P., Macura, B., Collins, A., et al., 2015. Making literature reviews more reliable through application of lessons from systematic reviews. Conservation Biology 29 (6), 1596–1605.

Hall, N., Lacey, J., Carr-Cornish, S., Dowd, A.M., 2015. Social licence to operate: understanding how a concept has been translated into practice in energy industries. J. Clean. Prod. 86, 301–310.

Handford, C.E., Elliott, C.T., Campbell, K., 2015. A review of the global pesticide legislation and the scale of challenge in reaching the global harmonization of food safety standards. Integr. Environ. Assess. Manag. 11 (4), 525–536.

Heinz, I., 2002. Voluntary agreements as an instrument to solve conflicts between farmers and water suppliers. Int. Assoc. Hydrol. Sci. 273, 11–16.

Hellström, T., Jacob, M., 2017. Policy instrument affordances: a framework for analysis. Policy Stud. 38 (6), 604–621.

Hillocks, R.J., 2012. Farming with fewer pesticides: EU pesticide review and resulting challenges for UK agriculture. Crop Protect. 31 (1), 85–93.

Hood, C., 1983. The Tools of Government. Macmillan, London, UK.

Hood, C., 2007. Intellectual obsolescence and intellectual makeovers: reflections on the tools of government after two decades. Governance 20 (1), 127–144.

Hossard, L., Guichard, L., Pelosi, C., Makowski, D., 2017. Lack of evidence for a decrease in synthetic pesticide use on the main arable crops in France. Sci. Total Environ. 575, 152–161.

Howlett, M., 2004. Beyond good and evil in policy implementation: instrument mixes, implementation styles, and second generation theories of policy instrument choice. Policy Soc. 23 (2), 1–17.

Howlett, M., 2009. Governance modes, policy regimes and operational plans: a multi-level nested model of policy instrument choice and policy design. Policy Sci. 42 (1), 73–89.

Howlett, M., 2014. From the 'old' to the 'new' policy design: design thinking beyond markets and collaborative governance. Policy Sci. 47 (3), 187–207.

Howlett, M., Rayner, J., 2013. Patching vs packaging in policy formulation: assessing policy portfolio de-sign. Politics Gov. 1 (2), 170–182.

Jacquet, F., Butault, J.P., Guichard, L., 2011. An economic analysis of the possibility of reducing pesticides in French field crops. Ecol. Econ. 70 (9), 1638–1648.

Jansma, J.E., Van Keulen, H., Zadoks, J.C., 1993. Crop protection in the year 2000: a comparison of current policies towards agrochemical usage in four West European countries. Crop Protect. 12 (7), 483–489.

Karuppuchamy, P., Venugopal, S., 2016. Integrated pest management. In: Omkar, O. (Ed.), Ecofriendly Pest Management for Food Security. Elsevier Science, pp. 651–684.

Kim, K.H., Kabir, E., Jahan, S.A., 2017. Exposure to pesticides and the associated human health effects. Sci. Total Environ. 575, 525–535.

Kleijn, D., Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? J. Appl. Ecol. 40 (6), 947–969.

Kohoutek, J., 2014. Analysing instrument mixes in quality assurance: the Czech and Slovak Accreditation Commissions in the era of mass higher education. Qual. High Educ. 20 (1), 83–102.

Kudsk, P., Jørgensen, L.N., Ørum, J.E., 2018. Pesticide Load—a new Danish pesticide risk indicator with multiple applications. Land Use Policy 70, 384–393.

Kuhfuss, L., Préget, R., Thoyer, S., Hanley, N., 2016. Nudging farmers to enrol land into agrienvironmental schemes: the role of a collective bonus. Eur. Rev. Agric. Econ. 43 (4), 609–636.

Lamichhane, J.R., Messéan, A., Coordinators, 2016. Strategic research agenda for IPM in Europe. Available at: http://c-ipm.org/news/nyhed/artikel/coordination-of-integrated404pest-management-on-the-agenda/.

Lamichhane, J.R., Dachbrodt-Saaydeh, S., Kudsk, P., Messean, A., 2016. Toward a reduced reliance on conventional pesticides in European agriculture. Plant Dis. 100 (1), 10–24.

Lamichhane, J.R., 2017. Pesticide Use and Risk Reduction in European Farming Systems with IPM: an Introduction to the Special Issue. Crop Protection 97, 1–6.

Lamichhane, J.R., Aubertot, J.N., Begg, G., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Hansen, J.G., Hovmøller, M.S., Jensen, J.E., Jørgensen, L.N., Kiss, J., 2016. Networking of Integrated Pest Management: A Powerful Approach to Address Common Challenges in Agriculture, vol. 89. Crop Protection, pp. 139–151.

Lamichhane, J.R., Bischoff-Schaefer, M., Bluemel, S., Dachbrodt-Saaydeh, S., Dreux, L., Jansen, J.P., Kiss, J., Köhl, J., Kudsk, P., Malausa, T., Messéan, A., 2017. Identifying obstacles and ranking common biological control research priorities for Europe to manage most economically important pests in arable, vegetable and perennial crops. Pest Manag. Sci. 73 (1), 14–21.

Lamichhane, J.R., Devos, Y., Beckie, H.J., Owen, M.D.K., Tillie, P., Messéan, A., Kudsk, P., 2017. Integrated weed management systems with herbicide-tolerant crops in the European Union: lessons learnt from home and abroad. Crit. Rev. Biotechnol. 37 (4), 459–475.

Le Dang, H., Li, E., Nuberg, I., Bruwer, J., 2014. Understanding farmers' adaptation intention to climate change: a structural equation modelling study in the Mekong Delta, Vietnam. Environ. Sci. Policy 41, 11–22.

Lechenet, M., Dessaint, F., Py, G., Makowski, D., Munier-Jolain, N., 2017. Reducing pesticide use while preserving crop productivity and profitability on arable farms. Nat. Plants 3 (3), 17008.

Lefebvre, M., Langrell, S.R., Gomez-y-Paloma, S., 2015. Incentives and policies for integrated pest management in Europe: a review. Agron. Sustain. Dev. 35 (1), 27–45.

Leimu, R., Koricheva, J., 2005. What determines the citation frequency of ecological papers? Trends in Ecology and Evolution 20 (1), 28–32.

Levitan, L., 2000. "How to" and "why": assessing the enviro–social impacts of pesticides. Crop Protect. 19 (8–10), 629–636.

Liebman, M., Baraibar, B., Buckley, Y., Childs, D., Christensen, S., Cousens, R., Eizenberg, H., Heijting, S., Loddo, D., Merotto, A., Renton, M., 2016. Ecologically sustainable weed management: how do we get from proof-of-concept to adoption? Ecol. Appl. 26 (5), 1352–1369.

Liefferink, D., Jörgens, H., Lenschow, A., 2014. Introduction: theoretical framework and research design. In: Jörgens, H., Lenschow, A., Liefferink, D., [eds]. (Eds.), Understanding Environmental Policy Convergence: the Power of Words, Rules and Money. Cambridge University Press, pp. 1–38.

Lokhorst, A.M., Staats, H., van Dijk, J., van Dijk, E., de Snoo, G., 2011. What's in it for me? Motivational differences between farmers' subsidised and non-subsidised conservation practices. Appl. Psychol. 60 (3), 337–353.

Manner, M., Gowdy, J., 2010. The evolution of social and moral behavior: evolutionary insights for public policy. Ecol. Econ. 69 (4), 753–761.

Mayer, F., Gereffi, G., 2010. Regulation and economic globalisation: prospects and limits of private governance. Bus. Polit. 12 (3), 1–25.

Mees, H.L., Dijk, J., van Soest, D., Driessen, P.P., van Rijswick, M.H., Runhaar, H., 2014. A method for the deliberate and deliberative selection of policy instrument mixes for climate change adaptation. Ecol. Soc. 19 (2).

Mickwitz, P., 2003. A framework for evaluating environmental policy instruments: context and key concepts. Evaluation 9 (4), 415–436.

Möhring, N., Gaba, S., Finger, R., 2019. Quantity based indicators fail to identify extreme pesticide risks. Sci. Total Environ. 646, 503–523.

Nave, S., Jacquet, F., Jeuffroy, M.H., 2013. Why wheat farmers could reduce chemical inputs: evidence from social, economic, and agronomic analysis. Agron. Sustain. Dev. 33 (4), 795–807.

Okello, J.J., Okello, R.M., 2010. Do EU pesticide standards promote environmentally-friendly production of fresh export vegetables in developing countries? The evidence from Kenyan green bean industry. Environ. Dev. Sustain. 12 (3), 341–355.

Oskam, A.J., Vijftigschild, R., Graveland, C., 1997. Additional EU Policy Instruments for Plant Protection Products. Wageningen Agricultural University (Mansholt Institute), Wageningen, The Netherlands.

Papadaki-Klavdianou, A., Tsakiridou, E., Giasemi, E., 2000. Comparison of perceptions and implementation of Integrated Pest Management (IPM) between IPM and conventional farmers of greenhouse vegetables in northern Greece. Environ. Conserv. 27 (1), 36–42.

Pedersen, A.B., Nielsen, H.Ø., Christensen, T., Hasler, B., 2012. Optimising the effect of policy instruments: a study of farmers' decision rationales and how they match the incentives in Danish pesticide policy. J. Environ. Plan. Manag. 55 (8), 1094–1110.

Peshin, R., Bandral, R.S., Zhang, W., Wilson, L., Dhawan, A.K., 2009. Integrated pest management: a global overview of history, programs and adoption. In: Peshin, R., Dhawan, A.K. (Eds.), Integrated Pest Management: Innovation-Development Process. Springer, Dordrecht, pp. 1–49.

Primdahl, J., Peco, B., Schramek, J., Andersen, E., Oñate, J.J., 2003. Environmental effects of agrienvironmental schemes in Western Europe. J. Environ. Manag. 67 (2), 129138.

Pullin, A.S., Stewart, G.B., 2006. Guidelines for systematic review in conservation and environmental management. Conservation Biology 20 (6), 1647–1656.

Raseduzzaman, M., Jensen, E.S., 2017. Does intercropping enhance yield stability in arable crop production? A meta-analysis. Eur. J. Agron. 91, 25–33.

Reus, J.A., Leendertse, P.C., 2000. The environmental yardstick for pesticides: a practical indicator used in The Netherlands. Crop Protect. 19 (8–10), 637–641.

Rudow, K., 2014. Less Favoured Area payments-impacts on the environment, a German perspective. Agric. Econ. 60 (6), 260–272.

Runhaar, H., 2016. Tools for integrating environmental objectives into policy and practice: what works where? Environ. Impact Assess. Rev. 59, 1–9.

Runhaar, H.A.C., Melman, T.C., Boonstra, F.G., Erisman, J.W., Horlings, L.G., de Snoo, G. R., Termeer, C.J.A.M., Wassen, M.J., Westerink, J., Arts, B.J.M., 2017. Promoting nature conservation by Dutch farmers: a governance perspective. Int. J. Agric. Sustain. 15 (3), 264281.

Saint-Ges, V., Bélis-Bergouignan, M.C., 2009. Ways of reducing pesticides use in Bordeaux vineyards. J. Clean. Prod. 17 (18), 1644–1653.

Salazar-Morales, D.A., 2017. Sermons, carrots or sticks? Explaining successful policy implementation in a low performance institution. J. Educ. Policy 1–31.

Schneider, A.L., Ingram, H., 1997. Policy Design for Democracy. University Press of Kansas, Lawrence.

Schneider, A., Sidney, M., 2009. What is next for policy design and social construction theory? Policy Stud. J. 37 (1), 103–119.

Schoonhoven, Y., Runhaar, H., 2018. Conditions for the adoption of agro-ecological farming practices: a holistic framework illustrated with the case of almond farming in Andalusia. Int. J. Agric. Sustain. 16 (6), 442–454.

Skevas, T., Stefanou, S.E., Lansink, A.O., 2012. Can economic incentives encourage actual reductions in pesticide use and environmental spill overs? Agric. Econ. 43 (3), 267–276.

Skevas, T., Lansink, A.O., Stefanou, S.E., 2013. Designing the emerging EU pesticide policy: a literature review. NJAS - Wageningen J. Life Sci. 64, 95–103.

Slabe-Erker, R., Bartolj, T., Ogorevc, M., Kavaš, D., Koman, K., et al., 2017. The impacts of agricultural payments on groundwater quality: Spatial analysis on the case of Slovenia. Agricultural Economics 43 (3), 267–276.

Stallman, H.R., James, H.S., 2017. Farmers willingness to cooperate in ecosystem service provision: does trust matter? Ann. Public Coop. Econ. 88 (1), 5–31.

Stavins, R.N., 2003. Experience with market-based environmental policy instruments. In: Mäler, K.G., Vincent, J., et al. (Eds.), Handbook of Environmental Economics. Elsevier, pp. 355–435.

Stenberg, J.A., 2017. A conceptual framework for integrated pest management. Trends Plant Sci. 22 (9), 759–769.

Sugavanam, B., 1996. Risk reduction in pesticide development in developing countries - challenges and opportunities. J. Environ. Sci. Health - Part B Pesticides, Food Contam. Agric. Wastes 31 (3), 307–323.

Tey, Y.S., Li, E., Bruwer, J., Abdullah, A.M., Brindal, M., Radam, A., et al., 2014. The relative importance of factors influencing the adoption of sustainable agricultural practices: a factor approach for Malaysian vegetable farmers. Sustain. Sci. 9 (1), 17–29.

Thorlakson, T., Hainmueller, J., Lambin, E.F., 2018. Improving environmental practices in agricultural supply chains: the role of company-led standards. Glob. Environ. Chang. 48, 32–42.

Timprasert, S., Datta, A., Ranamukhaarachchi, S.L., 2014. Factors Determining Adoption of Integrated Pest Management by Vegetable Growers in Nakhon Ratchasima Province, Thailand, vol. 62. Crop protection, pp. 32–39.

Trevisan, M., Di Guardo, A., Balderacchi, M., 2009. An environmental indicator to drive sustainable pest management practices. Environ. Model. Softw 24 (8), 994–1002.

Van den Berg, V.S., van Lamoen, F., 2008. An integrated approach on pollution abatement in rural areas; regional pilot projects in the Province of North-Brabant. Desalination 226 (1–3), 183189.

Van der Vlist, A.J., Withagen, C., Folmer, H., 2007. Technical efficiency under alternative environmental regulatory regimes: the case of Dutch horticulture. Ecol. Econ. 63 (1), 165173.

Van Eerdt, M.M., Spruijt, J., van der Wal, E., van Zeijts, H., Tiktak, A., 2014. Costs and effectiveness of on-farm measures to reduce aquatic risks from pesticides in The Netherlands. Pest Manag. Sci. 70 (12), 1840–1849.

Van Kasteren, J., 2012. Globalisation and crop-protection policy. In: Wijen, F., Zoeteman, K., Pieters, J., van Seters, P. (Eds.), A Handbook of Globalisation and Environmental Policy, Second Edition: National Government Interventions in a Global Arena. Edward Elgar Publishing, pp. 272–294.

Vedung, E., 1998. Policy instruments: typologies and theories. In: Bemelmans-Videc, M. L., Rist, R.C., Vedung, E. (Eds.), Carrots, Sticks and Sermons: Policy Instruments and Their Evaluation. Transaction Publishers, New Brunswick, New Jersey, USA, pp. 1–58.

Waterfield, G., Zilberman, D., 2012. Pest management in food systems: an economic perspective. Annu. Rev. Environ. Resour. 37, 223–245.

Weber, M., Driessen, P.P., Runhaar, H.A., 2011. Drivers of and barriers to shifts in governance: analysing noise policy in The Netherlands. J. Environ. Policy Plan. 13 (2), 119137.

Wilson, C., Tisdell, C., 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecol. Econ. 39, 449–462.

Wyckhuys, K.A., Bentley, J.W., Lie, R., Fredrix, M., et al., 2018. Maximizing farm-level uptake and diffusion of biological control innovations in today's digital era. BioControl 63 (1), 133–148.

Zilberman, D., Millock, K., 1997. Financial incentives and pesticide use. Food Policy 22 (2), 134144.