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Framework for assessing the socio-economic impacts of Bt maize cultivation

European GMO Socio-Economics Bureau
2nd Reference Document

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2016

Joint Research Centre

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This Reference Document is the result of work carried out by the European GMO Socio-Economics Bureau, which consists of the following European Commission staff and experts nominated by EU Member States and Norway:

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Contents

Abstract

Bt maize is the only genetically modified (GM) crop grown in the EU for commercial purposes and so far adopted mainly in Spain. Its cultivation can have a number of socio-economic consequences for farmers, upstream and downstream industries, as well as consumers. The European GMO Socio-Economics Bureau (ESEB) has compiled topics, indicators, methodological guidelines and potential data sources to carry out analyses of these socio-economic effects. This document provides a framework applicable to EU Member States currently growing Bt maize and those potentially cultivating it in the future. Over 30 topics and 100 indicators, which range from farm adoption rates to consumer surplus, have been identified by the ESEB Technical Working Group, which is composed of representatives of Member States and assisted by the European Commission's Joint Research Centre. Evidence of impacts in the EU already exists for some topics both *ex post* and *ex ante*, but for most topics it is very limited. Methodologies have been developed by the scientific community for many of the topics and indicators, from simple partial budget analysis to complex aggregated models. It is concluded that while methodologies are available for many of the topics and indicators, the main constraint is a lack of data.

Executive summary

The European GMO Socio-Economics Bureau (ESEB) was established in 2013 in order to organise and facilitate the exchange of technical and scientific information regarding the socio-economic implications of genetically modified (GM) crops between Member States (MS) and the European Commission. The mission of ESEB is to develop Reference Documents that enable a science-based assessment of these impacts in MS across the EU. Following the first Reference Document representing a general framework, this second Reference Document focuses on Bt maize and includes a list of topics that could be used in assessments, along with appropriate indicators and methods. It is based on contributions from the ESEB Technical Working Group (TWG), which is composed of representatives of MS and assisted by the ESEB secretariat located at the European Commission's Joint Research Centre (JRC).

Following a brief introduction (Section 1), the background section (Section 2) lays out the legislative context for GM cultivation in the EU, the mandate of ESEB, the scope of the document and the process leading to its publication. The process consisted of a series of consultations and a meeting in September 2015 between the members of the TWG. The consultations and meeting were organised by the ESEB secretariat, which also drafted the document with MS contributions. In collaboration with their national experts and stakeholders, TWG members proposed topics to be included in the document, subject to the availability of measurable indicators, causal mechanisms and sound assessment methods. In April 2016, the Standing Committee on Plants, Animals, Food and Feed, the Regulatory Committee of Directive 2001/18/EC and the Advisory Group on the Food Chain and Animal and Plant Health were also given the opportunity to comment on the document.

Chapter 3 provides some details about maize cultivation in the EU, plant protection practices and Bt maize, as well as the maize supply chain. Maize is affected by several insect pests, and insecticide treatments are the most common control measure. Bt maize is resistant to some of these pests and represents an alternative pest control method that is widely adopted in the Americas but so far only on a small scale in the EU (mainly Spain).

Chapter 4 is concerned with the methodology for assessments. Assessments can be conducted before (*ex ante*) or after (*ex post*) cultivation takes place. The general approach of conducting an impact assessment consists of the definition of baseline and impact scenarios and an estimation of the value of selected indicators for each of the scenarios. The methods that can be employed vary by topics and indicators. Some topics, including many of those concerning farmers, can be assessed using primary data from farm surveys and econometric techniques. Other topics, such as those concerned with downstream industries, require more aggregate economic models. Data sources include secondary data and literature reviews, although farm/industry/consumer surveys are required for most topics.

Sections 5–7 contain the topics identified by ESEB as relevant for impact assessments. The topics are introduced and complemented with the respective indicators, methodological remarks and references. The effects on crop farming (Section 5) are divided into impacts on adopters and non-adopters. Adoption rates, farmer characteristics, income and other economic effects, management practices, input use and efficiency, coexistence and time management are included among others. The effects outside the crop farming sector (Section 6) are divided into upstream and downstream industries, consumers, and the government budget. They involve effects on the seed and agro-chemical industries, the feed/livestock and food/retail sectors, trade, as well as consumer prices and choice, consumption, public acceptance, and the government budget. Section 7 contains the aggregate consumer and producer surplus. In the final remarks (Section 8), it is concluded that while methodologies are available for many of the topics and indicators, data are very scarce.

1. Introduction

Bt maize[1] is a genetically modified (GM) crop that is resistant to certain pests. In 2014, it was grown in 17 countries on about 48 million hectares, most widely in the USA, Brazil, Argentina, South Africa and Canada, among others (James, 2014). In the EU, Bt maize has been grown since 1998. In 2014, it was adopted to a significant extent in Spain, and on a smaller scale in a few other countries (Portugal, the Czech Republic, Romania and Slovakia).

The cultivation of Bt maize can have socio-economic impacts on farmers, industries and consumers. For example, adopting farmers have in many cases experienced yield increases, pesticide expenditure reductions, and/or higher gross margins (Areal et al., 2013; Gómez-Barbero et al., 2008a; Klümper & Qaim, 2014). The adoption of Bt maize may also have increased global maize production and thus prices may be lower than they would have been without it (Barrows et al., 2014a, 2014b).

While some evidence is available on the socio-economic impacts of growing Bt maize, it is far from complete. There are many potentially relevant socio-economic issues where the evidence is only suggestive or even entirely absent. Furthermore, little evidence is available on the potential impacts in countries and regions where Bt maize has not yet been grown.

In 2013, the European GMO Socio-Economics Bureau (ESEB) was established in order to organise and facilitate the exchange of technical and scientific information regarding the socio-economic implications in the EU of the cultivation and use of genetically modified organisms (GMOs) between Member States and the European Commission. In 2015, ESEB published a 'Framework for the socio-economic analysis of the cultivation of genetically modified crops', which compiled a list of topics[2] that could be included in assessments of any GM crop, along with appropriate indicators and methods (Kathage et al., 2015). The Reference Document presented here applies that general framework to make available a list of topics, indicators and methods that are relevant to Bt maize.

The document is structured as follows: the next section establishes the legislative context for GM cultivation in the EU, the mandate of ESEB and the scope of this document. Section 3 gives an overview of the cultivation of maize in the EU, plant protection and the Bt technology, as well as the maize supply chain. Section 4 discusses methodological issues. Sections 5, 6 and 7 are dedicated to a description of the topics and indicators regarding effects on crop farming, outside crop farming, and the aggregate impact, respectively. Section 8 contains final remarks.

1 Bt stands for *Bacillus thuringiensis*. Bt maize contains one or more genes from *B. thuringiensis*, making the plant produce Bt proteins (toxins) that are lethal and specific to certain orders of insects. Bt toxins are innocuous to humans, vertebrates and plants (Bravo et al., 2007).

2 Some examples of topics are farm income, seed industry and consumer prices.

2. Background

This section describes the legislative context for GM cultivation in the EU, the mandate of ESEB, and the scope of this document.

2.1 Legislative context for GM cultivation

The authorisation of GM crops for cultivation in the EU is subject to specific regulation.[3] Each event[4] has to receive individual authorisation for cultivation. The process for authorisation takes place under Directive 2001/18/EC[5] (as amended by Directive (EU) 2015/412[6]) or Regulation (EC) No 1829/2003[7] (if the scope also covers food and feed).

Under Directive 2001/18/EC, an application for authorisation for cultivation must be submitted to a national competent authority. The summary of the notification has to be forwarded to the Commission, which makes it available for public consultation. The national authority that received the application has to prepare an assessment report within 90 days and send it to the Commission, which forwards it to Member States for comments. The Commission requests a risk assessment from the European Food Safety Authority (EFSA) if at least one Member State proposes one or more reasonable objections based on the assessment report. This risk assessment can be taken into account by the Commission. Within 3 months of receiving the competent authority assessment report, the Commission has to propose to Member States to grant or refuse the authorisation.

Under Regulation (EC) No 1829/2003, an application for authorising a GM crop must also be submitted to a national authority, which has to acknowledge the receipt within 14 days. The national authority then sends the application to EFSA for a risk assessment. EFSA makes the application summary available to the public. If the application also covers cultivation, EFSA delegates an environmental risk assessment to an EU Member State, which sends its Environmental Risk Assessment (ERA) report to EFSA. EFSA assesses the risks that the GM crop may present to the environment, human health and animal safety in the EU. EFSA's GMO Panel carries out the risk assessment. It may give recommendations on labelling or conditions of the use and sale. Normally, EFSA performs the risk assessment within 6 months of receiving the application and issues a scientific opinion published in the EFSA Journal. This process can take longer if EFSA has to request additional information from the applicant in order to complete the assessment. EFSA submits its opinion to the European Commission and to the Member States. The opinion is made available to the public. Once EFSA publishes its risk assessment, the public has 30 days to comment on the Commission website for applications under Regulation (EC) 1829/2003. Within 3 months of receiving EFSA's opinion, the Commission proposes to Member States to grant or refuse the authorisation.

After the Commission's proposal to grant or refuse an authorisation under Directive 2001/18/EC or Regulation (EC) No 1829/2003, national representatives approve the Commission's proposal by qualified majority in the Standing Committee on Plants, Animals, Food and Feed. If the Committee does not approve or reject the proposal by a qualified majority, the Commission may summon an Appeal Committee. If the Appeal Committee fails to reach an opinion by a qualified majority, the Commission has to take responsibility for the final decision. An authorisation for cultivation is valid for 10 years and is renewable for 10-year periods on application.

3 Section 2.1 is based on information provided by the European Commission available at http://ec.europa.eu/food/plant/gmo_en

4 'Event' refers to a unique DNA recombination event in a plant cell that was then used to generate transgenic plants. Derived transgenic lines are often referred to by the event name, for example MON 810, a Bt maize event that has been authorised for cultivation in the EU.

5 Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. Official Journal of the European Communities L 106, 17.4.2001, p. 1.

6 Directive (EU) 2015/412 of the European Parliament and of the Council of 11 March 2015 amending Directive 2001/18/EC as regards the possibility for the Member States to restrict or prohibit the cultivation of genetically modified organisms (GMOs) in their territory (Text with EEA relevance). Official Journal of the European Communities L 68, 13.3.2015, p. 1–8.

7 Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed (Text with EEA relevance). Official Journal of the European Communities L 268, 18.10.2003, p. 1–23.

Once approved, the cultivation of a GM crop must be recorded by Member States in a national register. Directive 2001/18/EC also requires a monitoring plan designed to detect any potential adverse effects arising from the GMO or its use on human health or the environment. Furthermore, the directive includes a provision for emergency measures, which allows Member States to restrict the cultivation of a transgenic line based on a newly identified risk to human health or the environment. In 2015, Directive 2001/18/EC was amended by Directive (EU) 2015/412, which allows Member States to restrict or prohibit the cultivation of GM crops on their territory on grounds distinct from health or environmental risks assessed in the authorisation procedure under Directive 2001/18/ EC or Regulation (EC) No 1829/2003.

Regulation (EC) No 1830/2003[8] also mandates that food and feed products containing GMOs must be labelled as such, with the words 'genetically modified' or 'produced from genetically modified (name of the organism)' clearly visible on the labelling of these products. Food and feed products that contain a proportion of GMOs of less than 0.9 % of each ingredient are not labelled as GMO on the condition that the presence of the GMO is adventitious or technically unavoidable. It is the responsibility of the farmers and feed and food processors to demonstrate to the authorities that the presence of a GMO in a food or feed product is adventitious or technically unavoidable. There is zero tolerance for unauthorised GMOs.

The coexistence between GM, conventional and organic farming is governed by the principle of 'subsidiarity', meaning that Member States can adopt their own rules governing coexistence. Coexistence rules are concerned with the potential economic impact of the admixture of GM and non-GM crops, the identification of workable management measures to minimise admixture and the cost of these measures. The European Commission has published recommendations to help Member States draft national coexistence strategies.[9] The European Coexistence Bureau[10] (ECoB) has also published a number of Best Practice Documents to assist Member States in defining coexistence rules. Many Member States have implemented specific legislation governing coexistence on their territory, which often differ from one another.

2.2 Mandate of ESEB

In 2011, the European Commission published a report on the socio-economic implications of the cultivation of GMOs,[11] calling for 'an advanced reflection at European level, with sound scientific basis, with the objective of:

- Defining a robust set of factors to properly capture the *ex ante* and *ex post* socio-economic consequences of the cultivation of GMOs, from seed production to consumers across the EU. A methodological framework should be built-up to define socio-economic indicators to be monitored in the long run, and the appropriate rules for data collection. The pool of consulted parties should embrace all the regulatory and economic actors of the 'seed-to-shelves' chain, as well as the wider society.

- Exploring different approaches to possibly make use of the increased understanding of these multi-dimensional socio-economic factors in the management of GMO cultivation in the EU. The expertise of the Member States that have already started reflecting on these aspects should be taken into consideration.

This reflection should be set up and implemented jointly by the Member States and the Commission. Stakeholders should also be actively associated to ensure the success of this process.'

One of the initiatives towards achieving this goal was the creation of ESEB,[12] which consists of scientific experts nominated by the Member States (Technical Working Group) and experts from the European Commission (ESEB secretariat).

The mission of ESEB is to organise and facilitate the exchange of technical and scientific information regarding the socio-economic implications of the cultivation and use of GMOs by Member States and the Commission. On the basis of this process, ESEB develops Reference Documents that enable a science-based assessment of these impacts in the Member States and across the EU. The ESEB secretariat works in close collaboration with the European Commission's Directorate General for Health and Food Safety (DG SANTE) and is hosted by the Joint Research Centre in Seville (Spain). As indicated, the Technical Working Group (TWG) is composed of experts from Member

8 Regulation (EC) No 1830/2003 of the European Parliament and of the Council of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC. Official Journal of the European Communities L 268, 18.10.2003, p. 24-28."

9 Commission Recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the co-existence of genetically modified crops with conventional and organic farming. Replaced by Commission Recommendation of 13 July 2010 on guidelines for the development of national co-existence measures to avoid the unintended presence of GMOs in conventional and organic crops. Official Journal of the European Communities C 200, 22.07.2010, p. 1-5.

10 http://ecob.jrc.ec.europa.eu/

11 Report from the Commission to the European Parliament and the Council on socio-economic implications of GMO cultivation on the basis of Member States contributions, as requested by the Conclusions of the Environment Council of December 2008.

12 https://ec.europa.eu/jrc/en/eseb

States[13], who come from national research institutes, universities and administrations. Members of the TWG are expected to access a wide network of expertise available in their Member State, and have the capacity to collate and consolidate the information gathered on behalf of their Member State and to communicate it to the TWG.

2.3 Scope of the document

This document concerns the assessment of the socio-economic impacts of the cultivation of Bt maize in the EU. The document should be understood as a series of recommendations for researchers and/or administrators interested in conducting such assessments at the EU, national or subnational level.[14] At the core of the document is a catalogue of topics and indicators that may be considered in assessments. These topics are structured in line with the different groups in society that may be affected by Bt maize cultivation, including upstream industries, farmers, downstream industries, consumers, and government. Apart from the effects on international trade, the impacts arising in the EU from domestic cultivation only are covered.

To help frame the socio-economic analysis of Bt maize, descriptions of maize cultivation, the Bt technology, and the maize supply chain are given. General methodological considerations applicable to many topics are provided in a separate section and complemented with specific ones in the description of individual topics.

The topics contained in this document represent an adaptation to Bt maize of the topics contained in the first Reference Document. The topics in the first Reference Document were selected from a comprehensive list compiled from contributions from the TWG members, covering what they considered to be 'socio-economic' issues. However, when deciding whether or not to include a certain topic in the first Reference Document, the following selection criteria were applied: the presence of (a) at least one related indicator that can be measured quantitatively or qualitatively, (b) a plausible causal mechanism by which GM cultivation might affect the indicator and (c) a sound method to assess the impact (preferably backed by reputable scientific publications). These criteria were considered necessary to maintain the mission of ESEB to enable science-based assessments.

13 In addition, Norway is also part of the TWG.

14 This document is of a purely technical nature and is not intended to serve any regulatory purpose. Also, it is unrelated to the assessment of risks to human health and the environment.

3. Maize and its cultivation in the EU

This section provides brief descriptions of maize cultivation, plant protection including the Bt technology, and the supply chain of the crop in the EU.

3.1 Maize cultivation

Maize is among the most widely produced cereal grains in the world. Together with wheat and rice, maize provides at least 30 % of the food calories to more than 4.5 billion people in developing countries. In the developed world (including the EU), maize is primarily a key ingredient in animal feed. Maize is also used in industrial products, including the production of starch, sweeteners, oil, beverages, glue, industrial alcohol, biofuel and biogas (Shiferaw et al., 2011).

Global production has been increasing steadily during the past 50 years. In 2013, 1.02 billion tonnes of maize were produced. Average land productivity has also risen consistently, from 2 tonnes per hectare (t/ha) in the early 1960s to 5.5 t/ha in 2013. The Americas account for 51 % of global production, Asia for 30 % and Europe for 12 %. The top producers are the USA and China, followed by Brazil, Argentina and Ukraine (FAO, 2015).

In the EU, maize production and yield increased until the mid-1990s, but have since then stagnated, fluctuating around an average of 60 million tonnes of total production and 6.5 t/ha, respectively (FAO, 2015). The most important producers are France (15 million tonnes in 2014) and Romania (12 million tonnes in 2014), followed by Italy, Hungary, Germany, Spain and Poland. The highest yields in 2014 were observed in Spain, Austria and Germany (around 11 t/ha). Among the large producers, Romania had the lowest maize yields with 4.5 t/ha (Eurostat, 2015).

Maize requires temperatures of 20–24°C for optimal growth, and the temperature should not sink below 14°C at night. Depending on variety and local climate, maize may need between 70 and 210 days for full development. Sowing can occur as soon as soil temperatures reach 8–10°C. Optimal sowing dates range from March–April in southern countries to April–May in central countries to May in northern countries. Silage maize is cultivated for feed and mainly used on-farm. Grain maize may be used for feed, food or industrial products. The shorter seasons and wetter climatic conditions in north-western European regions are more suitable for silage maize, because it can be harvested for this purpose while still unripe, while grain maize production dominates in drier and warmer regions of central and southern Europe (Rüdelsheim & Smets, 2011).

Before sowing, ploughing is done in order to incorporate crop residues and weeds into the soil. Heavy soils are ploughed in autumn so that the frost can break clods. Sandy soils are tilled shortly before preparing the seed bed. Minimum tillage in many cases results in lower yields and is not widely adopted. Nitrogen is the most limiting nutrient for maize and the most frequently applied fertiliser. Sometimes the fertilisation is divided into two stages, in which case one of these is before sowing. For silage maize, fertiliser is often applied in the form of semi-liquid manure from cattle at the start of the growing season, with a small addition of mineral nitrogen (Rüdelsheim & Smets, 2011).

Irrigation plays a role primarily in the Mediterranean region. In some regions of Spain, Portugal, Greece, Italy and France, almost the whole maize area is irrigated. In contrast, in central and northern countries maize is almost exclusively a rainfed crop. Maize is generally harvested between August and December, depending on the purpose of the crop, the maturity class and the climatic conditions (Rüdelsheim & Smets, 2011).

3.2 Plant protection and Bt maize

3.2.1 Plant protection

Maize is sown and closes rows late, which offers very good conditions for the germination and rapid development of weeds. In its development maize is also sensitive to competition that limits its nutrient supply. The most important monocotyledonous weeds are Poaceae, such as *Echinochloa crus-galli* and *Setaria viridis*, which cause problems in all EU countries.

Chenopodium album is perceived in all countries as the most important dicotyledonous weed. Several other weeds are important only in some regions. Weeds are controlled with herbicides in all EU countries on more than 90 % of the production area. Two applications are typical, the first after sowing and pre-emergence, the second at the 3–8 leaf stage (post-emergence). Mechanical cultivation is an alternative to the pre-emergence treatment and combined with a chemical treatment later in the season. Mechanical weed control in maize has been practised in several countries including Italy, France, Spain and Hungary. Nevertheless, tillage systems without soil inversion rely more on herbicide use (Rüdelsheim & Smets, 2011).

Regarding diseases, *Pythium* and *Fusarium* are the most important fungi damaging young seedlings. *Fusarium* also induces ear, stalk and root rot, resulting in significant economic losses. The mycotoxins produced by the fungus are harmful to both humans and animals. Other fungal diseases of high importance in Europe are root and stalk rot caused by *Rhizoctonia* spp. and *Acremonium* spp. Other diseases cause problems only in some regions of the EU. Almost all seed is treated with fungicides and fungicide sprays are very uncommon (Rüdelsheim & Smets, 2011).

The three main maize pests are the European corn borer (ECB), *Ostrinia nubilalis*, the Mediterranean corn borer (MCB), *Sesamia nonagrioides*, and the Western corn rootworm (WCR), *Diabrotica virgifera virgifera*, whose occurrence varies across different regions of the EU (Figure 1). The most important pest is the ECB. The ECB leads to yield losses of up to 30 % in infested areas and without control measures. In the Mediterranean region, the MCB can cause additional economic damage. Between 2 and 4 million hectares of maize in Europe are affected by these two maize-boring pests, with several other Lepidoptera causing more regional problems in the central and southern countries. Among Coleoptera, wireworms (*Agriotes* spp., *Elateridae*) cause damage in all European regions. The WCR causes economic damage in Hungary and other central and eastern European countries. Furthermore, populations of this species are already established in south-west Poland, south-west Germany and the Po Valley and are continuously spreading across Europe. Other pests of various orders have more regional importance (Meissle et al., 2010).

Insecticide applications are the most common pest control measures in maize. Seed and soil treatments are often used against soil insects such as WCR and are regularly combined with treatments against diseases (fungicides). Foliar insecticides against lepidopteran pests such as ECB or MCB are used in high-infestation areas, and typically applied once or twice per season (Rüdelsheim & Smets, 2011). Alternatives to insecticide applications include the preventative deep ploughing of crushed harvest residues in regions where ECB is present. Other pest control methods are crop rotations, employed on around half of the maize area in many countries, to combat different insect pests such as corn rootworm, wireworms and cutworms. The most common rotation is maize with wheat or barley in a 2-year cycle, although different rotations with various crops are practised regionally. Biological control measures include the use of the parasite wasp *Trichogramma* spp. (Rüdelsheim & Smets, 2011).

Figure 1: Distribution of the three main maize pests in Europe.

A: European corn borer (Ostrinia nubilalis); B: Mediterranean corn borer (Sesamia nonagrioides); C: Western corn rootworm (Diabrotica virgifera virgifera). Note that the area where the pest species cause damage to crops is generally smaller than the distributions of the species.

Source: Adapted from Meissle et al. (2011)

3.2.2 Bt maize

Bt maize contains one or several genes from *Bacillus thuringiensis* that make it produce proteins toxic to certain maize-feeding insects. The first generation of Bt maize was resistant only to corn borers, but later generations are also resistant to cutworms, earworms and/or rootworm. Bt maize has been grown in the USA and Canada since 1996. In several countries, it is usual to grow GM maize containing multiple ('stacked') Bt genes, and often also genes conferring herbicide tolerance (HT). GM maize adoption in 2014 reached 30 % of the global maize area. However, since some of the GM maize grown contains only other traits (such as HT), the adoption rate of GM maize containing Bt traits is somewhat lower. Table 1 shows the adoption rates of Bt maize in several selected countries and regions. In the EU, only Bt maize with corn borer[15] resistance has been authorised, and the only country with significant Bt cultivation is Spain, where it has been grown since 1998.[16] Farmers in France and Germany, who had started to plant Bt maize in 2005, have not grown it since 2008 and 2009, respectively, as a result of government regulations prohibiting its cultivation. Portugal, the Czech Republic, Romania and Slovakia still planted Bt maize in 2014, but on very small areas (James, 2014). In 2015, 19 Member States[17] banned Bt maize cultivation on all or part of their territory by making use of Directive (EU) 2015/412.

Table 1: Areas and adoption rates of Bt maize in 2014

	USA	Brazil	Argentina	Canada	South Africa	Spain	Rest of EU
Year first grown	1996	2008	1998	1996	2000	1998	2005
Area (million ha)	29.6	11.9	2.8	1.2	1.7	0.13	0.01
% of total maize	80 %	78 %	74 %	78 %	69 %	32 %	0.001 %

Notes: rest of EU: Portugal, the Czech Republic, Romania, Slovakia. Shares of stacked traits among total maize: USA, 76 % Bt/HT; Brazil, 48.8 % Bt/HT; Argentina, 52.8 % Bt/HT; Canada, 75 % Bt/HT; South Africa, 45 % Bt/HT. In Spain and the rest of the EU, all cultivated Bt maize contains one Bt gene and no herbicide tolerance traits.
Sources: James, 2014; USDA, 2014.

15 Bt maize with rootworm resistance is grown in some non-EU countries, but has not been authorised in the EU.

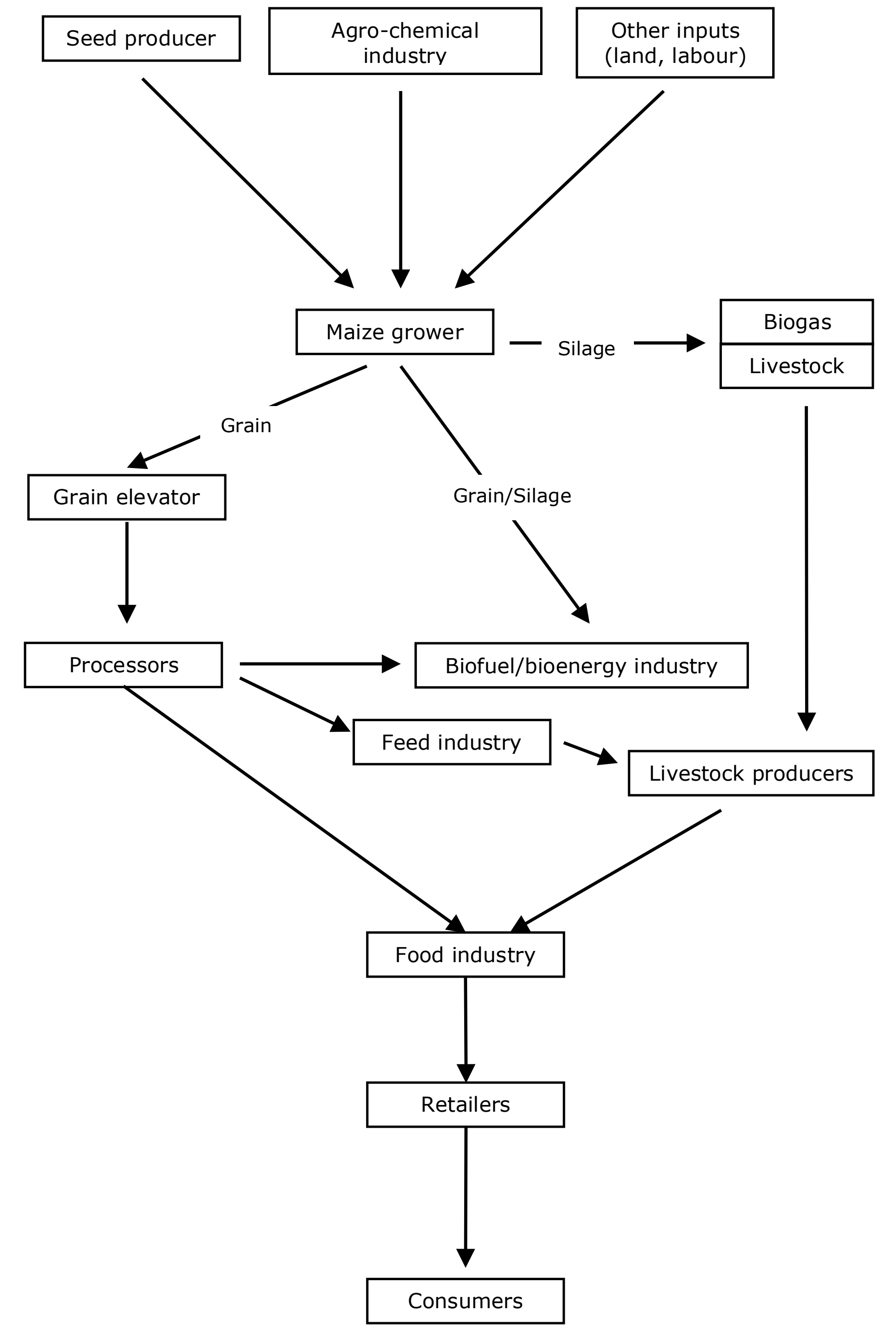
16 In this document, only Bt maize is considered because it is the first and so far the only GM maize cultivated in the EU.

17 Austria, Belgium (Wallonia), Bulgaria, Croatia, Cyprus, Denmark, France, Germany (except for research purposes), Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Slovenia, the United Kingdom (Northern Ireland, Scotland, Wales).

3.3 The maize supply chain

The maize supply chain consists of upstream industries, farmers, downstream industries and consumers (Figure 2). The upstream industries supply inputs such as seed and fertiliser to farmers. Farmers can choose to produce silage maize and/or grain maize. Whereas silage maize is usually not sold and is consumed by livestock on the farm or used as feedstock for biogas production, grain maize is collected, dried and stored in elevators that concentrate the grain in a limited area and sell it over an extended period of time. There are three main uses for grain maize: it can be consumed directly on the farm; it can be sold to feed manufacturers; or it can be further processed for use in downstream industries producing feed, food (e.g. maize-meal products, cornflakes) and industrial (e.g. starch, biofuels) products. Food products are typically sold by retailers to consumers (Gabriel & Menrad, 2015; Lecroart et al., 2012; Rüdelsheim & Smets, 2011).

Figure 2: Maize supply chain



Source: authors' own illustration

4. Methodology for assessments

Ensuring the quality of assessments of the socio-economic impacts of Bt maize cultivation requires the use of a scientific approach, reliable methods and appropriate data sources. These concepts are described in the following subsections.

4.1 Approach

Impact assessments of the cultivation of Bt maize can be conducted before (*ex ante*) or after (*ex post*) cultivation takes place. In principle, the impact of Bt maize cultivation on all indicators contained in this document can be estimated both *ex ante* and *ex post*, with *ex post* methods usually being more precise (but not feasible if cultivation has not taken place). Both types of analysis require a definition of the time period covered, as impacts may evolve over time. Assessments should cover at least one growing season, but it is recommended that multiple years are examined, as annual fluctuations (e.g. in pest pressure) influence the impact of Bt maize. Moreover, certain impacts may appear or diminish over time or need a certain period before they reach a steady state, as is the case, for instance, with market shifts and related price changes. Furthermore, the adoption rate of Bt maize may change from year to year. For *ex ante* studies, which are likely to be constrained by the range and complexity of variables affecting crop performance, the use of multiple impact scenarios (including variations in pest pressure) and sensitivity analysis is particularly relevant. The assumptions in terms of adoption rates among farmers, acceptance among consumers, adoption rates in other countries or regions, price elasticities and other relevant determinants of impacts should be specified for all scenarios as far as possible.

A successful impact assessment isolates the effect of Bt maize cultivation on the value of an indicator and separates it from any other influences. For example, the price of maize is determined by many different factors affecting its supply and demand, all of which have to be controlled for. The approach can be visualised in three main steps. First, a definition of the scenarios that are to be compared is needed. One scenario includes cultivation of Bt maize ('impact scenario'), while the second represents the situation without cultivation of Bt maize ('baseline scenario'). Second, the value of the indicator to be assessed must be estimated for each of the two scenarios. Third, the difference between the two values ('impact') is calculated. This is illustrated in the following equation:

Impact = (value of indicator under impact scenario with Bt maize cultivation) – (value of indicator under baseline scenario without Bt maize cultivation)

The approach so far implies a binary adoption decision. This is particularly suitable when considering impacts on a single plot cultivated by a farmer (either Bt maize is grown on it, or not). However, assessments usually cover more than one plot (often whole regions, countries or groups of countries) and not only adopting farmers but also non-adopting farmers and non-farming groups such as upstream and downstream industries as well as consumers. In these cases, the impacts depend crucially on the (regional) adoption rates of Bt maize. Low or high adoption rates will have radically different impacts for most actors. Therefore, the impact scenario should always be described considering the adoption rate (between 0 and 100 %). The baseline scenario will usually assume an adoption rate of 0 % of Bt maize. However, depending on the circumstances, the baseline scenario may also assume a positive adoption rate. This is the case if Bt maize is already grown by some farmers, but the release of new events and/or cultivars is expected to further expand its adoption rate. In these cases, both the baseline and the impact scenarios have positive adoption rates, with the impact scenario having a higher one.

The definition of the adoption rate under different scenarios can be approached in two main ways. The adoption rate can be estimated based on an explicit model (predictive), or it can be assumed in the absence of an explicit model (exploratory). In both cases, it is possible to employ varying assumptions to define multiple impact scenarios, which are then individually assessed against the baseline scenario. The use of multiple impact scenarios can provide insight into the robustness of the results. Apart from the adoption rate, assumptions can also be varied regarding other relevant parameters such as pest infestation patterns or alternative means of control.

A central question is how farmers and other stakeholders (e.g. upstream and downstream industries as well as consumers and the government) behave under the impact and baseline scenarios. The adoption of Bt maize may lead farmers to choose different varieties or even different crops than the ones they would have grown in the absence of Bt maize, as well as modify their use of inputs and practices. Since only one scenario can be observed and the others are hypothetical, the most common approach is to compare adopters and non-adopters in the same area/region (Gómez-Barbero et al., 2008a). However, the methodology should as much as possible control for the heterogeneity in agro-climatic, economic and managerial characteristics among farmers and plots in order to avoid selection bias. Selection bias can arise when adopters and non-adopters differ in some characteristics (apart from the adopted technology) that have an impact on the indicator and that are not controlled for. An alternative way to estimate the impact of a technology is to compare Bt and non-Bt plots within the same farm, which can help reduce selection bias (Kathage & Qaim, 2012). Furthermore, the heterogeneity in farm and farmer characteristics and behaviour can also lead to heterogeneity in impacts of Bt maize cultivation, which should be recognised. For example, different farmers may face different pest pressures, meaning that the impact of Bt maize may differ between them. Results can be presented for an average farm and also be aggregated, but should be reported on a more disaggregated level in the case of considerable heterogeneity.

A more complicated situation for evaluation purposes arises when farmers expand the area devoted to maize as a result of Bt maize adoption (Barrows et al., 2014a). Such area expansion is referred to as 'adoption along the extensive margin', in contrast to 'adoption along the intensive margin' where Bt maize substitutes conventional maize on the same area. Adoption along the extensive margin can happen if Bt maize offers a profitable opportunity on areas previously not cultivated or used for other crops. Then, in order to estimate the effects of Bt maize, different outputs will have to be made comparable through appropriate indicators. For example, if maize cultivation expands on areas formerly planted with another crop, the differences in input use between these two crops will have to be compared as well as the value of the output. The most common indicator of the value of a crop is its monetary value. In a similar vein, the adoption of Bt maize could affect the cultivation of other crops through equilibrium effects, for example if it changes maize supply and prices or the demand for inputs.[18]

18 Because adoption along the extensive margin and general equilibrium effects are generic issues that apply to all topics in this document, their discussion is mainly restricted to this section. However, both issues should be kept in mind when conducting an impact assessment.

This Reference Document does not give detailed recommendations regarding a summary or synthesis of the impacts of GM cultivation across different topics. Furthermore, the list of topics is not comprehensive of all potential impacts, and also not for all countries. Instead, the document should be seen as offering a compilation of topics that can be considered for inclusion in an impact assessment. However, it should be recognised that in some cases in Sections 5–7 the indicators of different topics overlap. This is a by-product of highlighting particular topics. Double counting of overlapping topics should be avoided when conducting an impact assessment. For example, when calculating the total cost of maize production, each cost component should only be counted once, even if some of these cost components might also be considered under other topics.

4.2 Methods and data sources

While different topics and indicators may call for different assessment methods, there are a number of issues that apply across almost all of them. More specific guidance on suitable methods for individual indicators can be found in the scientific publications cited in the descriptions of the associated topics in Sections 5, 6 and 7 of this document.

Assessing the impact of Bt maize cultivation on farmers may involve farm surveys of adopters and non-adopters (Fernandez-Cornejo & Wechsler, 2012; Gómez-Barbero et al., 2008a, 2008b; McBride & El-Osta, 2002; Pilcher & Rice, 1998; Riesgo et al., 2012). Data from these surveys should be analysed using appropriate statistical techniques ranging from partial budgeting to econometric models specific to the indicator concerned. For example, partial budgeting and econometric models with various specifications and control mechanisms can be used to estimate the impact of Bt maize cultivation on insecticide use, yield, and gross margin, or to estimate the determinants of Bt maize adoption (Areal et al., 2012; Demont et al., 2008; Fernandez-Cornejo & Wechsler, 2012; Gómez-Barbero et al., 2008a; McBride & El-Osta, 2002).

If available, data from field trials can be used in the absence of or in addition to surveys of commercial farms (Nolan & Santos, 2012; Wesseler et al., 2007). Assessments can also employ information from literature reviews, expert consultation and modelling. Appropriate consideration should be given to any potential data limitations. For example, the performance of a technology in field trials can differ significantly from its performance on commercial farms (Barrett et al., 2004).

Assessing the effects of Bt maize cultivation on prices and upstream and downstream industries and markets requires complex socio-economic models and a combination of primary and secondary data. Welfare economics provides tools for conducting such assessments (Qaim, 2009). Partial equilibrium models allow for the estimation of the economic welfare effects and their distribution among different groups in society such as farmers and consumers. More complex general equilibrium models consider linkages across the whole economy and can be used for more comprehensive analyses. Published studies show methodological variations regarding data sources, model types and assumptions, levels of regional aggregation, applied price elasticities, price transmission along the supply chain and developments over time (Franke et al., 2011; Gómez-Barbero & Rodríguez-Cerezo, 2006).

The analysis of the segregation between Bt and non-Bt maize products in the supply chain from seed suppliers to retailers requires integrated models with endogenous price formation that are able to determine, for instance, how the operators of the chain will react to the adoption of Bt maize and deal with the demand for conventional food/feed (i.e. establishing identity preserved (IP) markets and price premiums on these products). This type of analysis is still rare in the existing literature and requires primary and secondary data that are difficult to obtain (Tillie et al., 2012).

In economic analysis, consumer preferences for GM/non-GM products can be estimated as stated or revealed preferences (Dannenberg, 2009). Stated preferences can be measured in choice experiments, resulting in the hypothetical willingness to pay (WTP). Revealed preferences can be measured in experimental auctions. In the case of GM products, revealed preferences tend to be more accurate as they avoid socially desirable answers (Lucht, 2015). *Ex post* estimates can be derived from the recording of real purchasing behaviour such as supermarket scanner data (Kalaitzandonakes et al., 2005).

Even with a proper methodological approach, the data needed to estimate the values of most of the indicators described in this document are not available, and there are no initiatives at the EU level under which such data will be collected in the near future. If a country wants to obtain the required data, it is often necessary to collect it directly from farmers, industry and consumers through surveys. Additional data sources are consumer and producer panels, accounting and official data based on legislation, expert opinion and experiments. All data collection methods should use adequate techniques to generate datasets that are representative of the target population. Panel datasets can facilitate unbiased impact assessments and the analysis of dynamics over time (Kathage & Qaim, 2012). Assessments may cover countries or groups of countries, although a more disaggregated analysis can in many cases be more appropriate given regional differences in agronomic, economic and legal characteristics.

5. Effects on crop farming

The cultivation of Bt maize in the EU can have impacts on adopters and non-adopters of Bt maize. Adopters of Bt maize might experience effects on their agronomic and pest management practices and associated costs and revenues, production efficiency, crop rotation, tillage and insect resistance management, as well as coexistence and time management. Non-adopters may face segregation cost and the opportunity cost of not adopting Bt maize. Both adopters and non-adopters might see effects such as changes in input and output prices, as well as crop protection spillovers.

5.1 Adopters

5.1.1 Adoption rate

Adoption rates can be expressed in several ways: most commonly as the number of hectares that are cultivated with Bt maize and the share of these hectares among the total maize area (James, 2014). Another indicator is the number of farmers using Bt maize on at least a part of their land and their share among all farmers. The number of farmers willing to adopt or not adopt Bt maize can be used as an *ex ante* estimate of its potential adoption or diffusion (Areal et al., 2011). A different approach of predicting adoption rates is based on a utility model according to which a farmer will adopt Bt maize if the expected benefits of adoption exceed the expected costs (Demont et al., 2008, Dillen et al., 2010). Studies in several European and American countries have shown that the benefits of adoption mostly depend on the level of infestation with the pests Bt maize targets and the available crop protection alternatives (Consmüller et al., 2010; Demont et al., 2008, Dillen et al., 2010; Fernandez-Cornejo & McBride, 2002; Fernandez-Cornejo et al., 2014; Gómez-Barbero et al., 2008a; Křístková, 2010). The primary stated reason for most US farmers adopting Bt maize is an increase in yield (Fernandez-Cornejo et al., 2014). In Spain, lower risk of ECB damage and higher yield were the two most quoted reasons (Gómez-Barbero et al., 2008a). If Bt maize were to be made available in Hungary, Demont et al. (2008) estimate *ex ante* an adoption rate of 10 % owing to low ECB pressure. Dillen et al. (2010) estimate *ex ante* the adoption rate of rootworm resistant Bt maize in seven Central European countries based on several factors including the value of the crop and the comparative efficacy of alternative pest control measures. Coexistence rules can also have an impact on the adoption rate (discussed in Sections 5.1.6 and 5.2.3).

The proposed indicators are:[19]

- Number of hectares under Bt maize divided by total maize hectares

- Number and share of farmers adopting Bt maize

5.1.2 Typology of adopting farmers

A starting point for the analysis of the impacts of Bt maize cultivation on adopting farmers is their characterisation in terms of farm location, size, income, crop and livestock operations, proportions of grain and silage maize, access to irrigation and ownership status. Demographic characteristics of the farm manager such as education, experience, age, sex, income and occupational status should also be collected. These characteristics provide information on which groups or types of farms and farmers are directly impacted by Bt maize cultivation. For example, farmers with larger maize areas were more likely to adopt Bt maize in Germany, in part because of regulations requiring large isolation distances (Consmüller et al., 2010). The positive relationship between farm size and Bt maize adoption was initially also observed in the USA, the reason being that pest problems were most severe in those areas with the largest maize farms (Fernandez-Cornejo & McBride, 2002). In Spain, no differences between adopters and non-adopters in farm size and other socio-economic characteristics such as education, experience and age could be identified (Gómez-Barbero et al., 2008a).

- Farm characteristics (region/country, size[20], number and size of land plots, number of and distance to neighbouring maize farmers, type and size of crop and livestock

19 All indicators in this document are bulleted.

20 As an alternative indicator of the economic size of farms, the Eurostat Standard Output can be used.

operations, income -either total and or by type of crop and livestock-, share proportions of grain and silage maize, access to irrigation, ownership)

- Farmer characteristics (education, experience in farming and Bt maize production, age, sex, household size and income, off-farm income, time dedication to farming, membership of farmers' associations)

5.1.3 Income effects

Bt maize adoption can have an impact on fixed and variable cost, cost structure, yield and yield risk, mycotoxin content, the price received, subsidies and gross margin. In addition to income effects for farmers, the impact on the employment and wages of farm workers can be assessed.

5.1.3.1 Fixed cost

Fixed cost includes those parts of production cost that are independent of the area or volume of production. In a study in Germany, Consmüller et al. (2010) found that the adoption of Bt maize was associated with additional fixed costs due to regulation, even though the technology seems to be scale-neutral. Similarly, in the Czech Republic, some adopters reported that Bt maize adoption was associated with an increase in administrative costs (Křístková, 2010). In addition, any fixed cost related to coexistence and segregation (Topic 5.1.6) should be considered here as well.

- Fixed cost in €/ha and €/farm

5.1.3.2 Variable cost

Bt maize represents a technique of pest control and is thus a substitute for other techniques such as certain insecticides. Seed companies normally charge a higher price for Bt maize seeds than for conventional maize (Baute et al., 2002; Gómez-Barbero et al., 2008a). Changes in overall input demand (e.g. for insecticides) resulting from Bt maize cultivation may also change input prices. Several components of variable cost may thus be affected by the adoption of Bt maize, most importantly seed and insecticide costs. Data from the USA indicate that insecticide costs are reduced by Bt maize adoption, while seed costs increase, leading to an overall increase in variable cost compared with conventional maize (Fernandez-Cornejo et al., 2014; Hutchison et al., 2010). For Argentina, various industry sources suggest that variable cost has increased, as neither conventional nor Bt maize is commonly treated with insecticides there (Brookes & Barfoot, 2015). In South Africa, insecticide cost savings and additional seed costs have been roughly equal, such that overall almost no impact on variable cost was observed (Gouse et al., 2005). The evidence for Spain indicates that farmers have saved on insecticide costs as compared with conventional maize (Gómez-Barbero et al., 2008a). In 2009, however, the additional seed cost for Bt maize has led to an increase in variable cost (Riesgo et al., 2012). Evidence is much more limited for other European countries. Based on various private and public data sources, in France (during the time of commercial cultivation), the Czech Republic, Portugal and Slovakia, seed costs were higher for Bt maize (Brookes, 2008). In France, insecticide costs and also total variable cost were lower for Bt maize. In the Czech Republic, insecticide costs were lower, but total variable costs slightly higher for Bt maize. In Portugal and Slovakia, no change in insecticide costs was found and there was an increase in total variable cost for Bt maize.

In addition, any variable cost related to coexistence and segregation (Topic 5.1.6) should be considered here as well.

- Total variable cost in €/ha

5.1.3.3 Cost structure

Total cost is composed of fixed and variable cost. How Bt maize adoption changes the shares of these two components is not clear, as variable cost tends to increase, but also fixed cost related to administrative procedures may get higher. By changing the cost of individual variable cost components, the adoption of Bt maize can also alter the composition of variable cost. The available evidence suggests that Bt maize is increasing the seed and decreasing the insecticide share of variable cost.

- Proportions of total cost that are variable cost and fixed cost

- Composition of variable cost

- Composition of total cost

5.1.3.4 Yield and yield risk

Bt maize can improve the level of crop protection compared with the use of alternative pest management practices such as insecticides, leading to an increase in yield. In the USA, this yield increase was estimated at 7 % for the period 1996–2009 by Hutchison et al. (2010). In South Africa, average yield gain estimates have been positive, although with significant seasonal and regional variation (Gouse, 2012; Gouse et al., 2005). For Spain, average yield advantages of Bt maize have been around 10 %, with variations for different years and regions (Gómez Barbero et al., 2008a; Riesgo et al., 2012). In other EU countries, various public and private data sources indicate yield increases from around 7 % in Romania to 12 % in Portugal (Brookes, 2008).

Since Bt maize has the ability to reduce yield loss, it represents a risk management tool. The value of this risk management tool can be derived from annual variation in yield of Bt maize compared with conventional maize. In countries where crop insurance is common, insurance premiums paid by Bt maize adopters can be compared with those of conventional maize growers. As an illustration, the USDA Federal Crop Insurance Corporation offered a discount of 13 % (about €5/ha) in 2008 to Bt maize growers (National Research Council, 2010).

- Yield in t/ha

- Yield risk measured in annual variation in t/ha or crop insurance premiums paid by farmers in €/ha

5.1.3.5 Mycotoxin content

Fungi of the genus *Fusarium* are common fungal contaminants of maize and also produce mycotoxins, which can adversely affect human and farm animal health. The level of mycotoxins is an important quality attribute of maize. High mycotoxin content can lead to the rejection of maize for food production (although it might be downgraded to feed production). Since fungi enter the maize plant through lesions caused by pests, the adoption of Bt maize can result in lower mycotoxin levels. This has been confirmed in several studies (Bakan et al., 2002; Křístková, 2010; Munkvold, 2014; Ostry et al., 2010; Wu, 2007).

- Level of fungal infections and mycotoxins

- Frequency of incidents and rejections due to high mycotoxin levels

5.1.3.6 Price received for output

Aggregate Bt maize adoption may affect the prices received by Bt maize adopters if it leads to changes in the overall supply of maize (Barrows et al., 2014a).[21] Furthermore, individual Bt maize adopters switching from non-GM maize may experience a decline in the price received if non-GM maize receives a price premium, which can be the case especially if this non-GM maize is labelled as such or is sold as organic maize (Skevas et al., 2010). On the other hand, mycotoxin levels may be reduced by Bt maize, which can raise the price farmers receive (Wu, 2004). Studies that compare the farm gate price received by adopters and those of non-adopters have generally not found significant differences (Gómez-Barbero et al., 2008a; Gómez-Barbero & Rodríguez-Cerezo, 2006; Hall et al., 2013; Křístková, 2010).

- Price received for maize (€/t)

5.1.3.7 Subsidies

In some Member States, adopters of GM crops are sometimes exempted from receiving certain agricultural subsidies. For example, the Portuguese government stopped providing a subsidy for environmental measures to GM maize farmers from 2008 onwards (Skevas et al., 2010). Specialised non-GM growers such as organic farmers may lose some subsidies should they switch from organic to Bt maize cultivation (Consmüller et al., 2010). Subsidies can be categorised as direct payments (pillar I) and agri-environmental schemes (pillar II) of the Common Agricultural Policy (CAP).

- Subsidies (€/ha or €/t), by pillars I and II of the CAP

5.1.3.8 Gross margin

Because the cultivation of Bt maize may affect variable cost, yield, output price and subsidies, it can also affect the gross margin, which is defined as revenue minus variable cost. In order to put the absolute gross margin in percentage terms, it can also be divided by revenue (price times quantity sold). Peer-reviewed studies published in scientific journals indicate average increases in gross margin for Bt maize adopters in the USA, South Africa and Spain (Fernandez-Cornejo et al., 2014; Gouse et al., 2005; Gómez Barbero et al., 2008a; Hutchison et al., 2010; Riesgo et al., 2012). Various industry sources, governmental publications and field trials indicate gross margin gains also in Canada, Brazil, Argentina, France, Germany, Portugal, the Czech Republic, Slovakia, Romania, the Philippines, Uruguay, Honduras, Colombia and Paraguay (Brookes, 2008; Brookes & Barfoot, 2015).

Some farmers may not sell (all of) their maize, especially if they are livestock farmers growing silage maize for animal feed or if they use the maize as feedstock for biogas production. However, the value of potential yield effects of Bt maize can be accounted for, for example in terms of changes in feed purchasing cost or revenue from biogas production.

- Gross margin in €/ha

- Gross margin as a percentage of revenue

21 For individual adopters of Bt maize, any downward pressure this adoption may exert on the price of maize is so extremely small that a counterfactual scenario of individual non-adoption would in practice have no effect on the price.

5.1.3.9 Employment and wages

Bt maize may require a different amount of labour input from conventional maize because of a reduced need for insecticide applications. This can affect the number and working time of workers that are hired by the farmer.[22] If gross margins and farm income are affected by Bt maize adoption, then so too may be the wage levels of farmworkers. Employment and wages can be assessed by month in order to cover seasonality. Franke et al. (2011) conclude that the available evidence is insufficient to draw any conclusions regarding employment or wage levels.

- Number of farm workers and their total working hours
- Wages of employed farm workers in €/hour

5.1.4 Crop rotation, tillage and resistance management

Bt maize cultivation may affect the choice of rotations and tillage and also the use of measures to prevent pest resistance.

5.1.4.1 Crop rotation and tillage

One reason why farmers use crop rotation and tillage is to reduce pest infestation levels (Meissle et al., 2011). Since Bt maize is resistant to certain pests, it can act as a substitute for these two practices (Chavas & Shi, 2015).[23] Under certain circumstances, adopters of Bt maize may thus reduce the use of crop rotation and tillage, although this is highly dependent on the agronomic, economic and political context (Dillen et al., 2010).

- Types and frequency of crops used in rotation
- Type of tillage used by plot (conventional, conservation, no-till)

5.1.4.2 Insect resistance management

In the same manner that chemical insecticides can result in resistance of target pests if the same active ingredients are used continuously, the adoption of Bt maize may lead to the development of resistance to it in pest populations. Insect Resistance Management (IRM) comprises a number of strategies farmers can implement in order to delay resistance, for example the use of multiple treatments with different modes of action. Another strategy involves the killing of fewer susceptible insects, which can be achieved by reducing the frequency and intensity of treatments, or by planting refuge areas (Onstad, 2014).[24] Refuge areas are mandatory or recommended IRM measures in several countries (Skevas et al., 2010). Depending on farmer compliance, the adoption of Bt maize can thus affect the time and cost spent on IRM (Hurley & Mitchell, 2014). No empirical estimates of these effects have been published for the EU, but methods from studies in the US are available (Frisvold & Reeves, 2008; Hurley et al., 2001).

- Size of refuge areas (share of plot area)
- Time spent on IRM (h/ha)
- Cost of IRM (€/ha)

5.1.5 Input use and efficiency

Inputs used to produce maize are generally in limited supply; hence, any changes in their amount and the cost required to produce maize represent changes in production efficiency. The adoption of Bt maize can have effects on the use of land, insecticides, fertiliser, water, labour, machinery, energy and fuel (and associated greenhouse gas emissions). Inputs can be measured in physical quantities or monetary terms. Input use can be related to unit of area or unit of output. Since Bt maize might increase output per hectare and land is itself an input, it is recommended that input use is reported per unit of output (e.g. per tonne). Finally, overall production efficiency can be indicated by revenue divided by total input cost.

It should be noted that the efficiency of all inputs here could theoretically increase or decrease as a result of Bt maize adoption (even if not explicitly mentioned under each input). This is because Bt maize may replace non-GM maize but also any other crop (as discussed in Section 4.1).

5.1.5.1 Land

The efficiency of land use is directly related to yield. Hence, any yield changes brought about by Bt maize adoption are synonymous with changes in land use efficiency. In that respect, some evidence is available (see Topic 5.1.3.4). Regarding adoption along the extensive margin, however, no evidence is available.

- Land area in ha and cost in € per unit of output

22 Note that the focus of this topic is the paid employment of farmworkers. Unpaid work done by the farmer should not be considered here.

23 If the adoption of Bt maize affects crop rotations, then the impacts of crop rotation changes should also be assessed (as discussed in Section 4.1).

24 Refuge areas refer to the planting of a sufficiently large and properly positioned area with conventional maize in the vicinity of Bt maize, which ensures that insects in these refuge areas that are susceptible to Bt maize will interbreed with those on the Bt maize area that are resistant.

5.1.5.2 Insecticides

Bt maize is a substitute for some chemical insecticides that target the same pests as Bt maize (e.g. ECB, rootworm). To the extent that these insecticides are used in conventional production, their volume and frequency of application are brought down by the adoption of Bt maize. In the USA, the adoption of Bt maize has led to significant reductions in the amount of insecticides used (Fernandez-Cornejo et al., 2014). In Spain, conventional maize would be treated with insecticides against ECB in regions with high infestation (e.g. Huesca), and there the adoption of Bt maize has led to significant reductions in the use of insecticides (Gómez-Barbero et al., 2008a). In Poland, Slovakia, Austria and the Netherlands, Bt maize with rootworm resistance (if authorised) might lead to reductions of the use of insecticides applied as sprays or seed treatments (Dillen et al., 2010; Riemens et al., 2012). For other EU countries, some available evidence suggests decreases or no change in insecticide use depending on the region (Brookes, 2008). In France, farmers use insecticides against ECB mostly in the south-west, where Bt maize could result in insecticide savings. In Germany, ECB occurs mainly in the south and east, although only a minority of farmers use insecticide treatments against it. In the Czech Republic, ECB is a significant pest and regular insecticide treatments are used, hence Bt maize has the potential for insecticide savings. In Portugal, only a limited amount of insecticides is used against ECB, suggesting that a large-scale adoption of Bt maize would not lead to large reductions in insecticide use in maize.

An important effect of Bt maize is that the large-scale and continuous adoption of Bt maize can lead to reductions in the overall pest population (Hutchison et al., 2010). With lower infestation levels, the insecticide-reducing effect of Bt maize on adopters thus decreases over time, which has been documented for the USA (Fernandez-Cornejo et al., 2014). In that respect, early adopters of Bt maize can be expected to realise higher insecticide savings than later adopters.

In cases where insecticide use per hectare remains unaffected by Bt maize, potential yield changes will result in changes in insecticide use per unit of output.

- kg of active ingredient of insecticides per unit of output (or per ha)

- Number and cost in € of insecticide applications per unit of output (or per ha)

5.1.5.3 Fertiliser

The optimal amount of fertiliser use depends on, among other factors, the expected yield. If Bt maize adoption diminishes crop damage it increases the marginal value product of fertiliser, which in turn could increase fertiliser use per hectare (Barrows et al., 2014a). There is also some evidence that Bt maize resistant to rootworm may increase the nitrogen use efficiency of maize (Haegele & Below, 2013). No evidence is available regarding the effect of Bt maize adoption on fertiliser use. Even if fertiliser use per hectare remains unaffected by Bt maize adoption, changes in yield will still have an effect on the use of fertiliser per unit of output.

- kg and € of nitrogen, phosphorus (P_2O_5), potassium (K_2O) per unit of output (or per ha)

5.1.5.4 Irrigation and water use

Bt maize with resistance to rootworm has shown better growth under combined rootworm and water stress, as a side effect of the root system not being damaged by the pest (Franke et al., 2011). Hence, the amount of irrigation needed to produce a given level of output may be lower for this type of Bt maize under specific circumstances. On the other hand, if Bt maize adoption diminishes crop damage it increases the marginal value product of water, which in turn could lead to higher water use per hectare (Barrows et al., 2014a). However, the available evidence on the net effect of Bt maize adoption on water use is very limited. If irrigation and water use per hectare remain the same after the adoption of Bt maize, any yield increase will result in less water use per unit of output.

- Cubic metres and € per unit of output (or per ha)

5.1.5.5 Labour

If the adoption of Bt maize entails savings in insecticide, fewer hours of the farmer's own and hired labour are spent on spraying, while the same or a higher level of output is maintained (Alston et al., 2002).[25] Similarly, the cost of hired labour could be affected. On the other hand, Bt maize may be more labour-intensive during sowing or when cleaning machinery and equipment due to potential efforts to keep it separated from non-GM materials (Křístková, 2010). If Bt maize adoption diminishes crop damage it increases the marginal value product of labour, which in turn could lead to higher labour use per hectare (Barrows et al., 2014a). Insufficient evidence is available regarding the effect of Bt maize on labour use. Labour use per unit of output

25 The focus of this topic is the overall use of labour. Therefore, the labour hours of the farmer and any hired workers should be considered. However, in the case of the cost of labour, only wages paid to hired farmworkers should be counted.

can be affected through yield increases, even if labour use per hectare remains unchanged.

Labour hours and cost in € per unit of output (or per ha)

5.1.5.6 Machinery

Bt maize adoption can lead to a reduction in the use of machinery per hectare for spraying if less insecticide is applied (Křístková, 2010). On the other hand, additional machinery cleaning costs may arise from the need to keep Bt and non-GM maize separated (Gabriel & Menrad, 2015; Messean et al., 2006). The available evidence regarding the effect of Bt maize adoption on machinery use is very limited. Without a difference between Bt and conventional maize with respect to machinery use per hectare, machinery use per unit of output is still affected by potential yield changes.

- Use of machinery in hours per unit of output (or per ha)

- Costs of operating machinery in € per unit of output (or per ha), including purchase, depreciation, and rental costs

5.1.5.7 Energy, fuel and greenhouse gas emissions

The production and application of insecticides consumes energy and requires fuel for machinery. To the extent that Bt maize reduces insecticide use, it can also affect energy and fuel use per unit of area (Franke et al., 2011). Similar considerations apply to alternative pest control strategies such as ploughing, and also water that must be pumped. Overall, only limited empirical evidence has been gathered regarding the effect of Bt maize on energy and fuel use. But even if energy use per hectare is not affected by the adoption of Bt maize, any yield increases due to Bt maize adoption lower energy and fuel use per unit of output.

Input use in maize production may entail the emission of greenhouse gases that contribute to global warming. Effects on yield could also translate into assimilation of carbon dioxide by maize plants (Brookes & Barfoot, 2015). The evidence available regarding these effects is very limited.

- kWh and € of energy per unit of output (or per ha)

- Litres and € of fuel per unit of output (or per ha)

- Greenhouse gas emissions (in CO_2 equivalent) per unit of output (or per ha)

5.1.5.8 Production efficiency

The overall efficiency of maize production considers the output and all inputs, with monetary value as the common denominator. Bt maize can affect the overall production efficiency of maize through the revenue and the cost side. The evidence suggests that Bt maize leads to increases in profit, be it through cost reductions, yield increases, or a combination of the two. Hence, production efficiency is likely to increase with Bt maize adoption.

- Revenue divided by total input costs

5.1.6 Coexistence management

Adopters of Bt maize may have to cope with the costs of coexistence regulations, which are meant to prevent an admixture of GM and non-GM materials (adventitious presence) and any economic damage arising from it. These regulations can be grouped into *ex ante* regulations and *ex post* liability schemes (Beckmann et al., 2006; Demont et al., 2009; Devos et al., 2009; Messean et al., 2006). *Ex ante* regulations prescribe practices to be followed by maize farmers wanting to grow Bt maize. They can consist of prohibition and approval procedures (e.g. case-by-case approval, compulsory training), registration and information duties (e.g. informing neighbours, record keeping), technical segregation measures (e.g. isolation distances, buffer zones[26]) and insurance measures (e.g. compensation funds, insurances). Many Member States also maintain *ex post* liability schemes, which determine legal liability for damages (e.g. civil law, liability for Bt maize adopters), rules for proving damage (with the burden of proof on the adopter in some cases) and penalties for non-compliance with *ex ante* regulations.[27] The costs of coexistence management should be indicated per tonne of produced output, per hectare and per farm.[28] The cost could be expressed in the estimated monetary value stated by farmers of complying with particular measures, or the actual sums paid as insurance costs or penalties. Little evidence is available regarding the quantitative extent of the coexistence costs Bt maize farmers in the EU are facing.

- Cost of complying with particular coexistence regulations in €/t, €/ha and €/farm

- Insurance costs (compensation funds, insurance premiums) and penalties in €/t, €/ha and €/farm

26 Note that buffer zones can overlap with refuge areas (Quedas & Carvalho, 2012).

27 Note that the monetary costs covered in this topic may also appear in Topic 5.1.3. The purpose of Topic 5.1.6 is to highlight the costs of coexistence farmers have to bear when adopting Bt maize, which can be regarded as distinct from other costs associated with growing maize. Note also that this topic focuses on only that part of the costs of coexistence that is borne by Bt maize adopters. Coexistence measures may also prevent farmers from adopting Bt maize (or limit its area), which is a cost that is covered in Topic 5.2.3.

28 Coexistence costs can be divided into fixed and variable costs, which are also accounted for in Topics 5.1.3.1 and 5.1.3.2, respectively.

5.1.7 Time management

Bt maize adoption may affect the time management of farmers in several ways.[29] If the adoption of Bt maize leads to insecticide savings, less labour hours are spent on spraying (Alston et al., 2002). On the other hand, coexistence regulations may imply an increase in working time when growing Bt maize, for example for notifications or inspections, training courses, or when cleaning machinery and equipment (Křístková, 2010). If Bt maize adoption diminishes crop damage, it increases the marginal value product of labour, which in turn could lead to higher labour use (Barrows et al., 2014a). Time management can be indicated by the hours or days spent on the management of a crop. Working time can be assessed by month to cover seasonal changes. Changes in working time on maize brought about by the adoption of Bt maize may affect the amount of time available to farmers. Farmers may therefore devote more or less time to working off-farm, and the income generated by this is an indicator of its value. Farmers can also be asked directly on the monetary value that they attach to the convenience of crop management of Bt maize as compared with conventional maize. In some cases, the convenience of crop management may be related less to working time, but rather to the insurance function Bt maize provides against pest damage. Evidence on the effect of Bt maize on time management is very limited, although for Spain there is some evidence that time spent on crop walking and insecticide applications is reduced (Brookes, 2002).

- Time spent on crop cultivation and coexistence in h/ha and h/year
- Time availability (h/week)
- Income from off-farm work
- Self-evaluation of convenience of crop management in €/ha

29 There is a significant overlap of this topic with Topic 5.1.5.5. The main difference relates to a broader set of indicators considered here.

5.2 Non-adopters[30]

5.2.1 Typology of non-adopting farmers

Non-adopters should be characterised using the same indicators as adopters (see Topic 5.1.2).

5.2.2 Economic impact of Bt maize cultivation

The cultivation of Bt maize can have effects on non-adopters via changes in input and output prices, crop protection spillovers and additional segregation costs due to private standards.

5.2.2.1 Input and output prices

If Bt maize reduces the overall demand for insecticides, their prices may decrease, which could lower the cost of production for conventional maize growers using these insecticides (National Research Council, 2010). Similar reasoning applies to changes in the demand for other inputs relevant to conventional maize growers.

Bt maize can increase the overall supply of maize through higher yields, and thus lower its market price (Barrows et al., 2014a). If markets for Bt and non-GM maize are integrated, as for example in the case of Spain, where Bt and non-GM maize are intermingled during processing (Gómez-Barbero & Rodríguez-Cerezo, 2006), the prices received by conventional maize growers may be lowered along with the prices received for Bt maize. On the other hand, if there is a demand for non-GM maize, the adoption of Bt maize offers non-GM maize producers a price premium, in particular organic growers (Smyth et al., 2015). The price premium may increase further as more farmers switch from conventional to Bt maize and thus lower the supply of non-GM maize.

The evidence on the quantitative extent of the effects of Bt maize adoption on the input and output prices faced by conventional maize growers is limited. Wu (2004) estimated that the downwards price pressure from the additional supply of maize generated by Bt maize adoption resulted in a 6.7 % decrease in the revenue for non-Bt growers.

- Input prices (insecticides, etc.)
- Output price (€/t)

30 Note that this section concerns the effects of the cultivation of Bt maize (by adopters) on the cultivation of conventional maize or other crops by non-adopters, i.e. farmers not cultivating Bt maize.

5.2.2.2 Crop protection spillovers

The cultivation of Bt maize can lead to a regional suppression of populations of pests such as the ECB. Growers of conventional maize, and other crops affected by the same pest, may thus be faced with reduced pest infestation levels compared with a situation without Bt maize cultivation in the region. Reduced pest infestation levels can lead to lower insecticide use and/or increased yield. Cumulative benefits over 14 years to conventional maize growers in the Midwestern USA from Bt maize have been estimated at over $4 billion (Hutchison et al., 2010). No evidence is available for Bt maize in other countries.

Another potential crop protection spillover from the cultivation of Bt maize is a reversal of insect resistance to synthetic insecticides, as a lower use of these insecticides reduces the evolutionary pressure for resistance development (National Research Council, 2010). No evidence is available regarding this effect.

The strength of crop protection spillovers depends on the current level of pest control achieved among the neighbours of Bt maize adopters, the distance to Bt maize adopters and the overall adoption rate in the neighbourhood. Adult ECB are known to readily disperse among farms at distances of at least 800 m throughout their lifetime (Hutchison et al., 2010).

- Pest infestations (e.g. number of corn borers per stalk)
- Number and cost of pesticide applications
- Yield (t/ha)

5.2.2.3 Segregation management

Farmers growing identity preserved (IP) non-GM or organic maize often receive a price premium for their products. In the event of GM cross-pollination, these products might lose their IP non-GM/organic status or sales contracts and the corresponding premium (Gómez-Barbero & Rodríguez-Cerezo, 2006). Subsidies linked to organic or other production standards with low GM tolerance may also be lost in this way (Consmüller et al., 2010). In order to prevent these losses, IP non-GM maize producers may implement segregation measures and conduct tests for adventitious presence. The cultivation of Bt maize might increase the costs of these measures. Payments received from compensation schemes can be another indicator of the cost of coexistence. Bt maize cultivation also has the potential to lead to disputes between neighbouring GM and non-GM farmers due to the various externalities that may or may not be covered by legislation.

Little to no evidence is available regarding the quantification of these indicators.

- Total segregation and testing cost in €/t
- Loss of IP non-GM/organic premium resulting from adventitious presence in €/year
- Value and frequency of payments to farmers from national compensation schemes
- Number of disputes between farmers (e.g. court cases)

5.2.3 Opportunity costs of non-adoption

Non-adopters of Bt maize might want to grow it but be unable to do so because it is either not yet approved for cultivation or under a national restriction. Softer regulatory measures such as isolation distances and other coexistence regulations might also prevent farmers from adopting Bt maize or limit its cultivated area (Beckmann et al., 2006; Groeneveld et al., 2013; Moschini, 2015). Potential opportunity costs caused by the non-adoption of Bt maize should follow the same topics and indicators as those mentioned under income effects (Topic 5.1.3) and input use and efficiency (Topic 5.1.5) for adopters. Park et al. (2011) estimate *ex ante* that the annual benefits that might accrue to EU farmers adopting Bt maize are in the range of €157–334 million. Wesseler et al. (2007) estimate that France and Italy forgo about €62 and €60 million, respectively, for postponing the introduction of Bt maize for another year.

- Income effects (see Topic 5.1.3)
- Input use and efficiency (see Topic 5.1.5)

6. Effects outside the crop farming sector

The cultivation of Bt maize in the EU can have effects upstream and downstream of the crop farming sector, both for users of GM maize and users of non-GM maize products. Upstream, seed companies and the agro-chemical industry might see changes in sales and costs. The price of land could also be affected. Downstream, exports and imports of maize and competing products, processors (including the feed, livestock, biofuel/bioenergy, food and retail industries), as well as consumers, might be affected by changes in commodity prices and quality attributes. Public consumption patterns and the understanding and acceptance of GM crops could also be affected. Furthermore, government revenues and expenses might be impacted.

6.1 Upstream

6.1.1 Innovation capacity of agricultural and plant sciences

The adoption of Bt maize can have an impact on the innovation capacity of agricultural and plant sciences. It can act as a signal of demand for and acceptance of related innovations, especially if it is the first GM crop adopted in a country or region. This in turn might increase Research and Development (R&D) investments in agricultural biotechnology, plant sciences and biosafety (Anderson, 2010; EASAC, 2013). As a signal, Bt maize cultivation could also have an impact on the progress of GM events that are already in the regulatory pipeline for cultivation in the EU or at earlier stages of development. The fact that Bt maize adoption has been very low across the EU may have contributed to a slowdown in innovation in other GM traits (Graff et al., 2009).

Bt maize adoption can increase the revenue of the innovating sector through higher technology fees, which can increase the funds available for R&D investments. At the same time, the cultivation of Bt maize and associated revenue streams to innovators may increase or reduce the concentration of the seed industry (Lusser et al., 2012). Changes in the concentration of the seed industry could affect investments in new seed technologies, although the direction is not obvious because firms may choose to raise or lower investments (Franke et al., 2011).

Evidence regarding these effects is very limited, and especially challenging to gather *ex ante*, as reliable models have not been developed.

- Number of GM/non-GM field trials
- Number of GM/non-GM crops in R&D and regulatory pipelines
- Number of GM/non-GM varieties in national registers
- Number and size (in €) publicly funded research projects on agricultural biotechnology and biosafety
- Patents issued in plant biotechnology
- Employees in plant breeding and seed industry
- Resources (in €) allocated to plant biology research

6.1.2 Seed industry

Bt maize cultivation could have an impact on the seed industry. The seed industry normally receives a price premium for Bt maize seeds relative to conventional seeds (Qaim, 2009). An increasing market share of Bt maize could also strengthen the market power of seed companies, as a result of either a higher concentration within the maize seed sector or an increase in market share at the expense of other input industries. However, the entry of Bt maize seed suppliers into a market formerly dominated by conventional maize seed suppliers exhibiting market power could also lead to a lower concentration. Changes in market power, in turn, could have an impact on seed prices. All these elements may increase the economic welfare of the seed industry. On the other hand, the adoption of Bt maize can lower the revenue of conventional maize seed producers, although the reverse is also possible if seed companies cater to a niche market such as organic growers, who are willing to pay premiums.

Seed companies may also incur additional production and operational costs, especially if a high degree of separation between Bt and non-GM maize seed is demanded in the market.

Some evidence is available on the revenue received by seed companies for selling Bt maize seeds. For example, Demont & Tollens (2004) estimated that during 1998–2003 the revenue of the seed industry increased by €5.2 million as a result of the adoption of Bt maize in Spain. However, studies generally have considered only gross revenue and have disregarded costs of technology research, marketing or administration (Carpenter, 2013). In addition, little is known about the effects of Bt maize cultivation on the revenue streams from conventional (and organic) maize seeds, which are essential for the estimation of the net economic effect on the seed industry.

- Economic welfare of seed industry (€/year)
- Production and operational costs (including cost of keeping Bt and conventional maize seeds separated)

6.1.3 Agro-chemical industry[31]

As Bt maize adoption may affect the demand of farmers for insecticides and fertiliser, it can impact the sales of the agro-chemical industry, the number of companies producing insecticides/fertiliser, and lead to changes in the welfare of the agro-chemical industry (Lusser et al., 2012). No evidence is available regarding these effects.

- Pesticide/fertiliser sales (volume and revenue)
- Number of companies producing pesticides/fertiliser
- Economic welfare of agro-chemical industry (€/year)

6.1.4 Land markets

An expansion in the cultivation of Bt maize might influence land prices through changes in the profitability of maize cultivation, which can make the area on which maize is grown more valuable and also enlarge it. On the other hand, a higher adoption of Bt maize might also lower land prices due to segregation cost (Moschini et al., 2005). Changes in prices, together with the possibility of Bt maize not being scale-neutral (Consmüller et al., 2010), could also affect parcel structure. Furthermore, land market effects may extend to the real estate market. No empirical evidence is available regarding these effects.

31 The agro-chemical industry may overlap with the seed industry, as some companies sell both plant protection products and seeds.

- Land purchase and rental prices
- Parcel size and number per farm
- Real estate prices

6.2 Downstream

6.2.1 Exports and imports of maize and competing crops

If more Bt maize is cultivated in the EU, the overall imports of maize and substitute crops may decrease. Exports might go up because the EU produces more domestically, or down because of trading partners demanding non-GM products. Similar considerations apply to trade patterns between EU countries within the internal market. It has been estimated that the cultivation of Bt maize in Spain reduced maize imports by 853,000 tonnes between 1998 and 2013 (Riesgo, 2013). More evidence regarding the effect of Bt maize cultivation in the EU on trade is not available.

- Imports and exports of maize and substitute commodities in volume (t/year) and value (€/year), by crop, GM/non-GM, and importing/exporting country/region (including internal market flows)

6.2.2 Segregation and identity preservation by processors

When Bt maize is cultivated, processors that want to capitalise on the demand for non-GM crops have to maintain a segregation and labelling system that prevents admixture with Bt maize along the food/feed chain (Franke et al., 2011). For example, extra storage and transportation facilities may be needed, testing systems of incoming maize may be implemented and additional cleaning procedures may become necessary, among others (Gabriel & Menrad, 2015). These measures and their cost may increase with the area under Bt maize.

- Non-GM certification cost (€/t)
- Cost of segregating GM feed and non-GM materials (€/t)

6.2.3 Feed industry

The feed industry might benefit from lower prices for raw materials (maize and substitutes) if an expansion of Bt maize cultivation leads to lower market prices (Lusser et al., 2012). Most of the EU feed industry accepts GM maize raw materials, which tend to be cheaper than their conventional counterparts. Segments of the EU feed industry producing non-GM feed may see an increase in the price that they have to pay for raw materials and higher costs of segregation and labelling (Riesgo et al., 2012). Furthermore, the quality of maize could increase with Bt maize cultivation if mycotoxin levels are lowered, which can be valuable to the feed industry (Wu, 2006). Little evidence is available regarding the extent of the welfare effect of Bt maize.

- Economic welfare of feed industry (€/year)
- Price of raw materials for feed industry (€/t)
- Price of non-GM raw materials (€/t)
- Cost of segregating GM feed and non-GM materials (€/t)
- Value of reduced mycotoxin levels (€)

6.2.4 Livestock producers

The livestock sector may benefit from less expensive feed and feedstuffs from maize and substitute products if Bt maize cultivation expands (Areal et al., 2015). At the same time, livestock producers demanding non-GM feed products may have to pay a higher premium if more Bt maize is cultivated (Lusser et al., 2012). In addition, segregation and labelling cost may be influenced by the level of Bt maize adoption. If livestock producers are also cultivating maize for the direct feeding of their animals then the impact of Bt maize adoption on the quantity and quality of this feed can also be considered. The contribution to animal health of mycotoxin reductions brought about by the cultivation of Bt maize has been estimated for the US (Wu, 2006). Other estimates of the welfare effects of the cultivation of Bt maize on livestock producers are not available.

- Economic welfare of livestock producers (€/year)
- GM/non-GM feed cost (€/t) per sector (e.g. poultry, dairy)
- Cost of segregating GM and non-GM feed (€/t)
- Value of reduced mycotoxin levels (€)

6.2.5 Food industry

The EU food industry could benefit from less expensive and/or better quality of raw materials, which may result from the increase in the cultivation of Bt maize. However, the food industry may be hesitant to accept GM materials that require labelling because labelling might have a negative marketing impact. Avoiding GM materials can be achieved by sourcing ingredients from certified non-GM markets (at higher costs) and separating GM and non-GM ingredients in processing facilities (Lusser et al., 2012). The food industry may also benefit from reduced mycotoxin levels (Wu, 2006). The overall welfare effect of Bt maize cultivation on the food industry has not been estimated.

- Economic welfare of food industry (€/year)
- Price of raw materials for food industry (€/t)
- Price of certified non-GM ingredients (€/t)
- Cost of segregating GM feed and non-GM materials (€/t)
- Value of reduced mycotoxin levels (€)

6.2.6. Biofuel and bioenergy industries

The biofuel and bioenergy industries, which use GM and non-GM maize as feedstock, can be affected by the cultivation of Bt maize mainly through the possibility of changing feedstock prices (Lusser et al., 2012). Biotechnology can increase yields in crops used as a feedstock, improve crop adaptation to marginal lands, increase the amenability of crops to bioprocessing, which in addition to the co-production of feedstock and food, will all be necessary for meeting current biofuel goals (Carpenter, 2011). However, no evidence is available concerning the effects of Bt maize cultivation.

- Economic welfare of biofuel and bioenergy industries (€/year)
- Cost (€/t) of biofuel and bioenergy feedstocks

6.2.7 Retail sector

The retail sector faces the same challenges as the food industry regarding the impacts of Bt maize cultivation. It could benefit from less expensive products or it may have to pay higher prices for non-GM certified products (Lusser et al., 2012). Depending on such price changes and consumer demand, the sector might also experience shifts in the share of revenue generated by GM and GM-free labelled products. In addition, segregation cost may be influenced by the level of Bt maize adoption. Evidence on the impact of Bt maize cultivation on the retail sector is not available.

- Economic welfare of retail sector (€/year)
- Costs of GM and non-GM products
- Revenue from GM and GM-free labelled products
- Cost of segregating GM feed and non-GM materials (€/t)

6.3 Consumers

6.3.1 Consumer choice

Freedom of choice in the context of GM products can relate to the freedom of consumers to choose between labelled GM products, labelled non-GM products and unlabelled products (Franke et al., 2011). The cultivation of Bt maize in the EU could have the effect that more products derived from or containing Bt maize ingredients would become available to consumers. Increased cultivation of Bt maize could also change the number of GM-free labelled maize products. Research on this topic has not been conducted.

- Number of GM labelled products
- Number of not labelled products
- Number of GM-free labelled products

6.3.2 Consumer prices

The cultivation of Bt maize may lower the prices consumers pay for maize and derived products such as animal products (Barrows et al., 2014b; Franke et al., 2011). On the other hand, some consumers preferring non-GM or GM-free products may have to pay a higher premium if the cultivation of Bt maize expands, or switch to substitute products. Studies estimating the consumer price effects of Bt maize cultivation are missing, although evidence for other GM crops indicate that the benefits are substantial (Carpenter, 2013).

- Economic welfare of consumers (€/year)
- Price premium paid for non-GM (no label) or GM-free (labelled) maize products (€/kg)

6.3.3 Consumption patterns

The adoption of Bt maize, by inducing absolute and relative price changes, might affect the consumption of maize, derived products and substitutes/complements. Furthermore, the increased cultivation of Bt maize in the EU may also have effects on consumer demand for Bt maize and GM crops, either positively or negatively. Research on the effects of Bt maize on consumption patterns and consumer demand for GM crops has not been conducted.[32]

- Consumption of different food categories in kg per person and year, by GM/non-GM
- Percentage of consumers willing and not willing to buy GM-labelled products
- Price premiums consumers are willing to pay for non-GM (no label) or GM-free (labelled) products (by product)

6.3.4 Public understanding and acceptance

The cultivation of Bt maize could have an effect on public understanding and acceptance of Bt maize and GM crops more generally. It is possible that with greater cultivation, people become more used to Bt maize, which could make them trust more in its health and environmental safety, and more accepting of their use in agriculture (Lucht, 2015). The acceptance of other GM crops could also be affected, in particular if Bt maize is the first GM crop to be more widely adopted. Alternatively, a greater cultivation might lead to heightened mistrust and greater rejection by the public. The direction and extent of this effect is difficult to predict and has not been studied.

- Citizen beliefs about the health and environmental safety of Bt maize (and other GM crops) and their socio-economic impact compared with the best scientific evidence
- Share of citizens rejecting and supporting the use of Bt maize (and other GM crops) in agriculture

6.4 Government budget

Bt maize cultivation might influence government revenue and expenditures, depending on the level of regulation foreseen. For example, controls might be required and their total cost might increase when the area under Bt maize expands. At the same time, public revenues might increase through taxation of companies and farmers (e.g. sales, corporate and individual income taxes). Very little evidence is available. Demont et al. (2008) estimate *ex post* that the adoption of Bt maize in the Czech Republic has substituted for subsidised biological control measures and thus reduced government expenditures.

- Government revenue and expenditure (€/year)

32 It should be stressed that preferences revealed in realistic market situations are more accurate than stated preferences.

7 Aggregate consumer and producer surplus

The aggregate economic welfare effects can be modelled as the sum of consumer surplus and producer surplus. The cultivation of Bt maize can have an influence on both. Depending on the relative gains or losses, certain producers or consumers might be more affected than others. To further explore the distributional impacts, it is possible to study the impact on groups with different levels of income and wealth. Demont and Tollens (2004) estimate a total welfare gain of €15.5 million from the adoption of Bt maize in Spain during 1998–2003, of which Spanish farmers captured two thirds, the rest accruing to the seed industry. Apart from that, the aggregate welfare effects of cultivating Bt maize have not been estimated.

- Consumer and producer (including farmers) economic welfare (€/year), disaggregated by income/wealth

8. Final remarks

This document is the result of collaborative work between experts from Member States and the European Commission, organised under the umbrella of the European GMO Socio-Economics Bureau (ESEB). The document represents a framework for the assessment of the socio-economic impacts of the cultivation of Bt maize at the EU, national or subnational level. In order to provide the appropriate context, a background section contains details on maize cultivation, plant protection and the Bt technology, as well as the maize supply chain. A section on methodology is included, which discusses the general approach of impact assessments, methods and data sources. This is followed by a catalogue of topics and indicators that could be considered in assessments, which comprises farmers, upstream and downstream industries, consumers, and government. The topic descriptions are short explanations of the mechanism and extent of the impact that the cultivation of Bt maize might have, as well as references that provide information on existing evidence, methods and data sources.

The document is not intended as a comprehensive literature review regarding the socio-economic impacts of Bt maize in the EU and it should not be considered as such. Rather, at its core is a list of topics that could be included in impact assessments. A comprehensive literature review that contains all available *ex post* and *ex ante* theoretical and empirical evidence regarding the impact of Bt maize in the EU has not been published. Producing such a review could result in a valuable complement to this document.[33]

An adequate amount of good-quality evidence exists for only very few topics and EU countries. For adopters in Spain, Bt maize has on average led to higher yield owing to improved pest control, reduced insecticide use and gains in gross margins. However, for most of the topics and indicators described in this document, little to no empirical evidence is available. When conducting socio-economic impact assessments, it is recommended that a sound scientific methodology is followed, for which this document and the references contained in it provide a useful guide. Although methodologies for assessing many topics are established and hypotheses can be formulated, data are very scarce and would need to be gathered from farmers, industry and consumers.

33 The GRACE project has systematically gathered the evidence available regarding the socio-economic impact of GM crops (http://www.grace-fp7.eu/).

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