Sustainability of Bt maize in Spain (1998-2021): An economic, social and environmental analysis.

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Francisco J. Areal and Laura Riesgo

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Sustainability of Bt maize in Spain (1998-2021): An economic, social and environmental perspective.

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1. Introduction

The EU's Green Deal growth strategy aims to achieve economic growth whilst increasing resource efficiency leading to zero net emissions of greenhouse gases by 2050. At the core of the EU's Green Deal there are two strategies: the Biodiversity and the Farm to Fork strategies, both acknowledging the interconnectivity between the human activity and nature and the need to find sustainable solutions. In other words, there is a need for taking into account the interconnectivity between the socio-economic system and the ecological system in the agri-food supply chain to ensure the sustainability of both systems.

The EU's Farm to Fork strategy acknowledges the need to find ways to reduce environmental impact in food systems and aims to achieve a sustainable agri-food supply chain. This means to have a sustainable production, processing, manufacturing, distribution, retailing and consumption of food products including food waste (process). A sustainable agri-food system contributes to produce healthy, sustainable and affordable food products. In addition, a sustainable agri-food system means to contribute to protect the environment, and preserve the biodiversity as well as contributing to mitigating climate change.

The EU's Farm to Fork strategy highlights that "*New innovative techniques, including biotechnology and the development of bio-based products, may play a role in increasing sustainability, provided they are safe for consumers and the environment while bringing benefits for society as a whole*".

This report provides an overview of the sustainability benefits associated with biotechnology, with a specific focus on Bt maize, which is the only biotech crop allowed to be grown in Europe. Bt maize is only currently grown in Spain and Portugal being Spain the largest producer. Hence the report evaluates the sustainability benefits of Bt maize in Spain from 1998 to 2021 from an economic, social and environmental viewpoint.

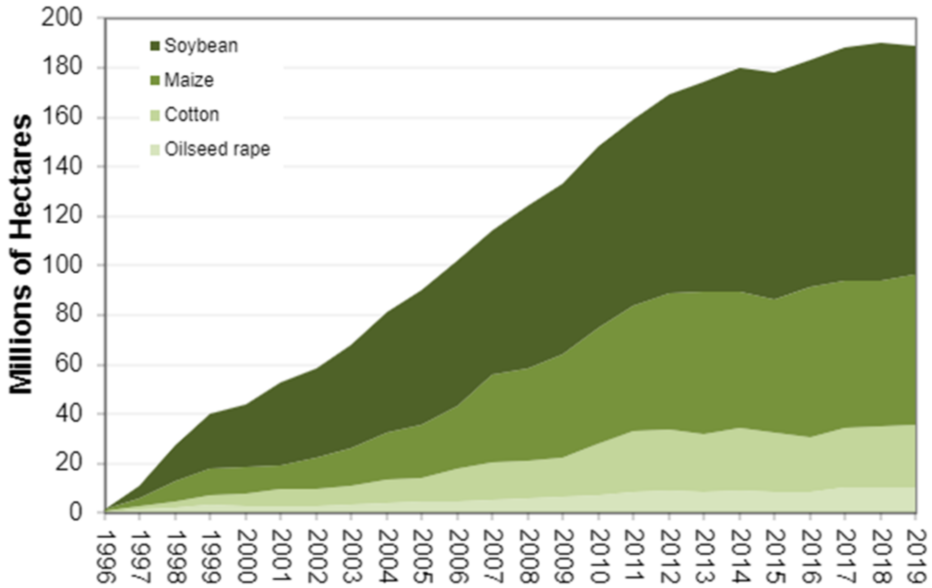
The report is structured as follows. Firstly, it provides a brief overview of biotechnological crop adoption and production worldwide before assessing the sustainability of Bt maize. In particular, we evaluate the benefits associated with Bt maize adoption to farmers and broader society in Spain during the period 1998-2021. Finally, it is concluded that the adoption of biotech crops has contributed and can continue to contribute to achieving the aims within the EU's Green Deal.

2. The adoption of technological innovations and the evolution of Biotech crops adoption and production worldwide

A rapid rate in the adoption of innovations is typically associated with individuals (e.g. farmers) perceiving the innovation as relatively advantageous and compatible to the needs of adopters. In addition, the easier the innovation is to understand and use the more likely is that it will be adopted. Also, if the innovation can be tried and/or their efficacy observed more likely is that it will be adopted too (Rogers, 2003).

Since their commercialization in 1996 the adoption and production of biotechnological crops has continued to increase. The global total area for biotech crops in 2019 was 190.4 million hectares, a 5.95% up from 179.7 million hectares in 2015 (James, 2019). In 2019, biotech crops were grown in 29 countries by up to 18 million farmers. The distribution of crops by order of importance regarding cultivated area in 2019 is as follows: soy (48% of the total cultivated surface of biotech crops), maize (32%), cotton (14%) and oilseed rape (5%) (Figure 1).

Figure 1. World area cultivated with biotech crop varieties (1996-2019)

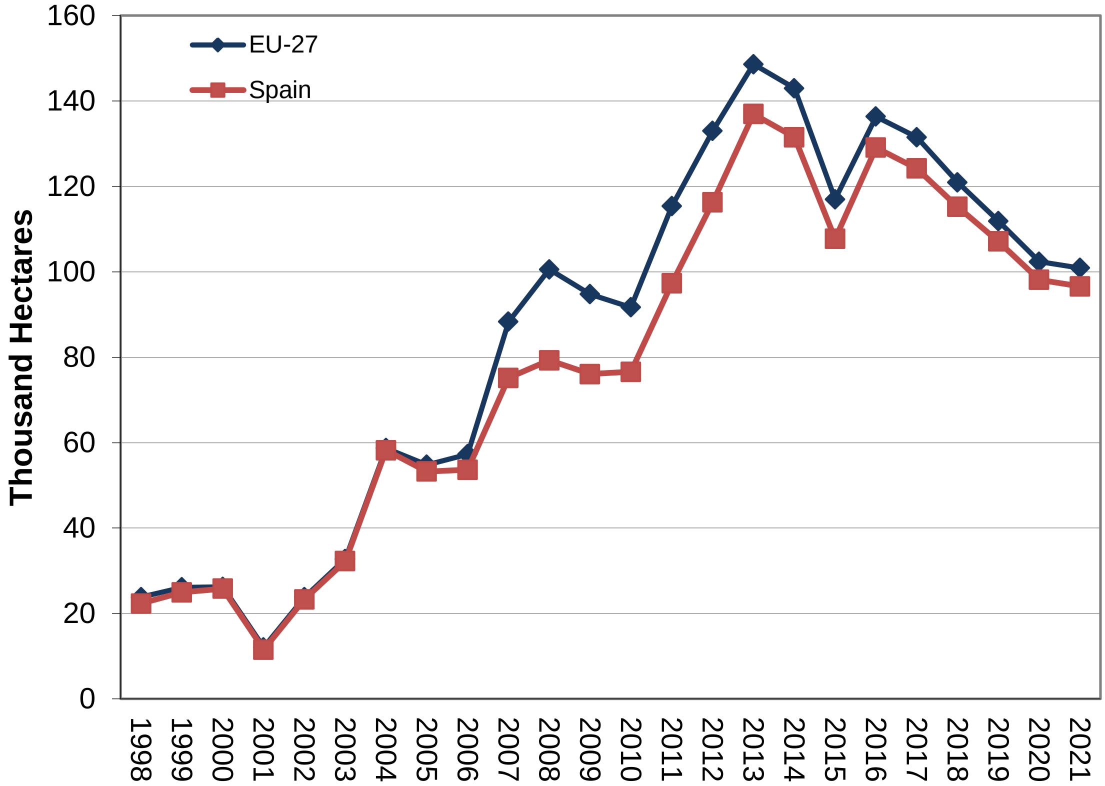


Fuente: Compiled from James (1997-2019)

It is worth noting the relatively small area allocated to biotech crops in Europe compared to other regions, 100,927 ha in 2021. Currently, Bt maize is the only biotech crop cultivated in the EU with 96% of crop area being located in Spain and the remaining in Portugal (Figure 2).

Figure 2 shows the trend of the cultivated area of Bt maize in the EU and Spain over the past few years. At the EU level, such a reduction is mainly due to the reduction in the global area cultivated with biotech and conventional maize in Spain. Since 2017, only Spain and Portugal are growing Bt maize in the EU.

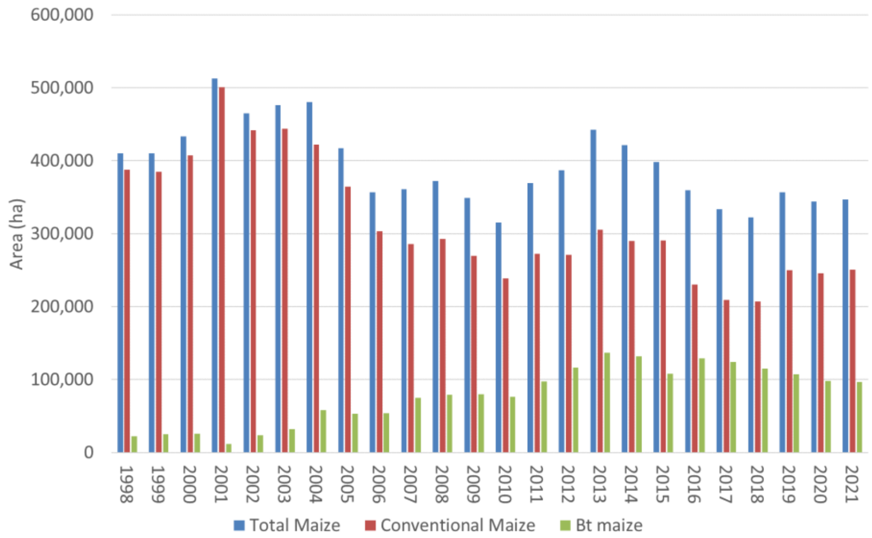
Figure 2. Trends in Bt maize acreage in EU-25 and Spain (1998-2021)



Source: Compiled from James (1997-2019), MAPA (1998-2021),

Figure 3 shows the evolution of total maize, conventional maize and Bt maize cultivation area in Spain. The total cultivated area of maize has been declining in the last two decades led by a decline in conventional maize since 2003. Bt maize has increased over the period 1998-2021 reaching a pick in 2013 with a cultivated area of approximately 137,000 ha and a decrease since then to just below 100,000 ha in 2021.

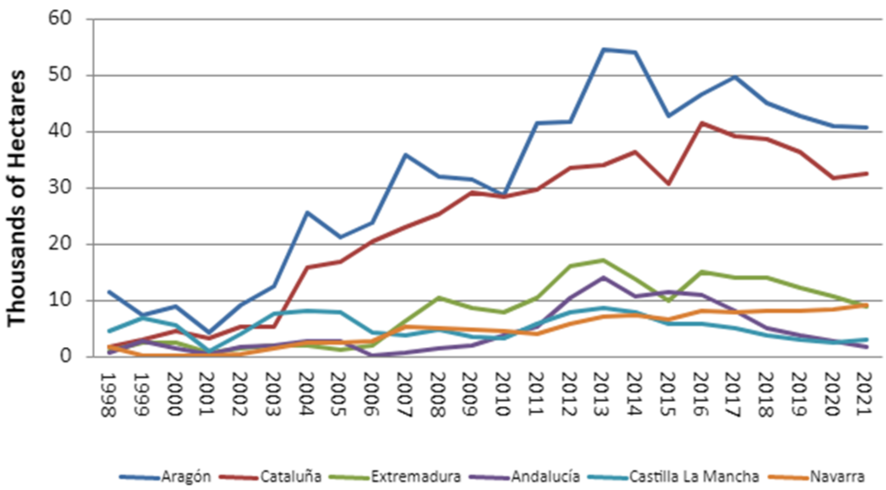
Figure 3. Trends in maize cultivation area in Spain: total, conventional and Bt maize (1998-2021)



Source: MAPA (1998-2021)

Figure 4 shows the evolution of Bt maize cultivated area by autonomous community (AC). Bt maize cultivation in Spain for the year 2021 is concentrated in Cataluña and Aragón, with 69% of the total EU area, followed by Navarra (9%), Extremadura (8%), and Castilla La Mancha (3%). The Ebro Valley, including the AC of Cataluña, Aragón and Navarra, is the area with the highest adoption of Bt maize in Spain (85%) due to the highest incidence of Bt corn borer. The number of cultivated hectares in these AC has been increasing since the introduction of Bt maize cultivation, with a marked acceleration in growth since 2010 and a decrease since 2013, with the exception of Navarra. So, taking into account the final data for 2021 released by the Ministry of Agriculture, Fisheries and Food (MAPA), since 2010, there has been an increase in the cultivated area of Bt maize in Navarra (103%), Aragón (42%), Cataluña (15%) and Extremadura (14%), and there has been a decrease in the cultivated area of Bt maize in Andalucía (53%) and Castilla la Mancha (7%).

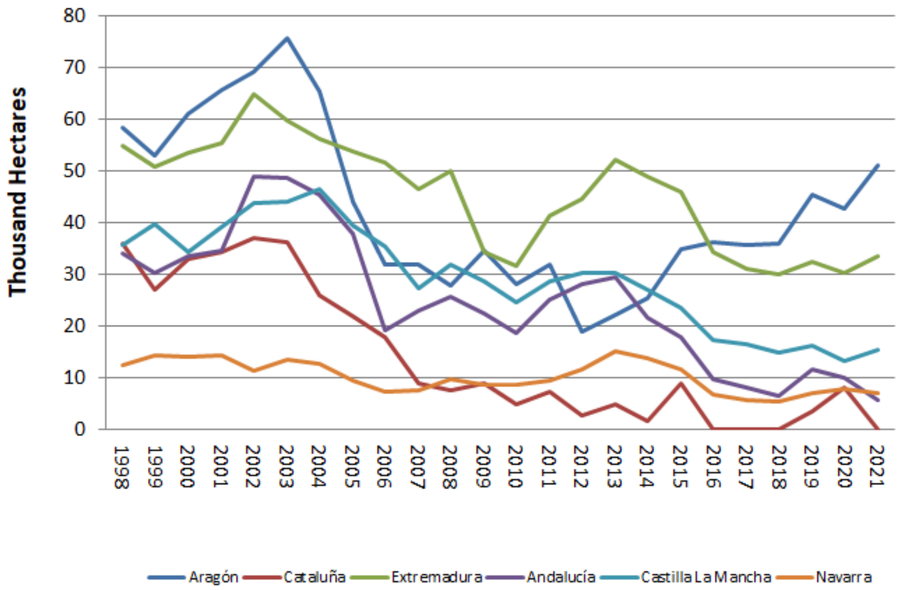
Figure 4. Evolution of Bt maize hectares by Autonomous Community (AC)



Source: MAPA (1998-2021)

Since 2004 conventional maize cultivated area in Spain has been significantly reduced in all regions cultivating also Bt maize, reaching a relatively stable cultivated area from 2016 in most of them. It is worth noting that cultivated conventional maize area in Aragón has doubled between 2016 and 2021 (Figure 5).

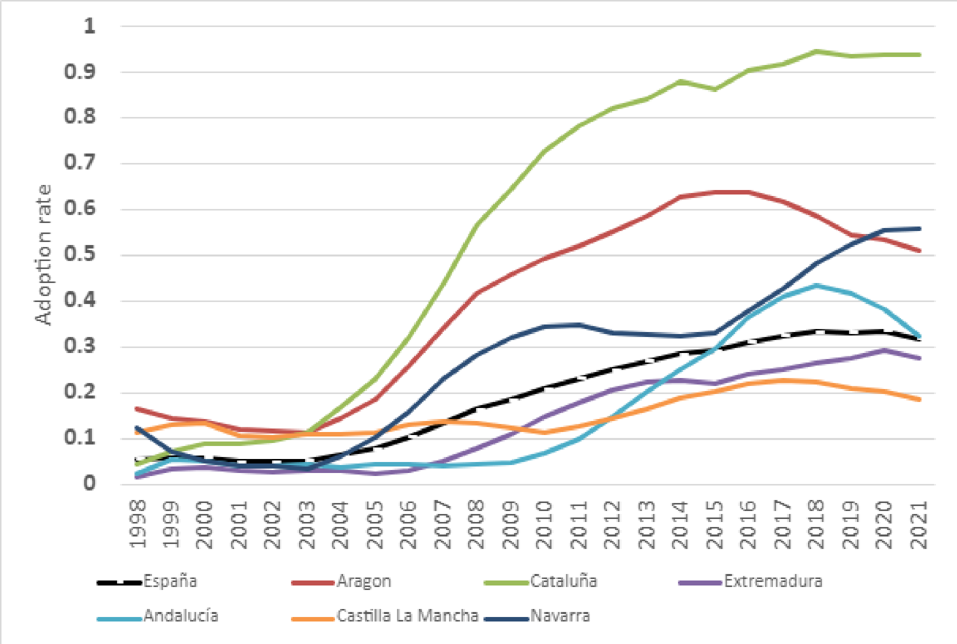
Figure 5. Evolution of conventional maize acreage by autonomous community (AC)



Source: MAPA (1998-2021). Figures for conventional maize are calculated as the difference between total maize and Bt maize. Bt maize area is estimated from MAPA considering certified seed bought by farmers, and assuming an average amount of 85.000 seeds per hectare.

It is worth highlighting that the percentage surface cultivated with biotech maize is maintained around 30% of the total surface of maize cultivated in Spain since the year 2013. Figure 6 shows the smoothed adoption rate for Spain and the relevant autonomous communities. These can be indicators of the incidence of corn borer in the different relevant regions in Spain. We can see how Cataluña and Aragón had a relatively high adoption of the biotech alternative between 2003 and 2013. Figure 6 suggests that incidence of the corn borer is relatively more important in Cataluña where practically all maize produced in the region is Bt maize and it seemed to become recently increasingly important in Navarra.

Figure 6. Evolution of adoption rate (cultivation area) of Bt maize by Autonomous Community (AC) - 5 year moving average



Source: Own analysis

3. Contributions of Bt maize cultivation to the sustainability

3.1. Benefits to farmers of cultivating Bt maize

Bt maize has been continuously cultivated in Spain since its introduction in 1998. There are a number of reasons that explain why Spanish farmers have opted to adopt Bt maize in regions where there is a corn borer issue. The diffusion of innovations is associated with how the characteristics of the innovations are perceived by their potential users. In the case of Bt maize the factors associated with its adoption by farmers can be summarised into agronomic and economic factors. Farmers who perceive that Bt maize has a relative advantage over conventional maize in agronomic/economic/convenience terms would be keener to adopt the innovation. Hence, the perception by farmers that Bt maize matches their needs increases the probability of farmers adopting the technology. We summarise the agronomic, economic and convenience reasons that farmers facing a corn borer issue have to adopt Bt maize found in the scientific literature.

3.1.1. Higher yields and quality

Farmers perceiving/experiencing a relative advantage of Bt maize over conventional maize is a key aspect for farmers to adopt the technology. Indeed, amongst the agronomic reasons behind the adoption of Bt maize by farmers several studies have highlighted their efficacy in controlling the corn borer, which have led to obtaining relatively higher yields compared to conventional maize (Carpenter, 2010; Demont and Tollens, 2004; Gianessi et al. 2002; Gomez-Barbero et al. 2008; Riesgo et al, 2012; Areal et al, 2013). At a global level[1] it has been reported that Bt maize is the GM crop that shows a higher yield compared to the conventional variety. Globally Bt maize has an average yield 0.55 t/ha higher than that of conventional maize (Areal et al. 2013).

In the case of Spain, Brookes (2008), Gómez-Barbero et al. (2008) and Hazard et al. (2012) show similar results. Brookes (2008) shows differences ranging between 1.5 and 0.15 t/ha depending on the degree of infestation by the drill in the Aragón area in 2002. The author collected average differences in performance from a later study (2003-2007), amounting to 1.30 t/ha. Gómez -Barbero et al. (2008) analyze differences in yields in three different areas: Albacete, Lleida and Zaragoza, which vary between 1.19 and -0.16 t/ha. Meanwhile Riesgo et al. (2012) show a statistically significant performance difference of 1.34 t/ha in the Ebro Valley (Aragón, Cataluña and Navarra) in 2009.

Table 1. Yield differences between Bt and conventional maize

Study	Zone analyzed	Year	Bt maize yield	Conventional maize yield	Yield differences (t/ha)
Brookes (2008)	Aragón	2002	11.5	10	1.5 (n.s.)
	Aragón	2002	10.15	10	0.5 (n.s.)
Brookes (2008)	Cataluña, Aragón, Navarra	2003-2007	14.30	13.00	1.30 (n.s.)
Gómez-Barbero et al. (2008)	Albacete	2002	12.36	12.14	0.22 (n.s.)
		2003	11.85	12.01	-0.16 (n.s.)
		2004	12.59	12.53	0.06 (n.s.)
	Lérida	2002	12.66	11.51	1.15 (n.s.)
		2003	12.01	11.52	0.49 (n.s.)
		2004	12.18	11.75	0.43 (n.s.)
	Zaragoza	2002	11.06	9.87	1.19 *
		2003	10.49	9.46	1.03*
		2004	10.64	9.53	1.11*
Riesgo et al. (2012)	Ebro Valley (Aragón, Cataluña, Navarra)	2009	11.94	10.60	1.34*

(n.s.) shows no statistically significant difference; * shows statistically significant difference at 99%

Source: Authors.

It should be noted that in areas where there are no major corn borer problems, Bt maize performance shows no significant yield differences compared to the conventional maize. In these areas farmers cannot perceive any relative advantage with the conventional crop and cannot observe any advantage in adopting it.

In addition to the relative advantage that Bt maize may present in terms of its efficacy in dealing with the corn borer and its higher yield performance another attribute of Bt maize is

[1] Included in this analysis are 33 findings from scientific articles published in international journals, including data from developing and developed countries.

the reduced incidence of mycotoxins compared to conventional maize (Hammond et al., 2004; Wu, 2006; GENVCE, 2007; Folcher et al., 2010 and López-Querol et al., 2013). Mycotoxins are toxic secondary metabolites produced by fungi that can cause disease and other health problems in animals and humans. The presence of mycotoxins, particularly fumonisins[2], is particularly prevalent in the presence of the hole and in hot, dry climates (FAO, 2003 and GENVCE, 2007). In areas affected by the drill, fumonisins can go over the maximum thresholds of Fusarium toxin content in maize and maize products pursuant to Regulation (EC) 1126/2007 of the European Commission (GENVCE, 2007 and López-Querol et al., 2013). Bt maize, therefore, offers an attractive option to farmers in these areas compared to conventional maize by allowing them to improve the quality in the final product on top of higher yields and dealing with the corn borer.

3.1.2. Economic benefits

The main economic reasons behind the adoption of Bt maize by Spanish farmers are associated with a combination of a potential higher income from higher crop yields and lower costs associated with pesticide use. Resistance to the corn borer incorporated into the crop through biotechnology results in less pesticide use, which means lower pesticide costs than for conventional varieties (Ervin et al., 2010; Qaim, 2009). Globally, Areal et al. (2013) show that Bt maize worldwide reaches an average return of €52.81 per hectare per year more than conventional maize in 2000[3]. It is worth noting that this increased profitability of biotech crops varies considerably between countries and regions, depending on infestation levels of pests and the cost of acquiring the technology (purchase of seeds).

In the case of Spain, Brookes (2008) shows an average return of 147 €/ha more for Bt maize in 2002 compared to conventional maize in the Aragón area. This is slightly higher in a recent study by the same author (Brookes, 2019), which establishes a higher average return of 185.70 €/ha for Spanish farmers. Gómez-Barbero et al. (2008) show differences in profitability of around 3.17 €/ha in the Lleida area, 9.49 €/ha in the Albacete area and around 120 €/ha in the Zaragoza area between 2002-2004. In another study, Riesgo et al. (2012) show an outperformance of 53.51 euros/ha a year 2010 for the area of the Ebro valley. In all case studies, the performance differences are explained by the increased agronomic performance of Bt maize. Thus, even though production costs are higher[4] for Bt and there are no differences in the prices received by farmers as between the two varieties of maize grain[5], there is a greater economic return with Bt maize than for the conventional counterpart. These returns have prompted the adoption of Bt maize in these areas in recent years, thus experiencing a significant increase in its surface as shown in Figure 3.

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[2] Fumonisins are a group of mycotoxins produced mainly by *Fusarium moniliforme*, a mould present worldwide and often found in maize.

[3] Included in this analysis are 16 findings from scientific articles published in international journals, including data from developing and developed countries.

[4] Differential production costs for Bt maize ({(Bt seed acquisition cost – conventional seed acquisition cost) + (Bt pesticide cost - cost conventional pesticides)} are higher, on average, than for the conventional variety. Thus Gómez-Barbero et al. (2008) obtained differential costs 25.62 euros / ha in the area of Lleida and 22.78 euros / ha in the region of Aragon for the years 2002-2004. For the Ebro area, Riesgo et al (2012) estimated production cost differentials of Bt are 8.48 euros / ha greater than conventional maize. In this latter study, the differential costs are due to the difference in acquisition costs of the seed (about 14.89 euros / ha higher) and the difference in costs of pesticide use (6.41 euros / ha lower) in Bt maize compared to conventional maize.

[5] Riesgo et al. (2012) show that there are no significant differences between the prices received by farmers for Bt maize grain Bt and conventional maize grain in the Ebro valley.

3.1.3. Ease of cultivation

The fact that the use of Bt maize is not complex compared to conventional maize facilitates its adoption. Indeed, there are a series of advantages of Bt maize on how it is handled and cultivated that have been positively contributed to its adoption. One of the characteristics that farmers view as most positive when choosing biotech crops is their ease of use (Areal et al., 2011), and specifically, farmers who choose Bt maize claim that one of its main advantages is its effectiveness in the fight against the corn borer, not only allowing a reduction in the time taken to inspect the farm or collecting the maize cobs but also in the reduction of the number of insecticide treatments necessary (Antama Foundation, 2012). The corn borer is very difficult to control in conventional crops as insecticide use is effective only if used within a very specific period of time from the onset of the problem (Agustí et al., 2005; Brookes, 2008; Farinós et al. 2004).

Another advantage of Bt maize is related to the harvest. In the absence of insect-damaged maize, farmers can harvest quicker and collect more straw per hectare for fodder (Antama Foundation, 2012).

Farmers mention that these advantages not only affect the use of these crops but also their costs of production. Fewer treatments and faster harvesting[6] can cut diesel costs and other energy costs associated with this type of farming. For its part, the generation of a larger amount of straw for fodder allows farmers to reduce their costs through consumption on site or by sale to third parties in case it is not needed.

Hence Bt maize offers an advantageous and relatively simple solution to deal with corn borer.

3.2. Environmental benefits

This subsection presents the environmental benefits associated with Bt maize cultivation in Spain between 1998 and 2021. We classify these benefits into those associated with the use of production inputs: pesticide use, irrigation water savings and water footprint; and the impact on the use of land and carbon fixation.

3.2.1. Sustainable use of pesticides

As pointed out in the previous sections the use of Bt crops leads to less use of insecticides which leads to less emissions to the environment and consequently lower environmental impact. More specifically, scientific literature shows that Bt crops need fewer insecticide treatments against the Lepidoptera insect pests (Barwale et al., 2004, Bennett et al., 2004, Carpenter, 2010; Gandhi et al., 2006, Qaim et al., 2006, Wang et al., 2008, Riesgo and Areal, 2013). At an aggregated level, Brookes and Barfoot (2012) estimate that the use of Bt maize has led to a 37.7% reduction in the use of insecticides against the corn borer between 1996 and 2010. For Spain, Gomez-Barbero et al. (2008) also show that Bt maize farmers apply less pesticides than conventional farmers. The authors reported that for three Spanish provinces (Albacete, Lleida and Zaragoza) 70% for Bt maize farmers did not apply pesticides as opposed to 42% of conventional maize farmers between 2002-2004. In addition, the authors found an average of 0.86 annual pesticide treatments were needed for conventional maize as opposed to 0.32 treatments for the Bt maize case. Brookes (2008) estimates that the reduction in

[6] Harvesting is slower when dealing with maize borer-damaged maize, so Bt maize cultivation encourages faster harvesting.

insecticide use derived from Bt maize cultivation in Spain was between 27% and 45% in the treated area, and from 26% to 35% in the use of insecticides between 1999 and 2001, this would be equivalent to a reduction of 35,000 to 56,000 kg of active ingredients. In a recent study, Brookes estimates that the use of insecticides was reduced by 678,000 kg of active ingredients used due to Bt maize since 1998 to 2018 (Brookes, 2019).

Such reductions in the use of insecticides translate in a lower impact on the environment and decreases the risks to which non-target organisms are exposed (Wesseler et al., 2011).

The lower environmental impact of biotech crops on plentiful non-target organisms and the use of insecticides is also highlighted by Areal and Riesgo (2015), at both the individual level and when the aggregated environmental impact was considered (use of insecticides and plentiful non-target organisms), observing that biotech crops perform environmentally better than conventional crops, with a probability ranging from 70 to 78%.

3.2.2 Water Footprint

Given the better agronomic performance of Bt maize, it is possible to estimate the volume of water use that has been averted by using this type of maize compared to conventional maize, to achieve the same volume of domestic production. To estimate the water used by maize, we use the water footprint indicator, introduced first by Hoekstra (2003). This indicator shows a connection between human consumption and the appropriation of freshwater. Thus, the water footprint for maize is defined as the total volume of freshwater used to produce maize (Hoekstra, 2009). Besides the total water used, water footprint also allows differentiating amongst three types of water use: blue, green and grey water footprints. The blue water footprint is related to the volume of irrigation water (surface and groundwater) consumed in the production of maize. The green water footprint refers to the rainwater consumed by maize (evapotranspiration), and the grey water footprint refers to the volume of water needed to assimilate the load of nitrogen fertilizers caused by the crop, based on existing water quality standards.

Given the water footprint caused by ton of maize produced in each of the regions analysed (Table 2), and the higher agronomic performance of Bt maize, we estimate the water footprint that has been averted by using this type of maize compared to conventional maize to achieve the same domestic production (Figure 6).

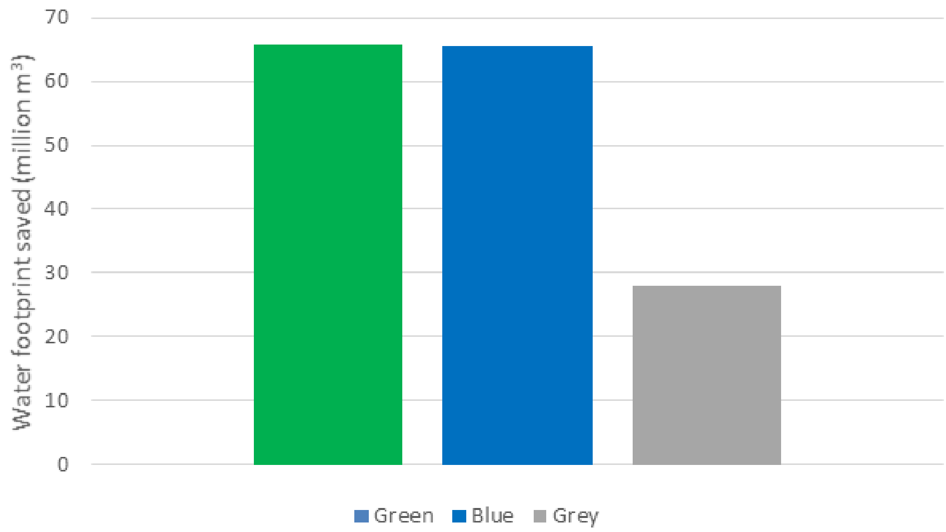
Table 2. Water footprint (m^3/ton) for maize by AC and type of water footprint.

Autonomous Community	**Water footprint**		
	Green	**Blue**	**Grey**
Aragón	39	35	16
Cataluña	39	29	15
Navarra	38	30	15
Castilla La Mancha	30	50	16
Andalucía	25	58	15
Extremadura	35	54	18

Source: Mekonnen and Hoekstra (2010)

The aggregated water footprint avoided in Spain for the period 1998-2021 reaches 65 million m^3 of green and blue water, and almost 28 million m^3 of grey water (Figure 6). The most relevant footprints are blue and grey in terms of environmental impact, since blue water footprint is related to the use of water for irrigation, and grey water footprint shows the impact of nitrogen used in agriculture on the water resources (i.e., water pollution). Two important considerations are pertinent considering both water footprints. Overall, Bt maize has saved 93 million m^3 of water between 1998 and 2021. Of these, Bt maize has saved 65 million m^3 of irrigation water and 28 m^3 of water used for treating nitrogen from agriculture compared to achieving the same domestic production with conventional maize. This is a conservative estimate for grey water footprints, since there are other relevant pollutants used in agriculture such as phosphorus that are not considered by the grey footprint estimate. Hence, if these were incorporated into the grey footprint the total positive effects on water savings of Bt maize cultivation would be higher.

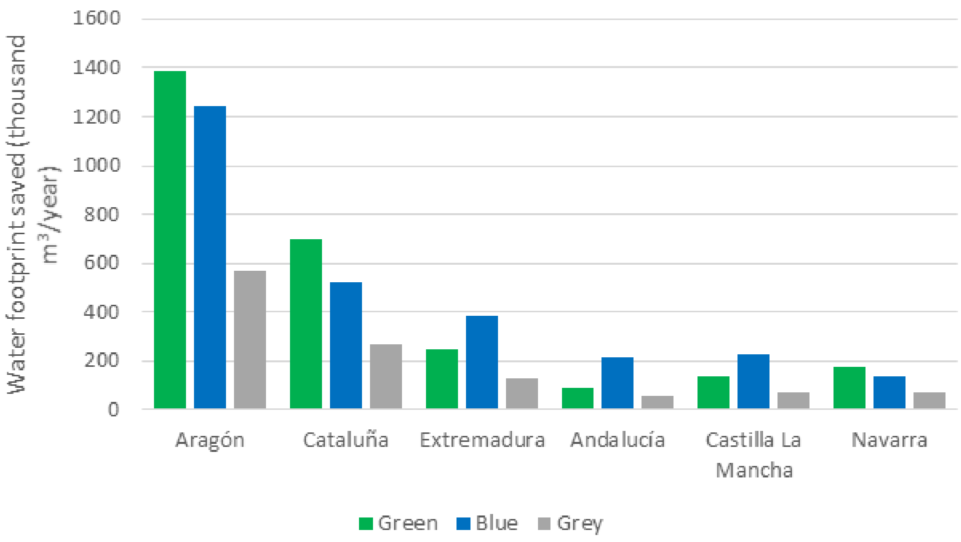
Figure 6. Water footprint saved per year in Spain (1998-2021)



Source: Own analysis

Figure 7 shows that Bt maize cultivation avoided a remarkable water footprint in Aragón and Cataluña, showing irrigation savings up to 1.2 million m^3 in Aragón and 0.5 million m^3 in Cataluña per year, compared to achieving the same production using conventional maize. In southern regions of Spain (Extremadura, Andalucía and Castilla La Mancha), we can see that irrigation water requirements (blue water footprint) are even higher than the rainwater consumed by maize (green water footprint). In this area irrigation water scarcity is a recurrent phenomenon, and avoiding water footprint, specially the blue one, is of higher relevance.

Figure 7. Water footprint saved per year by Autonomous Community



Source: Own analysis

Taking into account only the annual blue water footprint saved by Bt maize production and considering the average daily water consumption per person in each of the analysed AC[7] we find that these savings are equivalent to supplying water to a population of 58,932 inhabitants per year. Specifically, the largest water savings would be generated in Aragón and Cataluña, equivalent to an annual urban supply for almost 37,218 people. Likewise, considering the blue water footprint saved by Bt maize in Aragón for the whole period (1998-2021), water could have been used to cover water supply of Zaragoza, the biggest city in the region, for one year. In Cataluña, saved blue water footprint might have allowed to cover the water requirements of both Tarragona and Lleida for a year.

3.2.3. Use of land

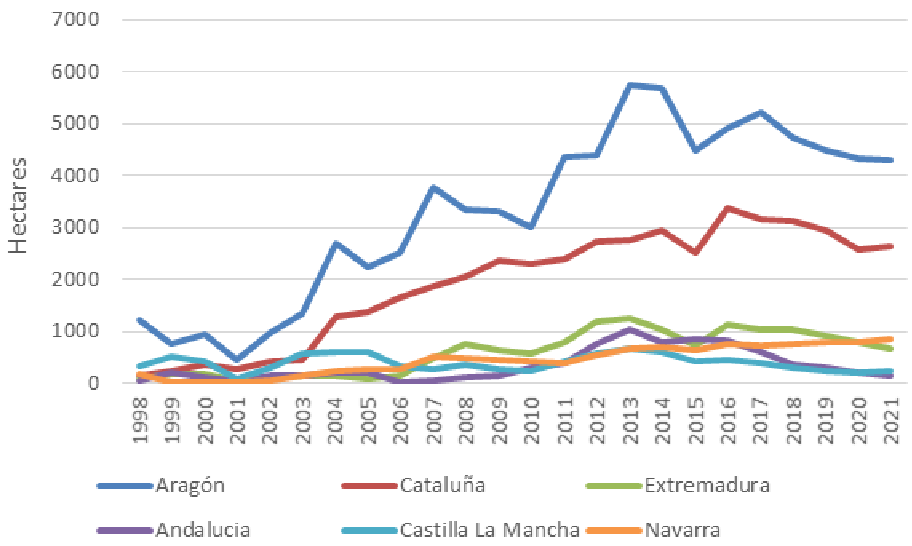
The cultivation of Bt maize has not only decreased the pressure on the water resources per ton produced, but also the pressure on the water currently used for irrigation. Maintaining the same total maize production in areas affected by the European corn borer plague would have greatly increased the current surface area destined to conventional maize[8] (Figure 8).

[7] Household water consumption (in litres/habitant/day) is 129 in Aragón, 123 in Cataluña, 126 in Extremadura, 128 in Andalucía, 135 in Castilla La Mancha and 114 in Navarra (INE, 2020b).

[8] To calculate the annual surface of conventional maize required to compensate the production of Bt maize in the areas analysed, the Bt maize production registered, and the conventional maize yield of each Autonomous Community have been taken into account.

Conventional maize surface required = production of Bt maize / conventional maize yield

Figure 8. Surface of conventional maize to compensate the increase in the yield of Bt maize



Source: Own analysis

For example, a total of 8,788 hectares would have been required to compensate the reduction in the use of Bt maize while maintaining the maize production levels in the areas affected by the European corn borer only during the year 2021 (see Annex 1 for the additional surface of maize that would have been required to compensate the higher production of Bt maize (Table A1.1)).

In cumulative terms for the whole time period, the total surface of conventional maize in Spain would have increased by 166,934 hectares to compensate the additional production volumes generated by the cultivation of Bt maize.

3.2.4. Carbon fixation

Due to the photosynthetic activity of plants, carbon fixation in cereal grains is much higher than the emissions associated with agricultural production. In this way, grain acreage can be considered as natural storage for CO_2. In the case of irrigated maize, the net fixation of carbon is estimated at 777 kg CO_2 equivalents/ton of maize produced (Altuna et al., 2012). With the net CO_2 fixation and the additional productivity of Bt maize compared to conventional (1,763,430 tons), Bt maize cultivation in Spain during the period 1998-2021 can be estimated to have added benefitted carbon fixation by the equivalent of 1,370,185 ton CO_2, which represents an annual average of 57,091 ton CO_2 for the period of study. Such aggregated net carbon fixation means that the use of Bt maize has contributed to compensate the emissions of over 9,103 million km travelled by vehicles for the period during which it has been cultivated, i.e., between 1998-2021, or in annual terms, Bt maize has contributed to compensate the emissions produced by 33,821 vehicles[9] (Figure 9).

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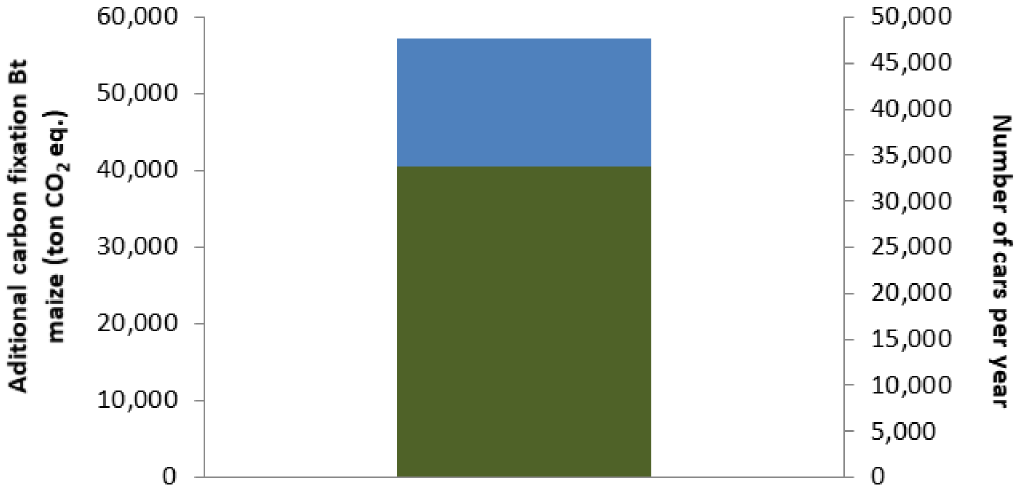
[9] To calculate the number of the average CO_2 emissions of a car in Spain have taken the data published by the Institute for Diversification and Saving of Energy (IDEA, 2015) compared to equivalent CO_2 emissions in diesel cars

Figure 9. Additional CO_2 fixation of Bt maize and annual equivalent number of cars



Source: Own analysis

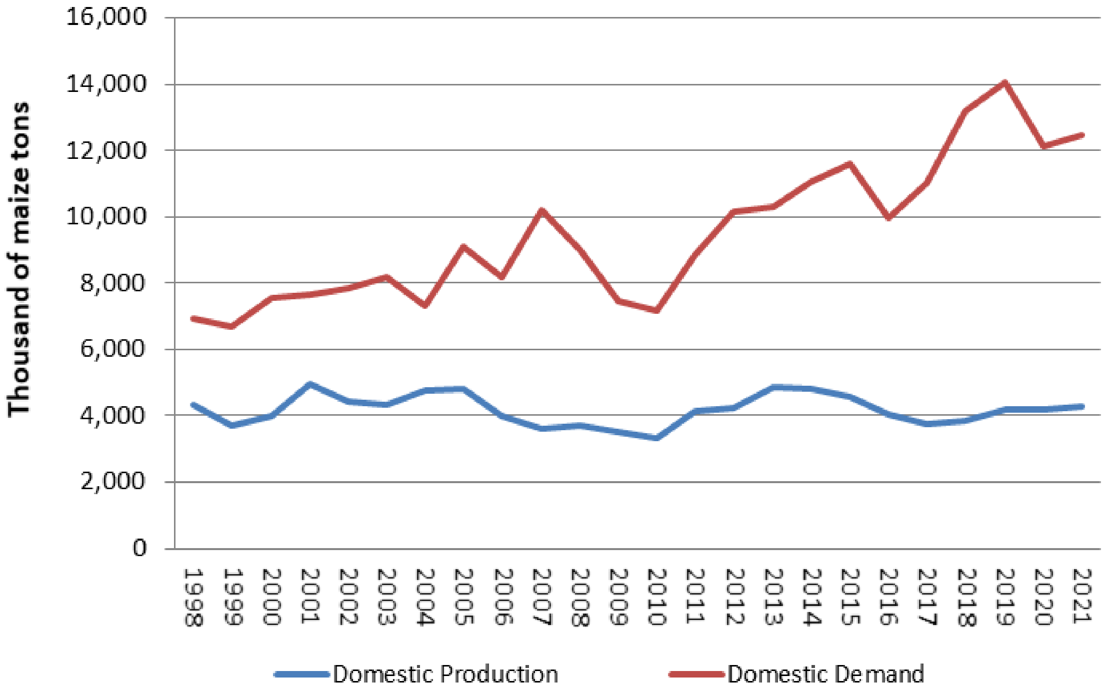
Agriculture is the sector with the highest land occupation levels, with the use and exploitation of land resulting in the emission of greenhouse gases, approximately 5,000 million equivalent annual tons of CO_2 during the 2001-2010 period (Tubiello *et al*., 2014). However, it has a noteworthy capacity to reduce the effects that are contributing to climatic change, such as through carbon fixation. This is precisely one of the tasks in which the cultivation of Bt maize can have the most positive effect, not only increasing the CO_2 fixation rates but also reducing the use of fossil fuels and associated emissions by means of reducing the volume of field operations, such as the phytosanitary treatments required in areas affected by the European corn borer.

and gasoline per kilometer, figures from Observatorio de Transporte y la Logística en España (Ministerio de Transportes, Movilidad y Agenda Urbana, 2021) to calculate the proportion of diesel and gasoline vehicles circulating in Spain and INE (2010) for the average number of kilometers traveled each vehicle type. It has been assumed that the average gas consumption of a car is 6 liters per 100 kilometers.

3.3. Benefits of cultivating Bt maize for foreign trade

Domestic demand[10] for maize grain has been growing since 2010, showing a progressively bigger margin of increase compared with domestic maize grain production (see Figure 10).

Figure 10. Domestic demand and production of maize in Spain



Source: Compiled from Eurostat (1998-2021)

Given the inability of domestic production to meet demand, the Spanish Agrofood sector needs to import maize. Since 2006, maize imports have exceeded domestic production (Figure 11a). Among the leading suppliers of maize to Spain in 2020 are, in order of magnitude, the Ukraine (41%), Brazil (31%), France (10%) and Romania (9%), (FAO, 2020).

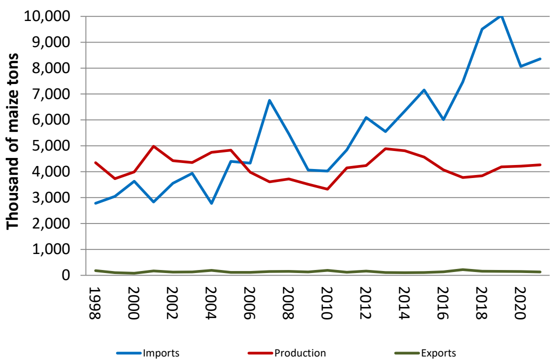
Due to the maintenance of grain prices over recent years[11], the relative increase in maize imports has produced a similar increase in the value of the imports (Figure 11b), up to 2020. Since 2010 to 2020, therefore, both the volume of imports and their value increased close to 100%. However, volume of imports increased 3.6% whereas its value increased 29.5% in 2021 compared to 2020.

[10] Domestic demand for maize is defined as: maize production in Spain plus Imports less Exports.

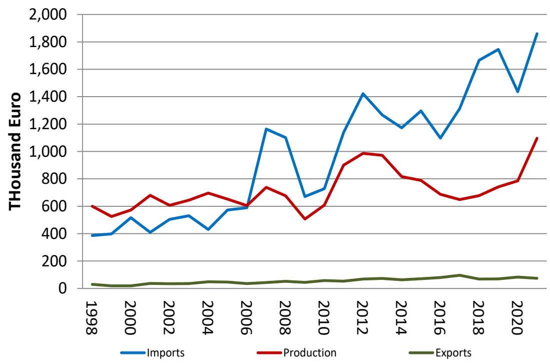
[11] In the case of maize, the average price of imports has grown over 60% since 1998, the year in which Bt maize started to be cultivated in Spain (Eurostat, 1998-2021). However, the price of maize imports remained quite stable from 2010 to 2020, a significant increase has occurred last year (25% of increase from 2020 to 2021).

Figure 11. Changes in production, imports and exports of maize

11a. Quantity (thousand tons)



11b. Value (thousand Euro)



Source: Own compilation from Eurostat (1998-2021), HS2,4,6 and CN8 maize classification (1005)

As mentioned in previous sections, one of the main advantages of Bt maize is its higher yield in relation to conventional maize in areas affected by the scourge of the corn borer. Considering the growing areas of this biotech variety in Spain, it is possible to estimate the additional maize requirements that would have been needed if the Bt variety of maize had not been available to farmers. Due to the lack of data on the extent of corn borer damage in Spain, it is assumed that corn borer had a significant presence in those ACs in which Bt maize area was greater than or equal to 5% of the total maize area over the period 1998-2021. These ACs are Aragón, Cataluña, Navarra, Castilla La Mancha, Andalucía and Extremadura.

Given the lack of official data on the difference in yield between Bt and conventional maize, a review of published data on the Spanish case has been conducted in peer-reviewed scientific journals. Table 4 presents the yield differences between both types of maize.

Table 4. Yield differences between Bt and conventional maize in Spain

Analyzed area	Increase of Bt maize yield compared to conventional (%)	Reference
Aragón	10,00 (year 1999-2001)	Brookes (2008)
Aragón, Cataluña and Navarra	10,46 (average for 2004-2007)	Brookes (2008)
Aragón	12,00 (average for 2004-2006)	Gómez-Barbero et al. (2008)*
Cataluña	5,97 (average for 2004-2006)	Gómez-Barbero et al. (2008)*
Castilla La Mancha	7,40 (average for 2004-2006)	Gómez-Barbero et al. (2008)*
Ebro Valley (Aragon, Cataluña, Navarra)	12,64 (year 2009)	Riesgo et al. (2012)*

* Data taken from studies published in scientific journals

Source: Own analysis

Results obtained assume average yields from the studies listed in Table 4, considering therefore the differences in yield by area between Bt and conventional maize (Table 5).

Table 5. Yield differences considered between Bt and conventional maize (%)[12]

Autonomous Community	Yield increase of Bt maize compared to conventional maize
Aragón	10,53
Cataluña	8,11
Navarra	9,48
Castilla- La Mancha	7,38
Andalucía	7,38
Extremadura	7,38

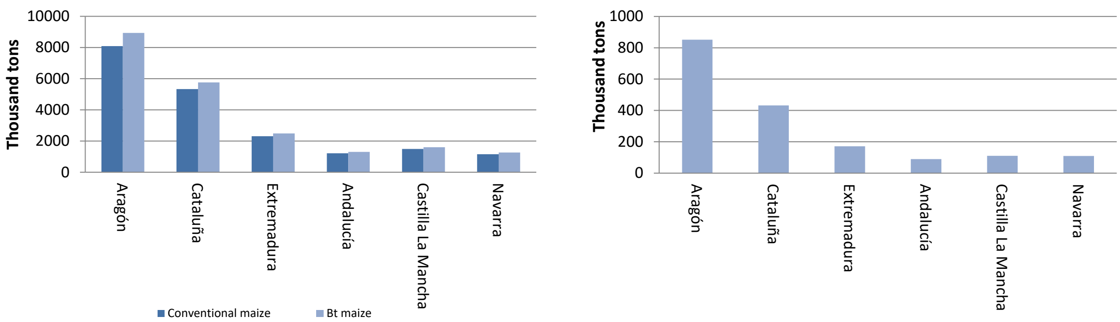
Source: Own analysis

On the basis of the differences in yields listed in Table 5 and taking into account the areas cultivated with Bt and conventional maize, it is possible to estimate the performance of both maize varieties by AC in the period 1998-2021[13].

Figure 12. Estimated maize production

12a. Production of Bt maize and estimated conventional maize

12b. Maize production losses



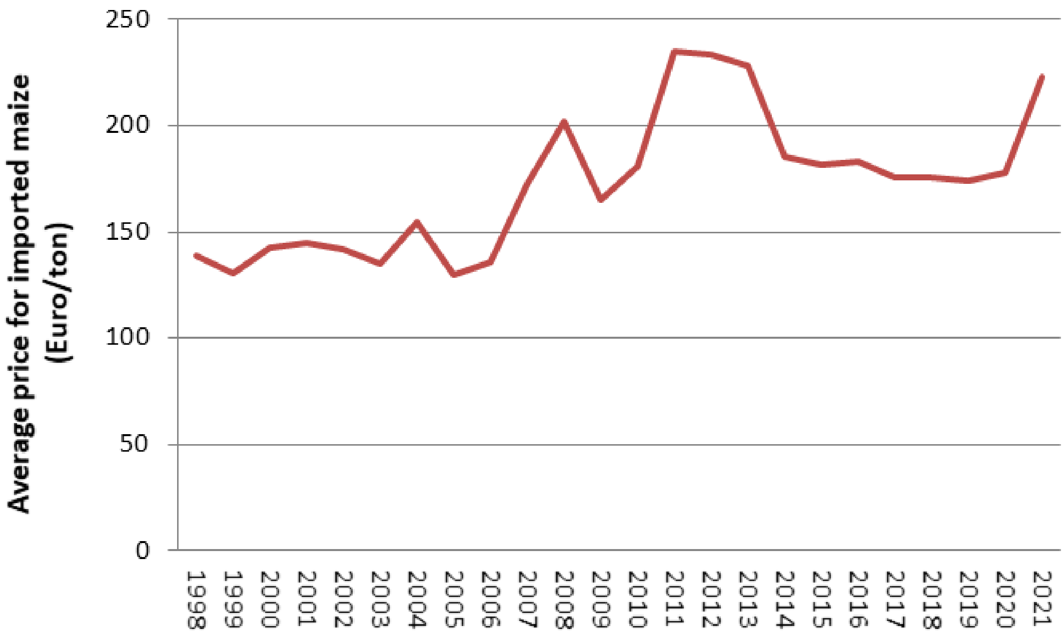
Source: Own analysis

[12] In the case of Aragón the arithmetic mean of the differences in yields was calculated and published by Brookes (2008), Gómez-Barbero et al. (2008) for Aragon and Riesgo et al. (2012) for the Ebro Valley. For Cataluña the arithmetic mean of the differences in yields was calculated and published by Brookes (2008), Gómez-Barbero et al. (2008) for Cataluña and Riesgo et al. (2012) for the Ebro Valley. For Navarre, the average of the yield gap was taken as the reference for the arithmetic mean as published by Brookes (2008) For Cataluña, Aragón and Navarra, Gómez-Barbero et al. (2008) for Aragón and Cataluña, and Riesgo et al. (2012) for the Ebro Valley. Finally, in the case of Castilla La Mancha, Andalucía and Extremadura taken as reference the arithmetic average of the yield gap as published by Gómez-Barbero et al. (2008) for Castilla La Mancha.

[13] Maize Yield Performance by AC = Bt · ((Bt maize area) / (Total area maize)) + Yield conventional maize · ((conventional maize area) / (Total area maize)). Performance data of maize by AC, Bt maize area and total maize area is taken from data collected from MAPA (1999-2021). Given the assumed differences in yields listed in Table 3 yields of Bt maize and conventional maize have been estimated.

Based on yield differences, we assess the production of maize that would have been achieved if instead of Bt maize conventional maize had been planted in the same area, in each region, for the period 1998-2021 ('estimated production'). Figure 12a shows the production of Bt maize and the 'estimated production' of conventional maize for each region for the whole period of analysis. The difference between Bt maize production and 'estimated production' of conventional maize by region and year, allows us to estimate the production losses that would have been occurred if Bt maize had not been available for farmers (see Figure 12b). Such aggregated losses accounted for 1,763,430 tons for the period analysed.

Figure 13. Average price of imported maize in Spain (1998-2021)



Source: Own analysis of date from Eurostat (1998-2021)

These production losses would have led to an increase of maize imports to cover Spanish domestic demand during the period analysed (imports that would had been occurred if Bt maize had not been authorized for cultivation). Considering the average price of maize imported by Spain during the period 1998 to 2021[14] (Figure 13) it is possible to calculate the value of the imports that would otherwise have been necessary.

[14] The average price of maize imports has been calculated as follows: Average price = (Value of maize imports) / (Quantity imported maize), using the values given for the years 1998-2021(Eurostat).

Table 6. Actual value of averted imports, by ACs

Autonomous Community	Value of averted imports (Euro in 2021)
Aragón	151.389.864
Cataluña	77.196.259
Navarra	19.688.636
Castilla La Mancha	17.778.567
Andalucía	16.262.674
Extremadura	31.342.358
TOTAL	*313.658.357*

Source: Own analysis

The actual value[15] of maize imports averted through the adoption of Bt maize in Spain for the period 1998-2021 accounts for nearly 314 million euros in 2021 (see Table 6).

3.4. Societal Benefits: rural communities

The adoption of Bt maize and biotech technology can contribute to achieving the EU's Green Deal growth strategy aims of increasing growth and resource efficiency. Since the commercialisation of Bt maize in the EU, farmers' adoption of Bt maize has provided benefits to farmers and to society as a whole through the reduction of pressure on the environment and natural resources by increasing resource efficiency (water and land use), increasing carbon fixation and reducing impacts to the environment , which is in line with the EU's Biodiversity and the Farm to Fork strategies of the EU's Green Deal.

The adoption of Bt maize technology by farmers in Spain has provided a sustainable solution to an agronomic issue. Between 1998 and 2021 farmers' adoption of Bt maize improved the agronomic, economic and environmental performance of farms facing a crop pest issue (corn borer) in a sustainable way. During this period the technology allowed farmers to increase maize yield and income, whilst providing social benefits such as mitigating the impact to the environment and contributing to retaining rural population through a more competitive agriculture. Bt maize has helped to reduce the use of land and water resources; reducing the impact into the environment whilst allowing crop yields and farmers' income to increase. In addition, Bt maize has contributed to reduce maize imports with a value of approximately 314 million euros.

The evolution of the adoption rates by cultivation area indicate that Bt maize adoption has probably peaked in Spain given the current corn borer pest infestation levels. However, it is evident that Bt maize has contributed and will continue to contribute in the future to achieve a more sustainable agriculture in those areas where corn borer is present.

Bt maize and biotech can be a complement to other sustainable production alternatives to achieve sustainability objectives included in the EU's Green Deal.

[15] The value of averted imports in each year has been updated for 2021. To do this we used the coefficients provided by INE (2021).

4. Conclusions

The adoption of Bt maize cultivation contributed to agronomic, economic, environmental and social sustainability in Spain, in particular in rural areas where corn borer is an issue.

It is evident that Bt maize has contributed and will continue to contribute in the future to achieve a more sustainable agriculture in those areas where corn borer is present. The adoption of Bt maize in Spain since 1998 has brought a solution to farmers that Bt maize and biotech technology can contribute to achieving the EU's Green Deal growth strategy aims of increasing growth and resource efficiency. Since the commercialisation of Bt maize in the EU, farmers' adoption of Bt maize has provided benefits to farmers and to society as a whole by increasing resource efficiency (water and land use), increasing carbon fixation and reducing pressure on the environment and natural resources (social benefits), which is in line with the EU's Biodiversity and the Farm to Fork strategies of the EU's Green Deal.

The adoption of Bt maize by farmers in Spain has provided a sustainable solution to an agronomic issue. Between 1998 and 2021 farmers' adoption of Bt maize improved the agronomic, economic and environmental performance of farms facing a crop pest issue (corn borer) in a sustainable way. During this period the technology allowed them to increase their maize yield, income, whilst providing social benefits such as mitigating the impact to the environment and contributing to retaining rural population through a more competitive agriculture.

Bt maize has helped to reduce the use of land and water; reducing the impact into the environment whilst allowing yield and farmers' income to increase. In addition, Bt maize has contributed to reduce maize imports with a value of approximately 314 million euros.

The evolution of the adoption rates by cultivation area indicates that Bt maize adoption has probably peaked in Spain given the current pest infestation levels. However, it is evident that Bt maize has contributed and will continue to contribute in the future to achieve a more sustainable agriculture in those areas where corn borer is present.

Hence, Bt maize and biotech can be a complement to other sustainable production alternatives to achieve sustainability objectives included in the EU's Green Deal. Bt maize adoption has demonstrated to be a way to reduce environmental impact in Spain bringing at the same time economic and societal benefits, and therefore contributing to achieve a more sustainable production.

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ANNEX 1

Table A1.1 shows the annual area of conventional maize that would have been required to compensate the annual production of Bt maize in Spain. In cumulative terms for the period 1998-2021, not cultivating Bt maize would have been required an additional area of 166,934 hectares of conventional maize to maintain the national maize production levels.

Tabla A1.1. Annual evolution of the additional conventional maize surface required to compensate the production of Bt maize in Spain

	Aragón	Cataluña	Extremadura	Andalucía	Castilla La Mancha	Navarra	Total
1998	1211	138	74	58	332	167	1980
1999	769	243	185	207	502	28	1934
2000	948	365	185	111	417	21	2046
2001	445	264	44	33	64	8	858
2002	969	430	111	133	306	47	1996
2003	1326	440	140	153	567	131	2758
2004	2691	1273	150	204	605	232	5155
2005	2239	1365	86	212	587	247	4737
2006	2500	1651	153	22	308	267	4902
2007	3777	1866	477	44	270	505	6939
2008	3356	2051	769	101	350	488	7115
2009	3307	2369	644	154	252	445	7172
2010	3018	2291	574	279	235	424	6821
2011	4357	2403	780	387	429	388	8745
2012	4389	2719	1178	765	582	550	10183
2013	5736	2757	1253	1039	647	665	12097
2014	5692	2950	1020	789	589	689	11729
2015	4488	2497	725	847	423	628	9608
2016	4903	3371	1110	806	438	765	11392
2017	5225	3170	1032	592	374	737	11130
2018	4733	3142	1044	367	281	768	10335
2019	4492	2954	905	280	229	782	9642
2020	4318	2581	791	201	192	788	8872
2021	4283	2639	657	131	218	860	8788