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Review

Social Impacts of GM Crops in Agriculture: A Systematic Literature Review

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Abstract: It has recently been argued that the fragmented knowledge on the social impacts of genetically modified (GM) crops is contributing to the polarised debate on the matter. This paper addresses this issue by systematically reviewing 99 peer-reviewed journal articles published since 2004 on the social impacts of GM crops in agriculture; summarising current knowledge, and identifying research gaps. Economic impact studies currently dominate the literature and mainly report that GM crops provide economic benefits for farmers. Other social impacts are less well studied, but present a more complex picture. Studies on access to and benefits of GM crops show that these vary significantly depending on the political and regulatory setting. Substantial evidence indicates that intellectual property rights (IPR) and the private industry's dominance limit the access and utility of available GM crops to many farmers. Wellbeing is frequently discussed in the literature, but rarely investigated empirically. Existing evidence is contradictory and inconclusive. Impact studies from the Global North are virtually non-existent. Moreover, two-thirds of publications are based on previously published empirical evidence, indicating a need for new empirical investigations into the social impacts of GM crops in agriculture.

Keywords: social impact; Genetically Modified Organism (GMO); biotechnology; agriculture; farm; sustainability

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1. Introduction

There is intense discussion in the research community and society at large on whether use of genetically modified (GM) crops in agriculture can contribute to sustainable development [1–3]. Previous discussions and evaluations of sustainability in general [4–6] and of agricultural practices [7] have been dominated by the ecological dimension, whereas the social aspects of sustainability have been rather neglected. However, the social impacts of GM crops in agriculture have been discussed in numerous studies (e.g., [8,9]). The sustainability-focused research on GM crops might thus be at the forefront of research addressing the social dimension of sustainability in agriculture.

Despite previous attention to the social impacts of GM crops in agriculture, only a few studies adopt a comprehensive approach and cover a wide set of social impacts. Many focus only on a limited geographical region [10–12], or on a certain crop or genetic modification [13,14]. The literature in general is also dominated by attention to the Global South [15–17]. Thus there is still a research gap regarding a more comprehensive set of crops, modifications and social impacts.

It has recently been argued that the currently rather fragmented knowledge on the social impacts of GM crops probably contributes to the much polarised debate on GM crops [8,18]. Due to lack of a systematic, broad overview of existing knowledge on the social impacts of GM crops, it is difficult to draw conclusions about the full range and type of social impacts identified and how they materialise in different contexts of growing GM crops. Therefore, this paper presents a systematic review of peer-reviewed literature published since 2004 dealing with the social impacts of GM crops in agriculture. The aim was to map existing knowledge about the social impacts: How and in what contexts have the social impacts of GM crops been studied empirically? Is one particular set of social impacts or crops or one specific geographical region more comprehensively studied than others? Are there any significant research gaps? What future research is needed to provide a more comprehensive understanding of the social impacts of GM crops in agriculture?

The review was limited to social impacts materialising at the farm level. Impacts occurring in other parts of the production chain (e.g., working conditions in the biotechnology industry or consumer impacts) were not included. General impacts on an aggregated societal level were only considered when relating directly to impacts at the farm level. Studies focusing on perceptions or attitudes about GM crops, without linking these to actual social impacts at the farm level, were not included. For example, while regulations on co-existence between farms producing GM crops and farms not producing GM crops might lead to social impacts at farm level for both farms, studies focusing on the impacts of co-existence on consumer choice [19] or the willingness of farmers to adopt GM crops [20,21] were not considered to be directly related to social impacts and were thus excluded from the review.

Defining Social Impact

Social impact can be defined as: “The consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society” [22].

It is now increasingly acknowledged that success in achieving sustainable development relies on also addressing its social dimension. This shift is exemplified for instance by Raworth [23], adding the notion of a social foundation to the renowned work on Planetary Boundaries by Rockstrom *et al.* [24]. Moreover, the majority of the newly proposed UN Sustainable Development Goals (SDGs), aimed at guiding global action on sustainable development from 2015 to 2030, address the social dimension [25]. In the agriculture sector, the UN Food and Agriculture Organisation (FAO) has recently developed a tool, Sustainability Assessment of Food and Agriculture systems (SAFA), for holistic sustainability evaluations in the food and agriculture chains. SAFA likewise acknowledges the importance of addressing aspects of social sustainability in agriculture and groups sustainability issues in four dimensions: good governance, environmental integrity, economic resilience and social wellbeing [26]. Overall, it is clear that the social dimension is an indispensable perspective when working towards sustainable development.

2. Material and Methods

A search was initiated to locate articles discussing the social impacts of genetically modified (GM) crops in agriculture, written in the English language and published in peer-reviewed journals since 1990 (beginning of the GM crop era). The search was designed to be replicable. This means that, in contrast to a non-replicable iterative search process, some papers of relevance to the topic were not captured by the search as they did not fit the pre-defined search criteria. To minimise exclusion of relevant papers, test searches were performed using different combinations of search terms. A substantial amount of the existing research on the social impacts of GM crops focuses on the developing world in general, and on the rural poor in particular [13,16,27]. To cover all relevant social impact literature, it proved necessary to include the term “poverty” in the search, as a test search confirmed that this resulted in a significant number of relevant hits not captured otherwise. In contrast, the term “food security” was excluded, as it resulted in a significant number of very narrow technical hits irrelevant for the review, without increasing relevant hits.

To further ensure the validity of the search presented, extensive iterative searches on the topic were performed with the aim of obtaining a good overview of papers that were excluded as a result of different search combinations. The iterative searches showed that while some papers of relevance to the topic (such as [28–37]) were indeed not captured in the search, these were sufficiently few not to challenge the overall findings presented here and did not address other topics than those also addressed in the reviewed literature. The iterative searches also showed that in particular, literature addressing cultural heritage impacts of GM crops in agriculture fell outside the search. Examples of relevant studies are [32–37]. However, even taking into account the additional papers found in the iterative searches, such studies remain few in comparison with the other impact groups (see Section 3.2). The final search was defined thus:

(Social* OR socio* OR poor* OR poverty*) AND (farm* OR agricultur*) AND (biotech* OR "genetic* modifi*") AND (impact* OR effect* OR consequence*).

The search was run on 16 June 2014 using five search engines (Web of Science core collection, Scopus, CABI, ProQuest ASSIA and Jstor). Removal of 224 doubles resulted in 1289 papers. This was deemed too many to process, so the sample was further limited in time to include only research published from 2004, because most studies published before 2004 rely on field trials (in contrast to actual adoption of GM crops by farmers) or limited datasets [38]. The limitation in time resulted in 805 remaining publications.

To capture all relevant hits relating to the social impacts of GM crops in agriculture, the search was designed to be rather broad. As a result, hits outside the focus on GM crops in agriculture (such as perception studies or studies on animal husbandry and biotechnological applications not defined as genetic modification) had to be removed manually after reading titles, abstracts and, when necessary, full-length articles. A further three papers were excluded because they were not accessible through our university libraries, leaving 99 publications. These were all read in full and classified according to article type and topics addressed (see Table 1). The classifications are explained below in more detail. A list of the 99 publications and the classifications for each publication is provided in the Supplementary Material for this review.

Table 1. Paper classification categories.

Type of paper	Review of other literature
	Bottom-up (First-hand farm level-data)
	Top-down (Papers drawing on secondary data, including theoretical accounts)
Genetic modification	(1) Bt (2) Herbicide-tolerant (3) Other (4) Not specified/discussion at another level
Crop	(1) Cotton; (2) Maize (3) Soybean; (4) Other (5) Not specified/discussion at another level
Groups of social impacts addressed	Economic (Yield, farm finances, labour productivity *etc.*)
	Distributional (Distribution of benefits depending on e.g., gender, farm size, income, education, local-national-global, *etc.*)
	Access and ownership (Patents, food sovereignty, market structure, land rights, *etc.*)
	Wellbeing (Food security, labour conditions, health, *etc.*)
	Cultural heritage (Indigenous knowledge, preserving traditional varieties, *etc.*)
Socio-economic context	(1) Global North (2) Global South (3) Both (4) Categories not relevant.
Country	All 17 countries appearing in the papers were classified according to a numerical code.

Genetic modification. This classification covered GM traits and crops dominating the market today. The most common GM crops are herbicide-tolerant (HT) crops, followed by insect-resistant (IR) crops and crops containing the two traits combined (so-called stacked trait crops) [39]. HT crops commonly provide resistance to broad-spectrum herbicides containing glyphosate (e.g., Monsanto's Roundup Ready® crops and Roundup® herbicide). IR crops are marketed today in the form of Bt crops, modified to contain genes from the soil bacterium *Bacillus thuringiensis* (Bt), which makes the crops produce proteins that are toxic to certain insect species.

Crop. Soybean, maize, cotton and rapeseed are the four most common GM crops today. Together, they currently occupy 99% of the global acreage planted to GM crops. GM rapeseed crops occupy roughly 10% of the global acreage of GM crops planted [39], but rarely appear in the papers reviewed here and therefore were not specified in the analysis.

Social impacts. The social impact groups used to classify the papers were inspired by the socio-economic dimension included in the SDGs [25], and the SAFA dimensions of economic resilience and social wellbeing [26]. To make the social impact groups relevant for GM crops in agriculture, the final definition was also influenced by how social impacts were addressed in the literature reviewed. Social impact studies commonly acknowledge the intertwined relations between social and economic sustainability [40,41], so this review included economic impact as one dimension of social impact. The economic impact group includes all aspects of farm economy such as changes in input and output costs, economic effects of changed management practices, *etc.* While also encompassing economic dimensions, impacts of distribution and access (as defined below) are separated here from the economic impacts. Distributional impacts concerned the distribution of benefits between groups, e.g., how adoption of a new GM crop varied with gender or age. Access and ownership concerned access to various resources, e.g., how different regulation of IPR resulted in restraining ownership over the means of production (seed) for some groups. While there are clear overlaps between the access and distribution impact groups, we found it valuable to keep them separate. In many cases, impacts relating to access resulted in different distributional impacts, but various studies focused on one or the other aspect. The wellbeing impact group was associated here with all aspects of health, including nutrition, absence of disease, *etc.*, but also with food security and quality of life more broadly (*cf*. [42]), which in the body of literature reviewed can concern e.g., labour conditions. The cultural heritage impact group relates to how introduction of GM crops into a community might affect, or be affected by, indigenous knowledge and local traditions *etc.*

Socio-economic context. The papers were classified as focusing on the Global North, the Global South or both (or that such categories were not relevant). The grouping was based on the World Bank classification of countries into low-income economies, lower middle income economies, upper middle income economies and high income OECD members [43]. Here, high income economies and OECD member countries were grouped together as Global North and the other countries (*i.e.*, low-income, lower middle income and upper middle income economies) were classified as Global South.

The literature classification and further analysis was performed jointly by all authors of the present review. To ensure consistency in the classification, the procedure was discussed during weekly meetings and a selection of publications was cross-read. The classifications for each paper were entered into an Excel spreadsheet and then analysed quantitatively, in terms of the frequency with which different topics appeared in the literature, and qualitatively, in terms of how different topics were addressed and related to each other.

3. Results

The 99 publications were spread over 67 different journals. AgBioForum was the most frequently occurring journal in the review with nine publications. The African Journal of Biotechnology and Journal of Development Studies were represented with five publications each. A total of 52 journals were only represented with one paper (the full list of reviewed literature is available as an on-line supplement). Section 3.1 presents an overview of the crops, modifications and countries discussed in the reviewed literature. In the subsequent sections, the way that social impacts are addressed in the literature is analysed in more detail.

3.1. Overview of Crops, Modifications and Countries

The crop most commonly studied in the papers reviewed was cotton (43 studies), followed by maize (20) and soybean (14). This differs from the global ranking of GM crops in terms of hectares planted, where soy bean dominates, followed by maize, cotton and rapeseed [39]. This discrepancy may be because India appeared most frequently in the dataset (Table 2) and cotton is the only GM plant commercialised in India [39]. Rapeseed appeared rarely in the dataset. It is only planted in the US, Canada, Australia and Chile, countries rarely studied in the literature reviewed (Table 2). Nineteen publications focused on other crops (e.g., aubergine, papaya, rice, rapeseed or wheat) and 32 did not specify a crop.

The most common modification to be studied was insect resistance through Bt (53 studies), which is the second most common modification globally. Herbicide tolerance (HT), the most widespread genetic modification in terms of hectares planted [39], was the focus of 20 studies; 11 studies addressed other modifications (e.g., drought resistance or nutritional enhancement) and 37 studies did not specify the modification. Many of the studies that did not specify plant or modification dealt with regulations or trade agreements regarding GM crops, where specific crops or modifications are not the focus of attention (some examples include [44–46]).

Pooling modifications and crops appearing in the papers, Bt and cotton was the most common combination (43 studies), followed by Bt and maize (15), HT and cotton (12), Ht and maize (12) and HT and soybean (11). Scrutiny of the papers confirmed that Bt cotton was the GM crop most commonly addressed. However, the results from pooling data on modification and crop must be treated with caution, as each paper was analysed for crop and modification separately and many papers included several crops and modifications.

Seventeen different countries were mentioned in the studies (Table 2). The majority of the studies (72/99) concerned countries in the Global South. Of these, 50 related to specific countries and 22 to the Global South in general. Only four studies focused on the Global North, all referring to specific countries (Australia, Canada, USA and Switzerland), 15 studies discussed both the Global North and Global South and eight studies did not discuss specific locations.

Table 2. Countries planting the most GM crops in the world compared with countries appearing in the dataset.

Ranking of countries based on million hectares of GM crops planted [39]	Ranking of countries based on appearance in the dataset (number of studies)
USA (73.1)	India (17)
Brazil (42.2)	South Africa (11)
Argentina (24.3)	Argentina (6)
India, Canada (11.6)	Philippines (4)
China, Paraguay (3.9)	Brazil, Burkina Faso, China, Pakistan (3)
Pakistan (2.9)	Australia, Mexico, USA, Canada (2)
South Africa (2.7)	
Uruguay 1.6	
Bolivia, Philippines, Australia, Burkina Faso, Burma, Mexico, Spain, Colombia, Sudan, Honduras, Chile, Portugal, Cuba, Czech Republic, Romania, Slovakia, Costa Rica, Bangladesh (1.0 and lower, descending order)	Chile, Ethiopia, Nigeria, Paraguay, Switzerland (1)

All countries appearing repeatedly in the dataset (Table 2) were countries where GM crops are planted commercially, indicating that the majority of studies presented empirical evidence. However, this was often indirect evidence, as seen in the number of studies without farm-level data (Table 3). Ethiopia, Nigeria and Switzerland, which appeared in one study each in the dataset, do not have commercial plantations of GM crops [39]. Surprisingly, the US, the country with the largest area planted to GM crops, only appeared in two studies in the dataset.

3.2. Range of Social Impacts Addressed

Among the social impact groups addressed in the papers reviewed (Table 3), economic impacts completely dominated, being addressed in 83/99 studies. Distribution (53/99) and wellbeing (48/99) were both commonly addressed, followed by access (37/99). Impacts grouped as cultural heritage were rarely addressed (15/99) (as noted in Section 2, this was partly an effect of how the search was designed).

Overall, relatively few of the studies took a comprehensive view on social impacts; 29 studies addressed only one impact group, most commonly economic impact (Table 3). While other impact groups were rarely addressed in isolation (Table 3), the majority of studies only addressed impacts from one to two different groups. Only 40 of the publications addressed impacts from three or more groups and only seven of 99 publications [45,47–52] addressed aspects from all five impact groups. However, all but one of these seven publications either addressed the impacts from a specific perspective, e.g., that of the Millennium Development Goals [49] or in relation to regulatory aspects [48], or relating to a specific geographical region, crop or modification. The only study to address impacts across all impact groups [50] was nine years old. Furthermore, none of the publications addressing impacts from all groups were based on new empirical material.

Overall, studies based on farm-level data were relatively few. When reviewing studies from 2004 onwards, a significant amount of studies on farmers adopting GM crops (in contrast to field trial-data) was expected. However, only 36 of 99 studies were based on first-hand data at the farm level. Sorting the studies by impact group addressed revealed that the same pattern applied to all impact groups, with 22%–37% of the studies being bottom-up (Table 3). However, some impacts or impact groups can be more relevantly addressed without farm-level data than others (see Section 3.3).

Table 3. Social impacts addressed in the whole dataset and in bottom-up studies.

The Whole Dataset (99 Publications)					
	Economics	***Distribution***	***Access***	***Wellbeing***	***Cultural Heritage***
Number of studies addressing specific impact groups [1]	83	53	37	48	15
Number of studies addressing only one impact group	23	0	1	4	1
Only Bottom-Up Studies (36 Publications)					
	Economics	***Distribution***	***Access***	***Wellbeing***	***Cultural Heritage***
Number of studies addressing specific impact groups [2]	31	19	8	11	4
Percentage bottom-up studies of total studies within each impact group	37%	36%	22%	23%	27%

[1] N > 99 because 70 publications covered more than one impact group; [2] N > 36 because 26 publications covered more than one impact group.

3.3. How Are Different Social Impacts Addressed?

Careful scrutiny of the papers provided a more in-depth understanding of the ways in which different social impacts were addressed. Economic impacts, by far the most commonly addressed group, almost invariably included studies on yield and farm finances. The combined results from such studies taken together indicated that on average, the GM crops available today have raised yields and improved farm finances (as highlighted in studies such as [53–55]). However, a significant number of studies discussed yield and farm finances without own bottom-up data (52/83 studies). This meant that existing empirical data on yield and farm finances were repeated in many studies (e.g., [14,56–59]). This could give the impression that claims of increased yields and profits have a more substantial empirical foundation than is actually the case.

Some economic studies without farm-level data assessed the kind of economic impacts that can be discussed without farm-level data. For example, the study by Parfitt [46] (which was also classified as addressing access and distribution impact groups) studied the effects of the increasing economic concentration within the biotech industry and concluded that this leads to crop varieties not being developed for more marginal environments, higher crop and input prices, and increased difficulty for smaller farmers surviving on only farming. Dowd-Uribe [60] studied the economic implications of the governance of Bt cotton production in Burkina Faso and concluded that high seed prices, corruption and late payments are important in dissuading farmers from producing cotton.

Distributional impacts were the second most common impact addressed. The type of distributional impacts covered was more varied than in the economic impact group and the studies concerned presented a less conclusive picture than the economic studies. At the farm level, the distributional impacts studied concerned mainly how adoption and economic benefits are distributed among farmers in different income groups or, more rarely, in relation to gender. Mutuc *et al.* [61] presented results from the Philippines showing that poorer farmers without access to irrigation and living further away from formal seed suppliers are less inclined to adopt Bt maize. However, in another study from the Philippines, Sanglestsawai *et al.* [62] showed that if they can adopt Bt maize, lower-yielding farmers, who also tend to be the poorest, experience higher yield increases than farmers with higher yields before Bt maize adoption. Distributional impacts with regard to Bt cotton (see Section 3.4) support this inconclusive picture, indicating that the institutional environment in which GM crops are introduced has significant effects on their distributional effects. Indeed, Newell and Mackenzie [44] argue that the effects of biotechnology in itself on poverty and food security are limited, and that it is the institutional framework in which the technology is introduced that largely determines its distributional effects.

Studies addressing distributional impacts between farmers and other actors included e.g., Rao and Dev [55], who point out that, as a result of different political and regulatory contexts, there are significant differences between countries regarding the share of benefits distributed to farmers. Those authors present figures from 2005 showing that distribution of economic benefits between agrochemical companies and farmers adopting Bt cotton in all countries in the example (China, India, Mexico, South Africa) except Argentina is to the benefit of farmers. Chinese farmers benefited the most, taking 94% of the benefits but, at the other end of the spectrum, Argentinian farmers received only 21% [43]. In the original source of these figures, farmer gains are calculated as the balance between additional input costs, determined by the price premium paid for Bt cotton seed and whether or not farmers can recycle seed or have to purchase new seed every year, and gains on the output side in the form of increased yields and savings in production costs due to reduced pesticide applications (cotton price to consumers is assumed to be constant in the model). Farmer gains are compared with the size of profits that the private sector can extract from their technologies in any given country, which is expected to depend on the strength of IPR protection and/or the availability of other measures to prevent farmers' own reproduction of seeds [63]. While the figures presented in Rao and Dev might well have changed since 2005, it can be noted that many articles in the review point out that agricultural policies and regulations surrounding GM crops have a significant influence on whether and how different farmers might benefit from GM crop adoption (e.g., [44,56,64]). The fact that Argentina provides such a negative institutional environment for farmers with regard to GM crops may explain why all studies (6 in total) addressing distributional aspects in Argentina concluded that adoption of GM crops have led to increased inequality in the Argentinean agricultural sector [51,65–69].

Rao and Dev [55] and Carpenter [56] concluded that, looking at the global average, farmers receive a significant share of the profits. As shown above, this does not mean that all farmers benefit equally. In fact, Rao and Dev [55] noted that, even though more resource-constrained and marginalised smallholders have also benefited from GM crops, the fact that a few multinational companies control the majority of crop biotech R&D has resulted in products being biased towards the needs of large, capital-intensive farms. Several other studies reviewed also acknowledged that the global dominance of private industry within biotech R&D reduces the potential benefits for smaller and more marginalised farmers [46,70]. Newell and Mackenzie [44] study the role that international organisations such as the World TradeOrganization (WTO) and the Cartagena Protocol on Biosafety (CBP) have on how biotechnology is governed in the Global South and show how these organisations have not been able to provide a negotiation climate that secures the interests of countries in the Global

South. The authors give many examples of where wealthier states and private interests have successfully pressured developing nations to change their biosafety and patent legislations to be more in line with the interests of the stronger parties. The authors argue that this inequality in the global governing of biotechnology might lead countries in the Global South to resent GM crops as such, without sufficiently considering the potential advantages of the technology.

Only 22% of the studies on access were based on farm-level data. However, such studies often addressed the effects of private industry dominance of the biotechnology sector, IPR or trade agreements, which may be studied in relevant ways drawing on national, regional or global level data (e.g., [44,67,71–73]). Studies on access generally showed how the system in which GM crops are introduced, including the global private sector dominance, and IPR associated with GM crops in some countries, leads to limited access for certain groups of farmers or certain countries (e.g., [44,46,73]). The study by Parfitt [46] can be mentioned as one example of many pointing out the mutual shaping of private sector dominance and the IP system. This body of literature described how the way in which IPR are attached to GM crops in some jurisdictions facilitates corporate concentration in the seed industry, which in turn leads to a more limited choice of seed in the shops and high seed prices, and makes it illegal for farmers to recycle seed. Developing countries in general and small-scale farmers in particular are cited as losers in this, as the industry directs its production to capital-strong buyers, *i.e.*, large farmers in the Global North [46,55,70,74]. However, there are different ways of governing biotechnology in different jurisdictions. Parfitt [46] mentioned India as a country where the state has retained extensive protection of farmers' rights to seed. Rao and Dev [55] confirmed this, but suggest that Chinese farmers receive an even larger share of the benefits than farmers in India, as IPR are less strictly enforced in China. However, Rao and Dev [55], like Parfitt [46], pointed out that even if GM seed in India and China is comparatively cheap and accessible to smallholders, the private sector dominance of the industry has so far resulted in there being very limited attention to crops and traits suitable for smallholders and more marginal environments. Thus, many studies mentioned a need for increased public sector investment and public-private partnerships to ensure that smallholders and the poorer sections of societies can access GM crops, and that the crops and modifications are relevant to them [44,55,75]. Improving access to unbiased agricultural advice through public investment was also highlighted as essential in allowing smallholders to benefit from a GM crop like Bt cotton [55,76,77]. Such investments could also reduce the negative ecological effects of GM crops, with potential secondary social impacts (as discussed by [55,75,78]).

Studies addressing wellbeing often focused on changes in exposure to toxins, allergenicity and improved nutrition due to changed diets or improved household income. Such aspects essentially need to be studied at individual or farm level. The many mentions of wellbeing in studies without farm-level data (37/48 studies) thus either relied on the limited number of empirically-based studies available or provided a more general discussion, or merely express future hopes or concerns, about potential wellbeing effects of GM crops (e.g., [49,54,79]). Eight of the 11 bottom-up studies connected wellbeing with empirically observed or farmers' experiences of effects on health. Seven of these related their empirical results to Bt cotton. The exception was Huang *et al.* [80], studying IR rice. The results presented are contradictory, indicating that the empirical base is still too small to draw any generalisable conclusions. Six studies indicated various positive effects on wellbeing for farmers. Two of these six studies provided first-hand data relating to wellbeing: Bennett *et al.* [81] reported declining hospital visits as a result of reduced pesticide use with Bt cotton in South Africa; Qaim and Kouser [82] found a correlation between improved caloric intake and increased household incomes resulting from the introduction of Bt cotton in India. The remaining four studies reporting positive wellbeing impacts did not measure impacts directly, but relied on farmers reporting such impacts. These studies reported that farmers in Australia, India and China experience reduced health problems as a result of declining pesticide use with Bt cotton and rice [80,83–85]. In contrast, studies by Bennett *et al.* [86] and Debyani and Neeta [87] from South Africa and India reported negative health implications for farmers as a result of adoption of Bt cotton, due to increased toxic exposure and allergic reactions, respectively. Both these studies made the connection between their data and wellbeing, without measuring wellbeing impacts directly. Bennett *et al*. [86] connected pesticide exposure to health effects without measuring health effects as such, and Debyani and Neeta [87] reported that farmers have claimed allergic reactions, without independently testing whether such reactions are connected with exposure to Bt cotton. The three remaining bottom-up studies did not connect wellbeing effects with empirical observations at farm or household level. Krishna and Qaim [88] predicted potential reductions in health treatment costs resulting from reductions in insecticide exposure with adoption of Bt aubergine in India. Botta *et al.* [68] generally discussed the potential health effects of GM crops and glyphosate and also reported unconfirmed connections between ill-health and glyphosate sprayings on HT soybean in Argentina. Newell and Mackenzie [44] examined the possibility to address health concerns in the regulations surrounding GM crops.

Cultural heritage was the impact group least frequently studied in the papers reviewed. Overall, this topic appeared in 15 studies, of which only four [44,76,77,89] were based on their own data. While in part relying on farm-level data, Newell and Mackenzie [44] did not discuss cultural heritage impacts in relation to these farm-level data, leaving only three studies actually addressing cultural heritage impacts empirically. They presented results regarding the effects of adoption of GM crops on local/traditional farming systems, knowledge and crop varieties. Stone [76,77] performed an empirically detailed case study of how introduction of Bt cotton in India is accelerating the current process of agricultural de-skilling. Rapid technological change, combined with lack of unbiased agricultural advice and widespread availability of cotton seed of unclear and sometimes dubious quality, has resulted in farmers being unable to use their agricultural knowledge to choose cotton varieties suited to their farming environment. The result is loss of farmers' agricultural knowledge. Hall *et al.* [89] concluded, based on empirical evidence from Brazil, that export-orientated soybean farmers have been able to integrate illegally imported and bred HT soybean with their existing farming practices and benefit from the new technology. They speculated that the benefits would not be the same if farmers had to pay the legally binding royalties to Monsanto. Furthermore, more marginalised farmers in the country, who have not yet adopted HT soybean, were not expected to benefit due to their limited access to education and capital. Factors such as agricultural knowledge, social conditions and adaptability were reported to be relevant for determining the ability of farmers to successfully adopt GM crops and integrate them into their farming system.

It is likely that the overall empirical dominance of the Global South in the literature reviewed here affected how social impacts were addressed. Looking in more detail at four studies in the dataset with an empirical and/or theoretical focus on the Global North [85,90–92], one of these, although empirically based in Hawaii, in fact only discussed implications for adoption in the Global South [91].

Thus only three out of the 99 studies reviewed focused exclusively on empirical settings in the Global North. Clearly this makes it impossible to make statistically sound statements about whether the way in which social impacts are discussed is affected by the focus on the Global South or North. However, it can be interesting to show what these studies actually address. Andrée [90] used two biotech products (bovine growth hormone and HT wheat) in Canada to examine the interplay between civil society, state and industrial actors in shaping biotech outcomes. The conclusion was that despite its monopolistic power and significant support from the state, the biotech industry is sometimes forced to compromise its intentions significantly due to strong civil society and academic counter-powers. Russell [85] used a case study of GM cotton farming in Australia to discuss how the outcome of GM technology depends on the local social context, while Speiser *el al*. [92] made an ex-ante assessment of different economic and ecological risks and benefits of introducing a number of GM crops into Swiss agriculture. A key conclusion reached by both Speiser *et al.* [92] and Russell [85] is that the interplay between type of plant, modification and socio-ecological context results in different outcomes in terms of risk and sustainability.

3.4. The Example of Bt Cotton

More in-depth analysis of the discussion around Bt cotton, the most commonly addressed GM crop in the studies reviewed, provides some additional insights into how social impacts are currently studied and discussed. Cotton is a crop strongly affected by pests and thus IR cotton has the potential to significantly lower pesticide inputs in areas with high pesticide use and to increase yields in areas with less comprehensive spraying regimes, by reducing crop losses to pests. Higher yields and/or reduced pesticide use can then have secondary social impacts such as improved household finances, better labour conditions and health improvements. Looking specifically at studies of Bt cotton relying on own farm-level data, there were 23 such studies in the dataset [53,66,67,70,76,77,81–87,93–102]. The majority (12) were from India, followed by South Africa (5), Argentina (2), Burkina Faso (2), Mexico (1) and Australia (1) as the only country representing the Global North. (With regard to the countries represented in these studies, it should be noted that Pechlaner and Otero [70] presented data from three countries, Canada, Mexico and the USA, but Bt cotton was only mentioned for Mexico and therefore only Mexico is mentioned here. In the overall classification of studies, Ezezika *et al.* [93] was classified as not providing data from a specific country, but rather a region (sub-Saharan Africa). Thus when numbers for the whole dataset are presented, this study is included as not focusing on a specific country. However, with regard to Bt cotton, Ezezika *et al.* [93] used interviews made in Burkina Faso and is therefore counted here as providing data on Bt cotton from Burkina Faso. As in the total dataset, economic impacts were most frequently addressed (20/23 studies), followed by distributional impacts (12), wellbeing and access (7) and cultural heritage (2).

The unanimous conclusion from bottom-up studies of Bt cotton, focusing on economic impact, was that on average, it provides economic benefits for farmers. These economic benefits were described as combinations of direct and secondary impacts of raised yields and/or reduced costs for pesticides [53,77,81–84,86,87,94–98,100,102]. A commonly cited example of secondary impacts related to changes in labour demand. Some studies pointed out reductions in labour as a cost-saving effect [81,95,100,102], or as a negative effect for those previously employed for spraying [85]. Labour needs were also shown to increase in some cases. For example, Subramanian and Qaim [101] showed that increased labour needs, resulting from higher harvests with adoption of Bt cotton, were positive for women in their study due to increased employment opportunities.

Regarding impacts of access and distribution, the results are inconclusive. Subramanian and Qaim [100,101] presented results from India showing that farmers across income levels benefit from adopting Bt cotton. However, Subramanian and Qaim [100] also showed that economic benefits are greater for larger farms. On the other hand, some South African studies showed that smaller-scale farmers do not benefit less than large producers [81,96]. There were also reports from South Africa and India that smallholders obtain greater economic benefits from growing Bt cotton than farmers with more land [77,81,86]. In contrast, Arza *et al.* [66] and van Zwanenberg and Arza [67] reported negative effects on distribution with the adoption of Bt cotton, due to the co-evolution of Bt cotton in Argentina with a political and regulatory environment favouring large farms. Large, capital-intensive farms have the possibility to control larger parts of the highly industrialised cotton production chain and can therefore secure higher returns, whereas smallholders become increasingly reliant on middlemen with the introduction of Bt cotton, reducing their benefits. Pechlaner and Otero [70] describe how the Mexican economic and regulatory environment has similar negative effects for smallholders, making them particularly negative to GM crops. Russell [85] showed how Australian farmers, although largely positive to the environmental benefits of Bt cotton, have expressed concerns about the monopolistic seed industry and the risks this poses through reduced variety in supply and pricing of GM products [85]. Based on evidence from Burkina Faso, Ezesika *et al.* [93] concluded that, as women are excluded from post-harvest sales of Bt cotton, they have limited possibilities to control the benefits of increased harvests. In summary, the accumulated evidence on Bt cotton indicates that a key reason why economic distribution and access impacts on the ground vary with context is that outcomes on the ground are largely affected by different political and regulatory contexts.

Studies from Argentina and India make it relevant to question whether the economic benefits of GM crops will persist over time [66,67,76,77,84]. A key reason for this is the widespread lack of unbiased, accessible and sufficiently detailed agricultural advice in both countries, resulting in farmers not knowing how to cultivate Bt cotton in a way that ensures good yield and delays insect resistance. Stone [76] presented results from Warangal in India, where the overall income gains with Bt cotton might be undermined by the widespread lack of understanding and practical implementation of refugia amongst farmers and retailers (the main source of information on Bt cotton for farmers in the region). Refugia are parts of Bt cotton fields planted with conventional hybrids for the sake of preventing or delaying resistance to the Bt toxins in target insects. In addition to the inadequacy of available agricultural advice, in both Argentina and India uncertified Bt cotton seed of dubious quality is circulating on the market. The outcomes of this are farmers planting seed that might not perform as expected and an increased risk of insect resistance development [76,77]. In contrast, Russell [85] presented evidence from Australia, where Bt cotton has been successfully adopted as part of a wider Integrated Pest Management (IPM) strategy. This indicates the importance of introducing Bt cotton in a functional agricultural advisory context, and the potential gains if this is done.

Shankar *et al.* [99] examined the role of production risk in determining the economic impacts of Bt cotton, an aspect which they argued is rarely investigated. Studying Bt cotton production in Makathini flats, South Africa, Shankar *et al.* [99] concluded that Bt cotton performs well when agricultural conditions are good, but that there are indications that under certain, less optimal agricultural conditions, production risk increases with Bt cotton. They also concluded that risk effects with Bt cotton are complex and difficult to predict and that more investigations into production risk are needed.

As for the whole dataset, the seven empirical studies addressing wellbeing gave an overall inconclusive picture (see Section 3.3).

4. Discussion and Conclusions

The aim of this systematic review was to determine the current state of knowledge on a broad set of social impacts of GM crops, in order to contribute to a more evidence-based and less polarised dialogue on GM crops in agriculture.

Firstly, it can be concluded that very few studies take a comprehensive view of the social impacts associated with GM crops in agriculture. The literature reviewed here (99 papers) was dominated by studies of economic impact. That this trend goes beyond our review is illustrated by a recent meta-analysis published by Klümper and Qaim [8], which initially indicated that it would take a broad approach to social impact but then focused only on economic impacts (specifically impacts on crop yield, pesticide quantity, pesticide cost, total production cost and farm profits). The belief that social impacts can be measured by only addressing economic aspects has resulted in a general past trend of measuring social progress only in economic terms [103]. However, this belief has been questioned, not the least by the renowned welfare economist Amartya Sen [104,105]. The wider understanding of development and sustainability has also penetrated policy, as seen in the SAFA guidelines [26] and the new UN SDGs [25], where the social and economic dimensions of sustainable development are conceptualised as extending far beyond economic development. Thus, while there is strong support in the literature reviewed here for GM crops contributing to average economic gain across years and groups of farmers, unlike Klümper and Qaim [8] we do not agree that this finding can be directly interpreted as showing that farmers benefit from GM crops. By going beyond focusing on farm-level economics, this review showed that economic impacts for different groups of farmers are very mixed and that the political and regulatory context has significant impact on the ability of different groups of farmers in different locations to benefit. The review also showed that we still know little about the effects of different GM crops on wellbeing and cultural heritage. The results show that while wellbeing is frequently discussed in the literature, but in fact rarely studied, cultural heritage rarely appears in the reviewed literature.

The review confirmed that the existing literature focuses almost exclusively on farming in the Global South. Including the term “poverty” in the search to capture all relevant references increased the number of hits focusing on the Global South, but the need for its inclusion to capture relevant hits also indicates the dominance of the Global South in the literature. This is not surprising, as the Global South and poor farmers have dominated the discussion in research and society since the beginning of the GM crop era [106,107]. The reasons for this are unclear, but there is some evidence that the industry has helped shape the trend as part of its marketing strategy [108]. The fact that both the EU and the US have engaged politically in making countries in the Global South adopt their (restrictive *versus* liberal) approaches to GM crop policy and implementation [109] further demonstrates that this focus has a political dimension. As the social impact studies reviewed here were dominated by a focus on raising yields, another possible reason is that many countries in the Global North have long had to deal with overproduction rather than insufficient production of agricultural products. From a purely economic perspective, it might thus seem less relevant to study the Global North. However, farmers in the Global North are also struggling to make a decent and meaningful living from farming, and numerous studies confirm that farmers' struggles in the Global North concern issues similar to those in the Global South, including how to deal with powerful multinational corporations, access and ownership over seed, gendered divisions of labour *etc.* [110–113]. If and how new technology, such as GM crops, can help farmers making a living is thus an equally relevant research question in the Global North and Global South. Studies from the Global North can also provide examples comparable to the situation in the Global South. In this review, such comparisons were used to examine the importance of a supporting institutional setting in making GM crops beneficial to farmers. Introduction of Bt cotton within a regime for IPM succeeded in Australia [85], whereas in parts of India the introduction of Bt cotton without comprehensive agricultural advice reportedly perpetuated the "pesticide treadmill" [76,77].

Despite the dominant focus on farmers in the Global South, only two of the papers reviewed focused on production risks relating to GM crops (HT maize and Bt cotton in South Africa) [99,114]. Looking beyond the review, there is a large body of literature discussing different framings of risk in relation to GM crops [115–119], but we found very few additional empirical studies on farm level risk and GM crops [37,120,121], confirming the statement by Shankar *et al.* [99] about this field being unexplored. It is well known that smallholders, because of their greater socio-economic constraints and often more marginalised locations, experience higher production risks than large-scale farmers [122,123]. Thus, it is important to study production risks relating to different GM traits and crops if we are to learn more about how GM crops can be of benefit to smallholders. Drawing lessons from the introduction of new high-yielding crop varieties during the Asian Green Revolution, it is worth noting that significant poverty reduction impacts were reported only when the second generation Green Revolution crops, where the focus in plant breeding was broadened from increasing yield to creating more robust varieties, became available to farmers [124]. Indeed, two papers in the review claim that lessons must be drawn from the Green Revolution in order to make GM crops of relevance to more marginalised farmers [75,125].

In addition to adjusting breeding efforts to suit marginalised farmers, the literature also claims that the regulatory regime needs to be revised if GM crops are to be widely accessible and useful. The free sharing and recycling of crops amongst farmers that permitted the successful spread of Green Revolution crops [126] is rarely possible today due to changes in the IPR system giving private companies much more control over agriculture by allowing them to patent genes in many jurisdictions [105]. Indeed, this review showed that the current private sector control of GM crops, which is reinforced by the IPR system implemented in many countries, reduces the benefits of GM crops for poor farmers due to high seed costs and distributional constraints. Therefore, several publications state that increased government engagement is important in ensuring that poor farmers benefit [44,55,75]. In countries such as India and China, with less comprehensive implementation of IPR, more of the economic benefits of GM crops have gone to farmers. However, the literature also shows that when the GM seed market is less controlled, the quality of the seed is sometimes doubtful. It is also likely that farmers do not receive the information and advice needed to cultivate the crop correctly. Resistance development in pest insects has been confirmed for both Bt maize and Bt cotton [127,128] and may partly be the result of inappropriate management regimes. This leads us to support previous claims for the importance of resolving the conflict between sufficient regulation of GM crop use and making GM crops accessible to marginalised farmers [31].

Three key findings of this review were that:

- Economic studies present a more positive picture of the role of GM crops in socially sustainable agriculture than is warranted, looking at the broader set of social impacts.
- The way in which GM crops are governed today reinforces market dominance by private industry and particularly reduces the possibilities for GM crops to benefit poorer and more marginalised farmers.
- There is a clear lack of knowledge regarding the social impacts of GM crop introduction for farmers in the Global North.

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Author Contributions

Klara Fischer and Elisabeth Ekener-Petersen designed the web-search and did the first two rounds of article screening, removing articles not meeting search criteria based on titles and abstracts.

Klara Fischer, Elisabeth Ekener-Petersen and Karin Edwardsson-Björnberg did the third round of screening of the articles in the search, removing further articles based on reading full papers.

Klara Fischer, Elisabeth Ekener-Petersen and Karin Edwardsson-Björnberg read all articles in full, designed the classification scheme and classified the papers according to the scheme.

Lotta Rydhmer and Klara Fischer performed the quantitative analysis using the programmes SAS and SPSS.

Klara Fischer and Elisabeth Ekener-Petersen together led the writing of introduction and discussion sections. All authors contributed with comments and text.

Klara Fischer led the writing of the results section, and all authors contributed with comments and text. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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