Economic and Environmental Consequences of the ECJ Genome Editing Judgement in Agriculture

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Abstract

Genome edited crops are on the verge of being placed on the market and their agricultural and food products will thus be internationally traded soon. National regulation, however, diverges regarding the classification of genome edited crops. Major countries such as the US and Brazil do not specifically regulate genome edited crops, while in the European Union they fall under GMO legislation, according to the European Court of Justice (ECJ). As it is in some cases impossible to analytically distinguish products from genome edited plants compared to non-genome edited plants, EU importers may fear the risk of violating EU legislation. They may choose to not import anymore agricultural and food products based on crops, for which genome edited varieties are available. As a consequence, crop products, for which the EU is currently a net importer, would become more expensive in the EU and production would intensify. Furthermore, strong substitution among products covered and not covered by genome editing would occur in consumption, production and trade. We analyse the effects of such a cease of EU imports for cereals and soy on the EU agricultural sector with the comparative static agricultural sector equilibrium model CAPRI. Our results indicate that effects on agricultural and food prices as well as farm income are strong, and the intensification of EU agriculture may result in negative net environmental effects in the EU as well as increases in global greenhouse gas emissions. This suggests that the trade effects should be taken into account when developing domestic regulation for genome edited crops.

Zahlreiche genom-editierte Kulturpflanzen stehen kurz vor ihrer Marktreife und werden daher bald ihren Weg in den internationalen Agrarhandel finden. Gegenwärtig gibt es jedoch große Unterschiede in der rechtlichen Einstufung dieser Produkte. Während beispielsweise in den USA und Brasilien genom-editierte Pflanzen keiner speziellen Regulierung unterliegen, werden sie in der EU nach dem EuGH-Urteil als gentechnisch veränderte Organismen angesehen und fallen daher unter die GVO-Regulierung. Da eine entsprechende analytische Unterscheidung von genom-editierten und konventionell gezüchteten Pflanzen unter Umständen nicht möglich ist, laufen Importeure Gefahr, nicht zugelassene Produkte in die EU einzuführen. Dies könnte dazu führen, dass die Einfuhr von bestimmten landwirtschaftlichen Produkten aus Ländern zum Erliegen kommt, in denen genom-editierte Pflanzen angebaut werden. Dies hätte einen Preisanstieg für diejenigen Produkte, für welche die EU Nettoimporteur ist, zur Folge. Auch würde der Anbau in der EU selbst intensiviert werden. Zudem käme es bei Produktion, Verbrauch und Handel zu Substitutionseffekten zwischen genom-editierten und konventionell gezüchteten Produkten. Mittels des komparativ-statischen Gleichgewichtsmodells CAPRI analysieren wir die Auswirkungen eins derartigen Aussetzens der EU-Agrarimporte auf den europäischen Agrarsektor am Beispiel von Soja und Getreide. Unsere Ergebnisse zeigen starke Auswirkungen auf die Preise für landwirtschaftliche Produkte und Lebensmittel sowie auf das Betriebseinkommen. Die Intensivierung der europäischen Agrarproduktion kann darüber hinaus zu negativen Umwelteffekten führen und einem globalen Anstieg der Treibhausgasemissionen. Dies legt den Schluss nahe, dass auch Handelseffekte bei der Ausgestaltung nationaler Regelungen im Umgang mit genom-editierten Pflanzen Berücksichtigung finden sollten.

JEL: F13, C6, C63, F47

Keywords: genome editing, CRISPR/Cas, asynchrony regulatory, trade distortion, economic modelling, partial equilibrium model CAPRI, agricultural economic and environmental impact assessment
Schlüsselwörter: Genom-Editierung, CRISPR/Cas, Asynchrone Regulierung, Handelsverzerrung, ökonomische Modellierung, partielles Gleichgewichtsmodell CAPRI, agrarökonomische und ökologische Folgenabschätzung

Content

List of figures

List of tables

1 Introduction

New plant breeding techniques have been developed recently allowing for the targeted modification of DNA sequences in a site directed manner. These techniques can be subsumed under the term genome editing and comprise a set of different molecular approaches (Modrzejewski et al. 2018)[1]. Among them, CRISPR/Cas9 is the most discussed genome editing system and has received significant attention (Friedrichs et al., 2019a). Compared to conventional breeding methods as well as other genome editing approaches, CRIPR/Cas holds the advantage of being low in cost and easy to apply (Friedrichs et al., 2019b). According to Ricroch (2019), genome editing can help to achieve several breeding goals. First, genome editing can reduce the time needed to breed a new crop variety from now 7 to 25 years to 2 to 3 years. Thus, resistance to pests, diseases and chemical weed control can be achieved faster. Another target is plant resistance to abiotic stress, such as drought, cold, salinity, and water and nitrogen deficiencies. As a consequence, genome editing has the potential to support decreasing food waste and enhancing nutritional traits. Most applications of genome editing entering the market in the near future selectively mutate or modify one or more base pairs without adding foreign DNA to the genome (SDN-1) (Lusser and Davies, 2013). SDN-1-induced spontaneous repair of DNA can lead to mutations causing gene silencing, gene knockout or changes in gene activity (Friedrichs et al. 2019b). Market-oriented research has taken place in 99 different applications with 28 different plant species. Most applications have been carried out in rice[2], followed by tomato, maize, potato, wheat, soybean and rapeseed (Modrzejewski et al. 2019). The table in the annex gives an overview of the relevant crops close to being placed on the market and their characteristics (Kohl et al., 2018; Modrzejewski et al., 2019). As indicated, most of the traits are SDN-1 based.

For some time, it had been unclear, how genome edited crops would be regulated in the EU. On July 25th, 2018, the ECJ concluded that “organisms obtained by mutagenesis are GMO” (ECJ, 2018) and thus fall within the scope of Directive 2001/18/EC, including all legal obligations which arise from this directive. Unlike in most other countries with strict regulations, SDN-1 thus falls within the scope of the GMO regulatory framework. Food and feed that either consist of, contain or have been produced from GMOs must seek approval for placement on the market in the EU according to Regulation (EC) No. 1829/2003. A detailed description of the approval procedure can be found in Hartung and Schiemann (2014). According to Article 5 (3, i) of Regulation 1829/2003, “methods for detection, sampling […] and identification of the transformation event and, where applicable, for the detection and identification of the transformation event in the food and/or in foods produced from it, must also be provided with the application”. The same requirements apply to feed according to Article 17 (3i). Grohmann et al. (2019) point out that there has to be a distinction between the detection of a specific sequence alteration in the ge-

[1] Side directed nucleases (SDN), including Meganucleases (MN), Zinc-Finger Nucleases (ZFN), Transcription Activator-like Effector Nucleases (TALENs) and Clustered Regularly Interspaced Short Palindromic Repeats/ CRISPR associated protein (CRISPR/ Cas), including SDN-1, SDN-2 and SDN-3; 2: Oligonucleotide-directed mutagenesis (ODM); 3: base editing (BE).

[2] Rice is an important crop but also a model plant.

nome, and the identification of its origin, i.e., it must be clear whether it originates from spontaneous (naturally occurring), untargeted (induced by irradiation or mutagenic chemicals) or targeted mutagenesis (genome editing). While the detection of a certain sequence mediated by genome editing might be possible if the specific sequence is known, the identification of its origin might be impossible if no further information is given. Especially for commodities that normally consist of a mixture of different varieties and origins and processed food or feed, identification of origin poses a significant challenge. Regulation (EC) No. 1830/2003 demands traceability and labelling of genetically modified food and feed. Traceability should facilitate both the withdrawal of products with unforeseen adverse effects on human and animal health and the environment and enable environmental monitoring. In addition, it is essential to ensure accurate labelling and consumers' freedom of choice. All products consisting of or containing GMOs must be labelled accordingly. Admixtures of approved GMOs must also be labelled if these traces are adventitious or technically unavoidable and exceed the threshold of 0.9%.

Other countries hold different views on the regulation of genome edited products. For some, the definition of a LMO ("living modified organism") from the Cartagena Protocol on Biosafety (Art. 3, g) draws the line between GMO and non-GMO. Since SDN-1 does not introduce new genetic material into the existing genome, organisms produced by SDN-1 are not considered to fall under the definition of the protocol and thus are commonly regarded as similar to those organisms produced by conventional breeding techniques (Tsuda et al., 2019). Countries such as Argentina, Australia, Brazil, the USA and Japan have already excluded SDN 1-produced organisms from GMO regulation (Eckerstorfer, 2019; Tsuda et al., 2019, Bömeke et al., 2018). Legislative alignment would also help trade partners in international commodity trade (Braidotti, 2019). With the launch of genome edited varieties, farmers will adopt and spread this technology, particularly in non-regulated markets. This increases the probability of unapproved GMOs entering European markets. According to the zero-tolerance policy in the EU, these products must be withdrawn from the market (Roiz, 2014). Given the experience in the past with rejected shipments of GMOs, we can presume that traders will stop shipping products into the EU for which they cannot be sure that genome editing was not used in breeding. The international agricultural bulk commodity trade is dominated by four companies: Archer Daniel Midland (ADM), Bunge, Cargill, and Louis Dreyfus, accounting for about 73% of the global grain trade in 2003 (Murphy et al., 2012). In the past, trade disruptions due to regulatory asynchronicity have been reported in the case of GMOs. Kalaitzandonakes et al. (2014) define regulatory asynchronicity when a traded GMO is approved in one country but not in another country. In the case of policies of zero tolerance an importing country will reject shipments. According to Phillipson and Smyth (2016), the Syngenta-developed maize variety Agrisure VipteraTM (MIR162) was approved in the US in 2010 and commercially planted in 2011. Canada, Japan, Australia, Brazil, Mexico, New Zealand, South Korea, Russia and Taiwan approved imports of this maize. China planned to approve it but did not before 2014. Due to the presence of the MIR162 trait in US shipments, China started to reject maize imports due to its zero-tolerance policy. As a result, US exports to China dropped by 85%. In the context of this disruption in international trade, several lawsuits have been documented. Due to the lack of approval for MIR162 in China and the country's zero tolerance policy for unapproved GMOs, the trading company Bunge refused any MIR162 maize at their facilities until approval would be given. In August 2011, the breeding company, Syngenta, sued Bunge for damage due to profit losses and harm of reputation. Shortly before the approval was given in 2014, Syngenta and Bunge agreed to dismiss the litigation without paying any fees or costs to each other (Polansek, 2017). In 2014, Cargill filed a lawsuit against Syngenta for having marketed GM maize in the US, which was not yet approved for market sale in China. Shipments from Cargill were stopped at the Chinese border. A total of 1.4 Mio tonnes of maize were affected and damage costs amounted up to $90 Mio (Pearson, 2014). Again, in 2014, the major US exporter of livestock feed products, Trans Coastal Supply, sued Syngenta for its loss of more than $41 Mio because of the lack of approval of MIR162 in China (Polansek, 2014; NZZ, 2014). In 2015, Syngenta sued Cargill and ADM over losses that US farmers were said to have suffered from rejections of boatloads of MIR162 to China (Reuters, 2015). This long-lasting dispute over MIR162 shows that regulatory asynchronicity can pose a severe hurdle to international trade and may cause considerable economic damage to breeders, farmers and traders along the value chain. An economic assessment of the MIR162 case carried out by the US-American National Grain and Feed Association (NGFA) found economic losses from $1 billion up to $2.6 billion for the US value chain (Fisher, 2014). We argue that this problem is aggravated by the introduction of genome edited crops. International trade will then not only be confronted with the already existing regulatory asynchronicity but also with regulatory divergence due to different legal interpretations of the GMO definition.

For the specific case of non-detection and non-identification of origin, genome edited crops can be classified as credence goods (Consmüller et al., 2019) and might thus require a functioning identity preservation system (Eriksson et al., 2019) to enable international commodity trade. For instance, identity preserved production and marketing (IPMM) is frequently applied in the grain and oilseed industry in order to facilitate the production and delivery of a certain quality along the entire value chain (Smyth and Phillips, 2002). This concept could be transferred to the commodity trade of genome edited crops. However, as Maaß et al. (2019) have already pointed out, identity preservation causes additional costs which can only be recovered through higher market prices for specific value-added products. In general commodity trade, where different batches from different sources are usually mixed along the production chain, this concept is deemed unlikely to work economically.

With special focus to international trade, Eckerstorfer et al. (2019) discuss the option to establish an international public registry in order to accommodate divergent national policies on genome edited crops. This database should cover all biotech products which are placed on the market, including those applications which are not exempted from regulation in some but not in all countries. Every country would thus be enabled to spot respective products, if prescribed by national legislation. However, it is not clear how countries should be encouraged to voluntarily give information on products, which are not regulated within their national boundaries. Beyond that, even if a database could tackle the challenge of detection, identification issues might remain unsolved.

Given this background, the aim of this article is to analyse the economic and environmental consequences of a cease of imports into the EU for agricultural products, where genome edited varieties are close to market introduction. Based on the current research of Kohl et al., 2018 and Modrzejewski et al., 2019 (Table 5 Annex), an import cease might become relevant soon for soy products and cereals[3] , including maize. In 2017, the EU imported 85% to 95% of its domestic use of soy products[4], 23% of cereals (FAOSTAT, 2019), either for feed use or for human consumption. That would have strong market effects. In particular, the large share of soy imports for pig and poultry fattening and, to a lesser extent, for other animals will result in strong substitution processes in feed component demand. We simulate the effects of such a cease of imports with the comparative static agricultural sector equilibrium model CAPRI, which explicitly accounts for feed input and output relations but also the interaction of biofuels with feed stock markets, substitution in human demand and bilateral trade flows. In Section 2, we first introduce the economic model used to analyse the economic consequences, and Section 3 discusses the implementation of the scenario. In Section 4, we present and discuss economic and environmental results and the article concludes with Section 5.

3 Cereals is the aggregate group encompassing soft wheat, durum wheat, rye and meslin, barley, oats, maize and other cereals.

4 Depending on how the different products are weighted against each other.

2 The Economic Impact Model

We apply a comparative static partial equilibrium model for the agricultural sector, CAPRI, developed for performing policy and market impact assessments from global to regional level. The core of the model is based on the linkage of a European-focused supply module and a global partial equilibrium market module (Britz and Witzke, 2012). The supply module covers a detailed representation of production activities for the EU, Norway, the Western Balkans and Turkey. This module represents all agricultural production activities, related output generation, and input use at the regional level (NUTS2). Each model optimizes the aggregated farm income under restrictions that are related to land balances, including a land supply curve, nutrient balances and nutrient requirements of animals, and, if applicable, quotas and set-aside obligations. The decision variables include crop acreages, total land use, herd sizes, fertilizer application rates and feed mixes. The mathematical programming model defines how many kg of certain feed categories (cereals, rich protein, rich energy, feed based on dairy products, other feed) or single feed stuffs (fodder maize, grass, fodder from arable land, straw, milk for feeding) are used per animal depending on its prices. The model accounts hereby for the nutrient requirements of animals, based on requirement functions from the literature. Total feed use might be produced regionally (grass, fodder root crops, silage maize, other fodder from arable land) or bought from the market at fixed prices. These prices, however, change with each iteration of the market module. The allocation response depends primarily on nonlinear terms in the objective function that are either econometrically estimated (Jansson and Heckelei, 2011) or derived from exogenous supply elasticities. The model includes a behavioural market representation for biofuels and biofuel feed stocks (Becker et al., 2013). Biofuel markets (ethanol and biodiesel) are endogenous. Biofuel supply and feedstock demand react to biofuel and feedstock prices, and at the same time, biofuel demand and bilateral trade flows react flexibly to biofuel and fossil fuel prices. The biofuel module extends the core CAPRI system (particularly its capability to analyses market effects at a very detailed spatial and agricultural product level) with a detailed representation of global biofuel markets, covering 1st and 2nd generation production technologies, biofuel by-products, bilateral biofuel trade and a link to global fuel markets, which are important in this study as biofuel feedstock is impacted strongly by a cease of imports of soy and cereals. The global partial equilibrium market module is a spatial, non-stochastic, global multi-commodity model for approximately 50 primary and processed agricultural products, and it covers approximately 80 countries or country blocks. It is defined by a system of behavioural equations that represent agricultural supply, human and feed consumption, multilateral trade relations, feed energy and land as inputs, along with the processing industry, all of which are divided into commodity and geographical units. On the demand side, the Armington approach (Armington, 1969) assumes that products are differentiated by origin, thereby allowing simulation of bilateral trade flows and related bilateral and multilateral trade instruments, including tariff-rate quotas. This submodule delivers the output prices used in the supply module, allows for market analyses at the global, EU and national scales, and includes a welfare analysis for the agricultural sector. The supply curve of the market model representing the EU is adjusted, during each iteration, to the aggregated supply of the NUTS2 regional programming models. This is repeated until an equilibrium is found.

3 Scenarios

We develop two scenarios for the year 2030: A baseline, and a cease of imports for all countries outside the EU. The baseline may be interpreted as a projection in time covering the most likely future development of the agricultural sector under the status-quo policies and including all future changes already foreseen in the current legislation. The baseline accounts for trends in population growth, inflation, GDP growth, technological progress such as yield growth and increasing feed and fertilizer efficiency. The purpose of the baseline is to serve as a comparison point for counterfactual analysis, in our case the cease of import scenario. The cease of imports scenario uses all specifications of the baseline, and in addition is technically implemented by prohibitive tariffs for all cereal products, maize, soybeans, soy cakes and soy oil by increasing the import price by a factor of eight[5], so that the price of imported commodities becomes prohibitively high. Missing other reliable information, we consider that the UK is still part of the free trade area of the EU. Alternatively, to our formulation of a complete cease of imports, we could have allowed further imports from regions with regulations similar to the EU. Simulation tests which such a scenario specification revealed that a cease of imports solely for countries such as the US, Brazil and China triggers EU import flow shifts to origins such as Russia and Africa, which would then have a strong incentive to import from non-regulated origins and in turn export their domestic production to the EU. Such a trade shift would not reduce the risk for trading companies, as the imports from Russia and Africa will be contaminated with genome edited varieties in the medium term, due to the low standards of seed replication schemes and the natural spread of certain crops. Consequently, we applied the scenario for all countries independently of the regulatory status of genome editing.

[5] We tested different import price increases to reduce the import of cereals and soybeans, oils and cake. The factor eight reduces these imports by almost 99%.

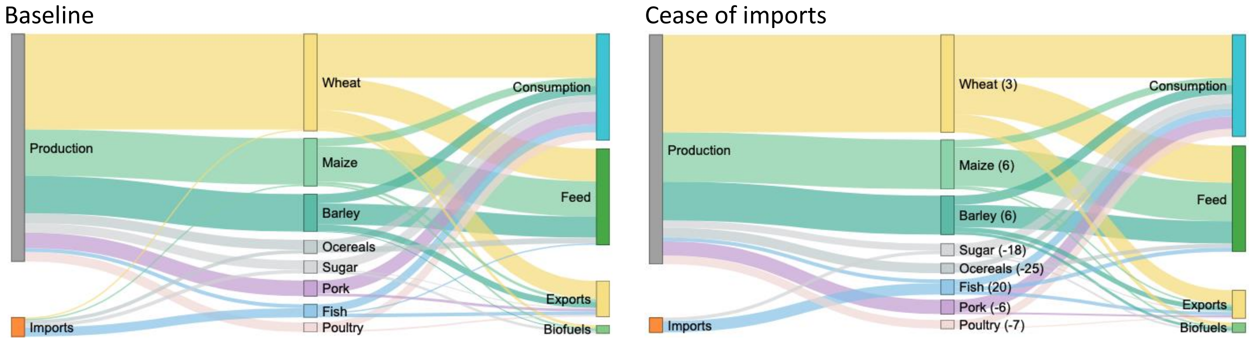
4 Results and Discussion

This section describes and discusses the effects of scenario compared to the baseline in the year 2030. In the first subsection we look at economic results. We first analyse EU market balances, finding substantially reduced imports and exports and increased domestic production for the products covered by the scenario. Second, we look at EU market prices and find that the scarcity of cereals and soy in the EU caused results in substantially increasing prices. Third, we analyse the substitution processes in feed rations, and we look at changes in the origin of trade flows. Fifth, we look at total welfare effects showing that consumers must pay a high price for a cease of imports while farmer benefit in the EU. In the second subsection (4.2), we look at land use change and environmental effects. We show that mainly permanent and temporal grassland is converted into arable land in the EU as a consequence of a cease of imports and discuss land use changes in other regions of the world. In addition, we discuss land use changes by crop and fodder type in the EU at regional level and the increase of nitrogen surplus and greenhouse gases at regional level for the EU. We conclude the environmental section by showing the effect of the scenario on total global greenhouse gas emissions by the agricultural sector.

4.1 Economic Analysis

Figure 4.1 presents the main results of the scenario. The flow charts in Figure 4.1 and Figure 4.2 de-scribes the EU. On the left the baseline and on the right the scenario (and in brackets of the scenario the percentage change to the baseline) are presented. The flow chart reads as follows: The EU production and the imports into the EU are depicted at the left and its usage (feed, human consumption (including processing) and exports) at the right-hand side. We present two product groups: “cereals, sugar & meat markets” and “oil and cake markets” to ensure readability. Each colour represents a sub-group of products. For a better representation, small values are neglected. Processing and human consumption were aggregated for all raw products in the flow charts. Absolute changes by category are presented in the corresponding Table 4.1 and Table 4.2, which present EU production and use for human consumption, feed and biofuels. Note that the values do not account for the EU intra trade. Table 4.1 and Table 4.2 report changes to the baseline in 1.000 tonnes and ordered by net production, as well as in % changes. Positive values indicate increases, negative values decrease compared to the baseline. In Figure 4.1, imports for cereals disappear in the scenario due to the cease of imports in the scenario. However, total market volume increases for wheat by 3% and for maize and barley by +6%. Additionally, EU production increases and overcompensates the decline in imports. The market volume of other cereals declines by 25%, due to the previously high share of imports not allowed anymore. Production (-23%) and imports (-6%) of sugar decline (total market volume -18%), driven by a declining use as bioethanol feedstock. Human consumption remains unchanged.

Figure 4.1: Elements of the market balance for cereals, sugar and meat markets for the EU in the baseline and a cease of import scenario in tonnes



Source: authors

As shown in Table 4.1 production in the EU increases for raw products subject to a cease of imports as well as close substitutes: These are wheat (5%), soybean (435%), followed by grain maize (95%) and barley (6%), rapeseed (2%), pulses (35%), other cereals (2%) and sunflower (3%) triggered by increasing domestic prices. In addition, poultry (-7%) and pork meet (-6%) production declines, given higher prices for feed concentrates. Together, exports are reduced in the EU for all products, except sugar. 8.4 million tonnes of wheat (+16%) additionally enters the feed stock for animals. Also, fish meal is imported and used to substitute protein from soy. The reduction of human consumption for pork and poultry meat is small (-1%). In the baseline 17% of the net production of both poultry and pork meat is exported. In the import cease scenario, most of the production decline is met by a decline in exports, so that human consumption decreases by only 1%.

Table 4.1: Absolute and percentage changes in elements of the market balance for the EU to the baseline for cereals, sugar and meat markets

	Production		Human con.		Processing		Biofuels		Feed use		Imports		Exports		Market volume*
	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	%
Wheat	7,029	5	685	1	-502	-11	1,769	41	8,407	16	-2,273	-100	-5,603	-19	3
Maize	6,783	9	231	3	-730	-13	-151	-5	6,840	12	-2,224	-100	-1,630	-39	6
Barley	3,770	6	84	1		-2	2,968	208	2,855	8	-295	-100	-2,431	-24	6
Other cereals	378	2	49	9	-2.725	-25	194	51	-2,529	-27	-5,794	-100	-404	-47	-25
Poultry meat	-1,038	-7	-168	-1		-19					53	99	-817	-31	-7
Pork meat	-1,482	-6	-285	-1	-27	-22					37	75	-1,133	-27	-6
Sugar	-3,439	-23	30		10	2	-1,088	-27	15	7	-358	-6	319	23	-18
Fish			-151	-1	-26	-12			4,384	194	4,133	28	-75	-1	20

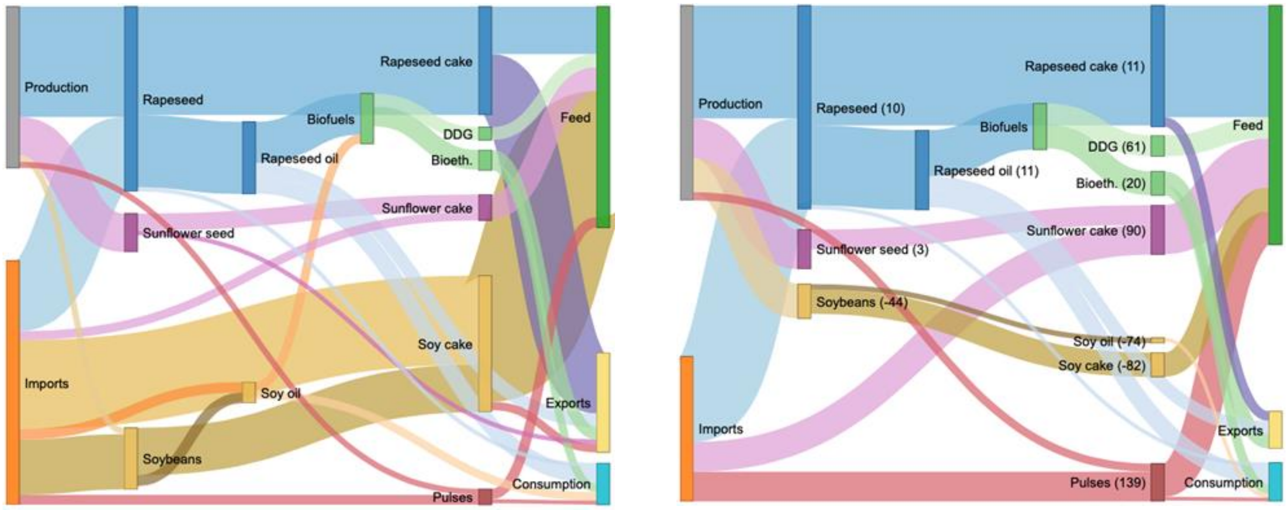
** Imports + Production*

Source: authors

Figure 4.2 shows the market balance for oil and cake markets in the EU under the baseline and the cease of import scenario. Soybean production in the EU increases by 436% to substitute the imported soybeans and soy cake. Imports of soy cake and soybeans disappear. Contrary, imports of rapeseed (21%), sunflower cake (234%) and pulses (204%) increase in order to fill the protein gap. As a consequence of missing soybean imports, processing to cake (-82%) and oil (-74%) declines in the EU. The dropped imports of soy cake for feed use (-82%), as depicted in the baseline in Figure 4.2, is substituted by increased rapeseed and sunflower cake, both being mainly imported, either as rapeseed processed in the EU to cake or directly as sunflower cake.

Figure 4.2: Elements of the market balance for oil and cake markets for the EU in the baseline and a cease of import scenario in tonnes

Baseline Cease of imports



Source: authors

Table 4.2 depicts the detailed market balance for oil and cake markets. The missing soy imports also caused a reduction in human consumption, processing and feed use. Human consumption of soy oil decreases strongly (-42%) and is substituted by sunflower seed oil (+9%), palm oil (+7%), rapeseed oil (+4%). The reduction in the availability of soy as a protein-rich feed results in increasing costs of production and hence higher market prices and hence a declining consumption of milk, cheese and beef (see Table 4.1). These declines are relatively small (-4%, -1% and -1%, respectively), as consumer prices for these products increase only modestly.

Table 4.2: Absolute and percentage changes in elements of the market balance for the EU to the baseline for oil and cake markets

	Production		Human con.		Processing		Biofuels		Feed use		Imports		Exports		Market volume*
	1,000 t abs	%	1,000 t abs	%	1, 000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	%
Soybeans	7,007	*436*	9	*5*	-6,182	*-42*			-170	*-56*	-13,667	*-100*	-317	*-87*	*-44*
Soy oil	-1,321	*-49*	-696	*-42*	-454	*-100*	-2,229	*-99*	-95	*-20*	-2,633	*-100*	-481	*-100*	*-74*
Soy cake	-5,861	*-49*	1	*1*	-440	*-100*			-25,638	*-81*	-22,318	*-100*	-2,101	*-100*	*-82*
Rapeseed	636	*2*	-43	*-4*	4,533	*10*			-53	*-10*	3,758	*21*	-42	*-13*	*10*
Rapeseed oil	1,910	*11*	132	*4*	57	*6*	1,225	*12*	581	*367*	9	*40*	-77	*-2*	*11*
Rapeseed cake	2,867	*11*	-1	*-5*	-107	*-85*			16,106	*135*	258	*176*	-12,873	*-84*	*11*
Sunflower seed	252	*3*	-4	*-1*	1,175	*16*			-42	*-8*	502	*275*	-375	*-32*	*3*
Sunflower oil	545	15	249	8	139	18	157	31	244	412	235	27	-8	-6	*18*
Sunflower cake	664	*15*	-1	*-4*					6,336	*106*	5,250	*234*	-422	*-83*	*90*
Pulses	531	*35*	-56	*-6*	-14	*-86*			5,715	*220*	4,990	*204*	-124	*-36*	*139*
Palm oil			*72*	*7*	*-18*	*-0,3*	*546*	*22*			*600*	*6*			*6*
Bio diesel	-280	-2					-160	-1			305	28	-34	-19	*0.1*
Bioethanol	1,019	*13*					182	*4*			-31	*-31*	563	*18*	*20*
DDG	2,000	*61*							2,014	*62*			-14	*-68*	*61*

**Imports + Production*

Source: authors

We find a strong interaction between animal feed and biofuel feedstock demand. Protein for fodder becomes short due to missing imports of soy. Among the substitutes are Dried Distillers Grains (DDG), which are high in protein and are a by-product of bioethanol production from cereals. The price of DDG increases as a consequence of this rise in demand and leads therefore to an increase in the use of cereals bioethanol production. The production of DDG increases by 61% to 2 million tonnes. Sugar as a feed stock is substituted by grains as it does not produce DDGs as by product and the reduced demand results in a declining production by 23% in the EU. Bioethanol production in the EU increases by 13%. At the same time, imports of bioethanol fall (-31%) and exports increase (18%). Sugar exports increase at the same time as prices in the EU (-5%) are reduced more than in the rest of the world (Table 1). Bio-diesel production declines by 2% due to the decline in soy oil imports, mainly substituted by rapeseed oil feedstock (+12%), sunflower oil (+31%) and palm oil (+22%).

The impact on the fodder ratios is shown in Table 4.3. For ruminants, rich protein fodder (including soy cake and or maize silage) is substituted by protein from grass silage and fodder from arable land (non-permanent grass). As the protein content of grass is higher than that of maize silage, maize silage is reduced. DDG and other protein cakes substitute for the category “feed rich protein”, containing a high share of soy.

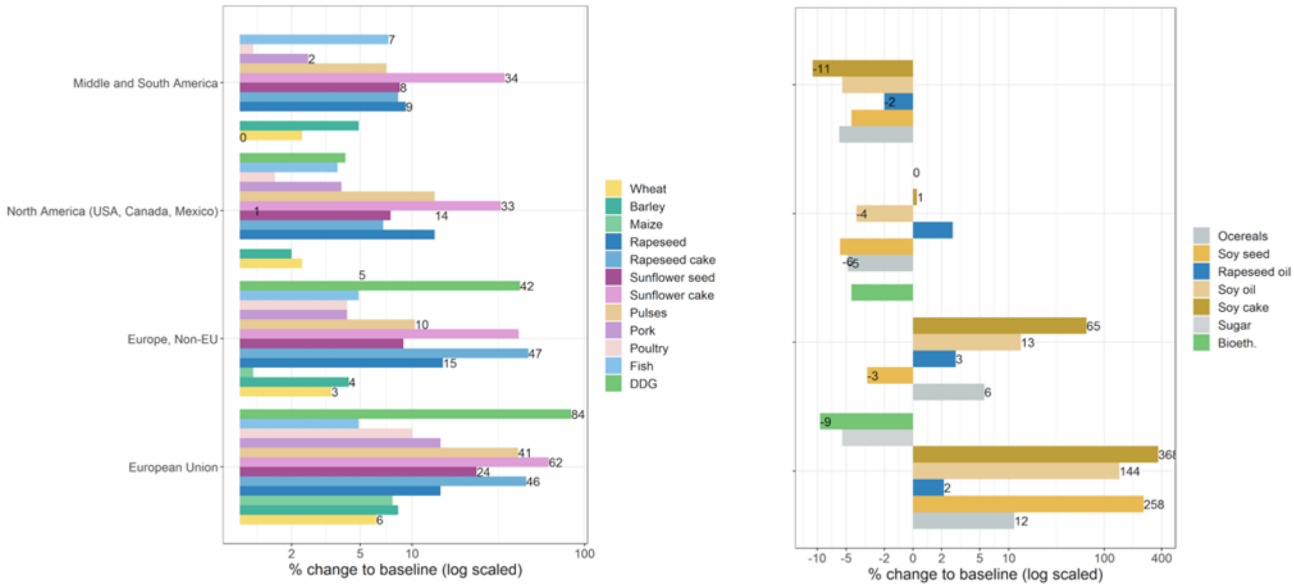
Table 4.3: Fodder ratio changes due to the cease of imports compared to the baseline

		Ruminants					Granivorous	
		for dairy production	other Cows	male adult cattle high	male adult cattle low	Sheep & Goat	Pig fattening	Poultry fattening
		kg dry matter/head						kg dry matter/ million heads
Feed cereals	baseline	753	95	985	204	11	223	5,427
	% to baseline	*6*	*-1*	*-3*	*0*	*-14*	*4*	*1*
Feed rich protein	baseline	652	165	245	210	20	75	1765
	% to baseline	*-20*	*-38*	*-31*	*-20*	*-7*	*-3*	*0*
Feed rich energy	baseline	36	31	25	10	0	14	33
	% to baseline	*-7*	*-17*	*-3*	*-4*	*-6*	*-4*	*-8*
Feed from milk product	baseline	9	3	3	2	0	2	131
	% to baseline	*3*	*4*	*2*	*3*	*2*	*3*	*2*
Feed other (like DDG)	baseline	65	22	24	16	15	4	304
	% to baseline	*4*	*13*	*5*	*6*	*3*	*7*	*6*
Gras	baseline	7881	11478	4587	3361	117		
	% to baseline	*14*	*4*	*23*	*15*	*17*		
Fodder maize	baseline	3449	1486	4153	1439	18		
	% to baseline	*-29*	*-26*	*-11*	*-22*	*-32*		
Fodder grass from arable land	baseline	3402	2055	270	184	10		
	% to baseline	*25*	*22*	*100*	*93*	*60*		

Source: authors

Under the scenario, most producer prices increase. We present price changes of more than one percent in Figure 4.3. The left-hand chart shows products, where prices increase in all regions of the world, including the EU, due to reduced exports (wheat and barley from the EU) and increased EU imports (rapeseed, sunflower seed, pulses, beef, pork and poultry) caused by the substitution of soy product. This applies mainly to wheat and barley (2 to 8%), sunflower cake (33 to 62%), sunflower seeds (6 to 24%), rapeseed (9 to 15%) and pulses (7 to 41%). Meat becomes also more expensive. Poultry meat prices increase (1 to 10%) as well as pork meat prices (4 to 15%) in all regions. The same holds for fish and for DDG.

Figure 4.3: Price developments in different geographical regions



Source: authors

The graph on the right shows products for which prices are falling in at least one geographical region. The price of other cereals increases in the EU as a result of a cease of imports. At the same time, exports of other cereals from the EU to non-EU markets decline and consequently, prices in non-EU Europe increase (6%). South, Middle and North America, which exported other cereals to the EU in the baseline realize price declines (-5 to -6%).

Strong price increases (258%) are observed for soy in the EU (+258% for seed, +144% for oil and +368% for cake). This creates an incentive to increase soy production in the EU. For Middle and South America, which exported soy in the baseline to the EU, declining prices are the consequence (-11% for cake, -5% for oil and -4% for soybeans). For soy oil and cake, prices drop also in other regions, including North America, being among the EU's main trading partners in soy products in the baseline scenario.[6] In the EU, the sugar price (-5%) and the bioethanol price (-9%) decline. This is a consequence of the high feed demand for DDG - as protein concentrate - and the by-production of bioethanol. Higher bioethanol production leads, in turn, to declining prices and also to a substitution of biodiesel to fulfil the bio-fuel mandates of the EU. For the other products, prices increase as EU demand increases for substitutes to the products covered by scenario.

In general, we find imports of non-soy oilseeds and protein crops, which are not covered by the scenario, increasing as they substitute for the former soy imports (Table 4.4). In addition, we find imports of animal products increasing, as their domestic production in the EU is getting less competitive.

[6] North America: Soybeans: -6%. Middle and South America: Soybeans: -4%, soy oil: -5%, soy cakes: -11%.

Table 4.4: Absolute and percentage changes of increased EU imports by origins

Commodities from the market model	from Europe, non-EU		from Middle East		from Africa		from North America (USA, Canada, Mexico)		from Middle and South America		from Asia		from Australia and New Zealand		total	
	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%	1,000 t abs	%
Sunflower seed	301	*270*			44	*258*	45	*275*	92	*272*	23	*502*			505	*21*
Rapeseed	497	*8*	0	*66*	1	*63*	2,850	*32*	34	*49*	210	*115*	178	*7*	3,770	*2,071*
Sunflower seed cake	2,277	*161*	11	*1,141*	48	*472*	41	*309*	2,737	*336*	168	*2,099*	3	*1,787*	5,285	*235*
Rapeseed cake	214	*150*			0	*13*			46	*2,023*					260	*177*
Pulses	719	*301*	22	*180*	196	*468*	2,765	*176*	436	*111*	824	*426*	84	*374*	5,046	*876*
Fish	312	*23*	8	*56*	148	*50*	130	*29*	1,868	*30*	1,691	*26*	17	*30*	4,174	*24*

Source: authors

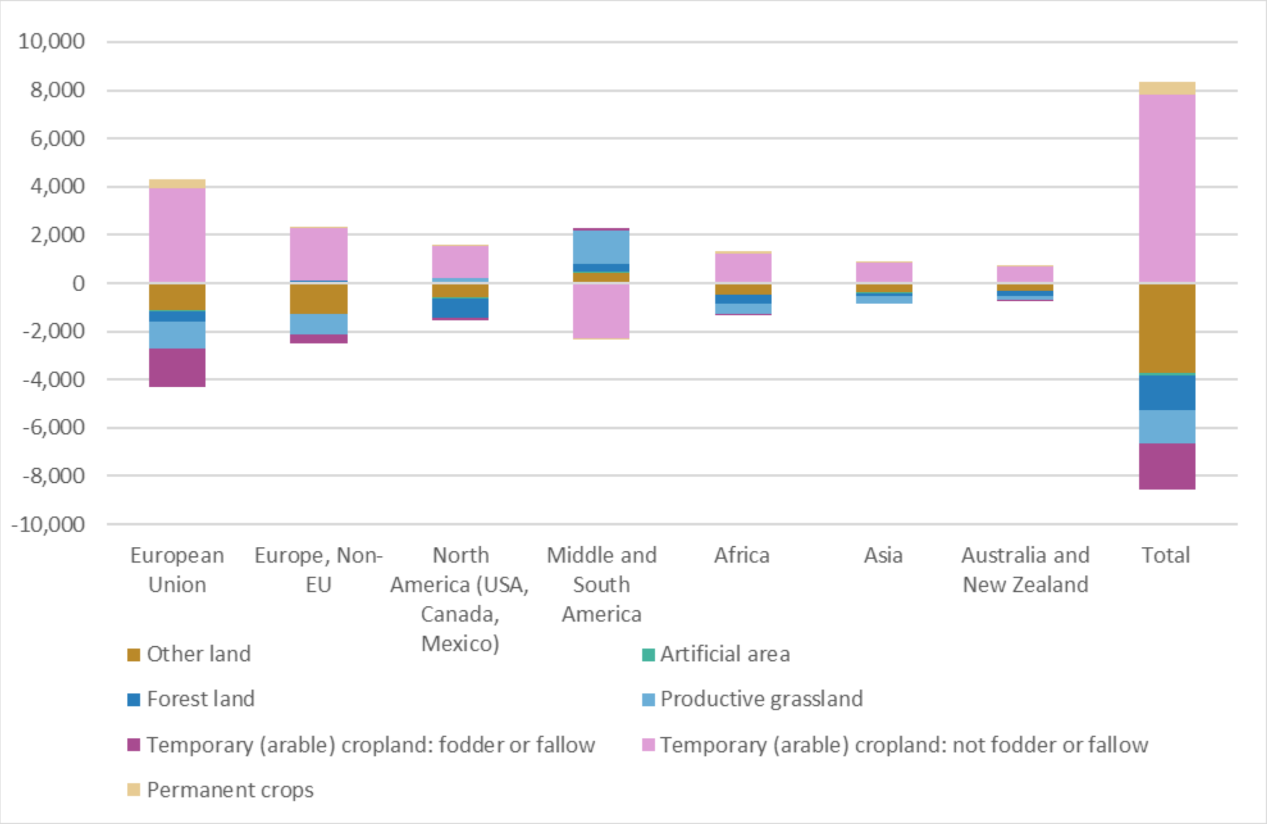
The larger the absolute quantities imported from a region into the EU, the larger the absolute reduction of imports from this region in the simulation. This is true for all the crops in Table 4.3 except for rapeseed. The increase in imports of sunflower cake mainly stems from Middle and South America and non-EU Europe, while the increase in imports of rapeseed is mainly due to an increase of the imports from North America. The increases in pulses come from North America, Asia and non-EU Europe.

The welfare analysis comprises changes in consumer and producer surplus as well as budgetary effects. Consumer welfare is measured based on the money metric concept, linked to the indirect utility function. On the producer side, gross value added (GVA) plus premiums is used as the main indicator for the renumeration of labour, capital and land in agriculture, irrespective of the ownership of these factors. Primary losses of about 27 billion € are experienced by consumers because of higher price levels. In addition, higher subsidies required in the agricultural sector of about 0.05 billion € due to increased land use. This is more than compensated by increasing tariff revenues of 0.48 billion €. Although imports are reduced for genome editing crops, tariff revenues for rapeseed and sunflower seed as well as fish and fish products increase. Finally, the farming sector benefits from higher prices and about 28 billion € are available for the payment to land, labour and capital in agriculture.

4.2 Land Use Change and Environmental Effects

Figure 4.4 looks at the balance of global land use change. It can be observed that due to higher agricultural product prices the marginal return to land increases and provides an incentive for increasing agricultural use. In the EU, 4 million hectares are converted to annual and permanent cropping. This land was formerly used in the category "forest and other land uses" (1.6 million hectares), as well as in the categories "fodder produced on cropland and fallow" and "permanent pasture and meadows". The same change in land use pattern can be observed in other regions, though to a lower extent, except for Middle and South America. Here the reduction of exports of soy products releases land, while the increased demand for beef increases the share of grassland. In addition, forest and other land is recovered.

Figure 4.4: Global land use change in 1,000 ha



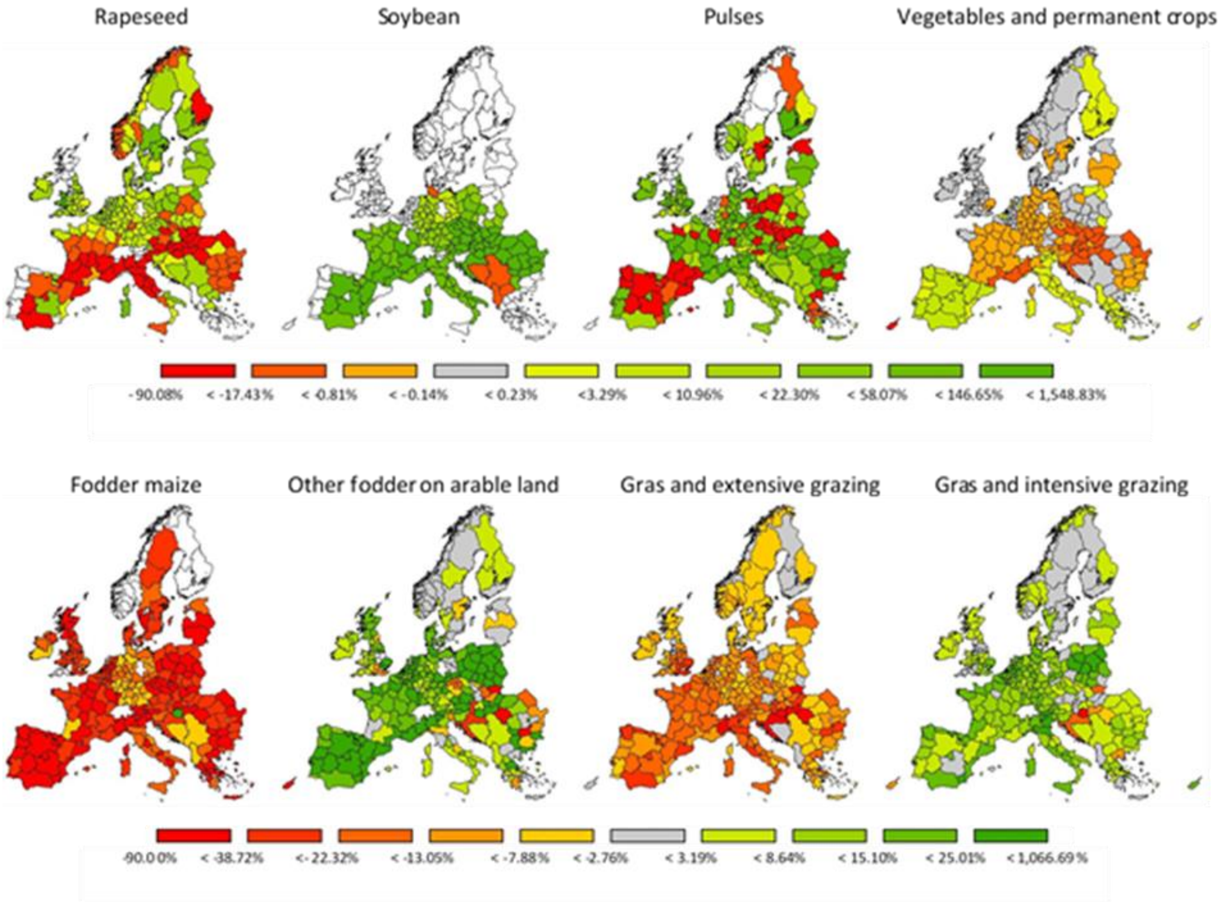
Source: authors

The distribution of land use changes across EU regions is depicted in the maps of Figure 4.5. The map shows the percentage change for the respective cropping type by NUTS2 region. The production of maize and sugar (included in other crops) declines due to substitution towards protein rich crops. The decline of extensively managed grassland and the increase of more intensively used grassland is interesting. This affects environmental goods like the provision of biodiversity in agricultural systems or nutrient emissions. The increase in crop and food prices makes it profitable to produce more intensively, e.g. with a higher use of inputs like fertilizer or change from extensive grazing on otherwise fallow land to artificial pastures. The change in intensity can also be observed for cereals, where the yields increase by 5%, for oilseeds (>0%[7]) and for other arable groups (+1%, of which: pulses +22%). An intensification in production can be seen in both the Eastern and the Western parts of the EU. Vegetable and permanent crops mainly increase in olive

[7] of which: rapeseed +1%, sunflower seed +6%, soy -7%.

production areas in Greece, Spain and Italy. The soy production increase particularly in Romania, Croatia, Hungary, Slovak Republic and Italy included in the crop group other arable crops.

Figure 4.5: Land use change by cropping type in percentage change to the baseline



Source: authors

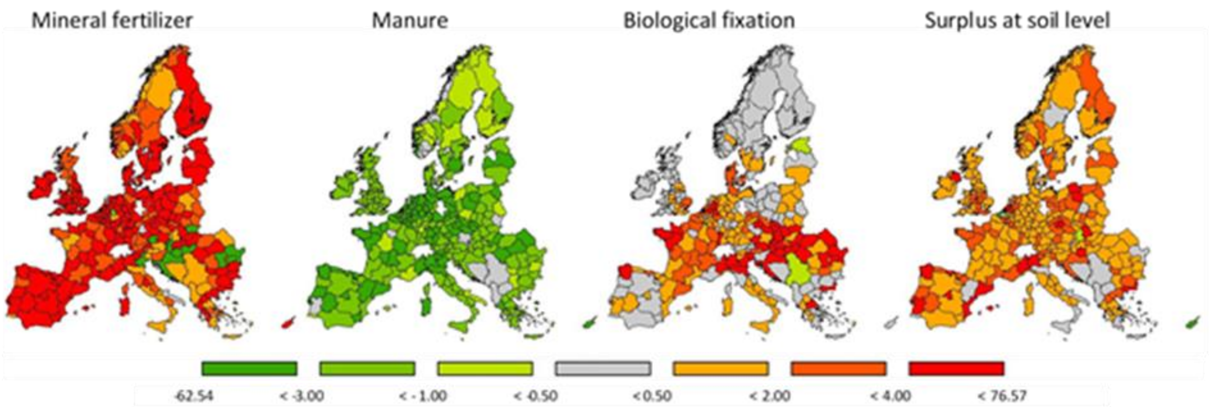
Olive oil is also a substitute for soy oil, which increase accordingly (see vegetable and permanent crops). Fodder maize is reduced and replaced by more protein rich fodder from grassland or fodder from arable land. Animal herd numbers decrease in the EU, particularly for fattening of pigs, poultry and beef. Increased product prices result in a higher production intensity. Particularly, the use of mineral fertilizer is increased (+10% in sum, +9% per ha), while the use of manure decreases (-6% both in sum and per ha). Due to the increased production of legumes, the biological fixation of nitrogen increases by 42% resp. 41% (see Table 4.5). The increase in fertilization with crop residues by 7% resp. 6% can be explained by an increased overall production in the EU. It is notable that the nutrient surplus for nitrogen at soil level increases by 5% both in total and per ha. The regional distribution is given in Figure 4.6. This may have direct implications for the quality of ground and surface waters as well as implications for biodiversity and GHG emissions.

Table 4.5: Sources and remains of nitrate used in the EU agriculture

		total (in 1,000 t)			Per ha (in kg)		
		value in baseline	abs. change	perc change	value in baseline	abs. change	perc change
source	Mineral fertilizer	11,252	1,074	10%	63	5	9%
	Manure	9,112	-503	-6%	51	-3	-6%
	Crop residues	9,801	650	7%	55	3	6%
	Biological fixation	1,614	683	42%	9	4	41%
	Atmospheric deposition	2,116	15	1%	12	0	0%
remains	Absorption by crops	22,936	1,591	7%	128	8	6%
	Gaseous loss	3,173	-62	-2%	18	-1	-3%
	Run off mineral	456	43	9%	3	0	8%
	Run off manure	447	-26	-6%	2	0	-7%
	Surplus at soil level	6,754	367	5%	38	2	5%

Source: authors

Figure 4.6: Changes in nitrate application and surplus, absolute changes in kg per ha

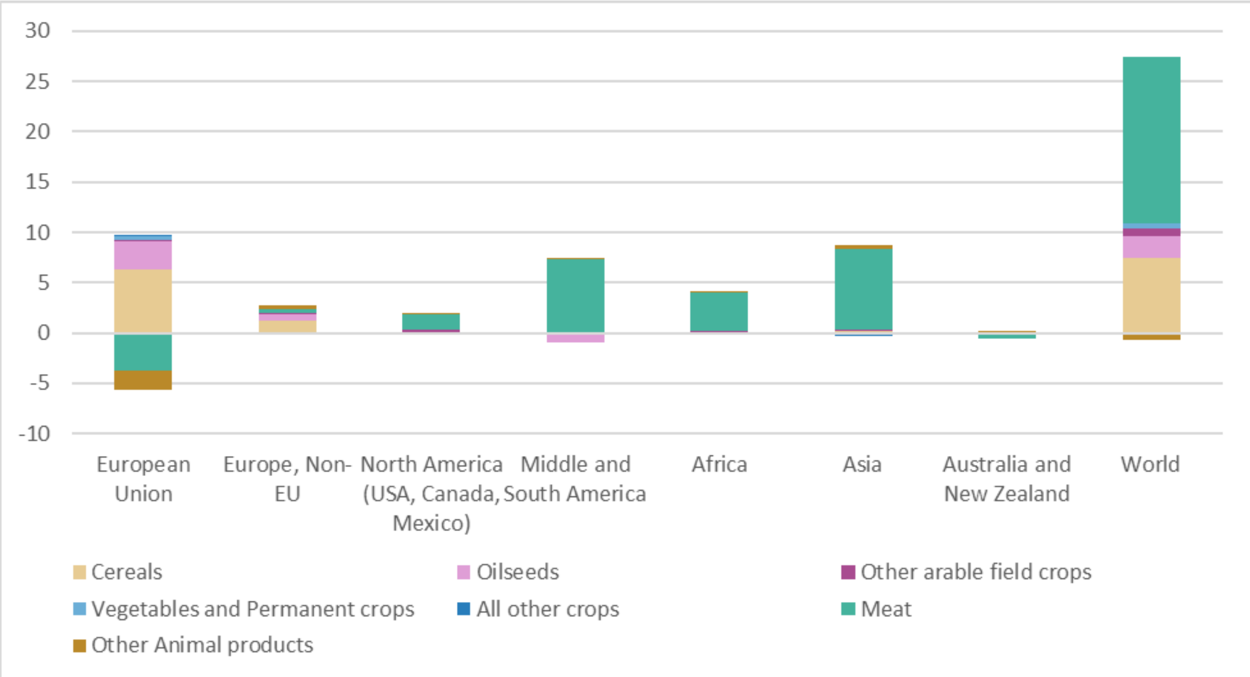


Source: authors

Greenhouse gas (GHG) emissions increase in the EU agricultural sector and in most other regions as well. In the EU this is driven by the increased and more intensive production of cereals and oil seeds, while the production of meat and other animal products decreases. Meat that has been formerly produced in the EU is still consumed there but now comes from imports. Also, less meat is exported from the EU (-25%).

Hence meat production and the associated GHG emissions increase in other regions, foremost Africa, the Americas and Asia. This accumulates to a global net increase in GHG emissions of the equivalent of 30 Mio tonnes CO_2 [8]. This is an increase by 0.5% at the global level and equals 6% of the baseline GHG emissions of EU agriculture. We see that a cease of imports of genome edited crops leads to the relocation of production to the disadvantage in terms of carbon efficiency.

Figure 4.7: Greenhouse gas emissions in millions of tonnes of CO_2-equivalents



Source: authors

While the production of one ton of soybeans is currently much more carbon efficient in South America than in the EU, the scenario results in decreasing production in the former and increasing production in the latter. The opposite is true for livestock and other animal products: Golub et al. (2012) list the carbon emission in the production of beef, pork and dairy to be among the lowest in the EU when compared internationally. Production in sub-Saharan Africa or Brazil is linked to significantly higher emissions. Hence, a substitution of domestic EU-production by imports from these regions will increase the overall average emissions per ton of product.

This study is to our knowledge the first comprehensive analysis on potential consequences of genome editing regulation in the EU. A comparison to other studies can be done for certain aspects. For example, the dependencies of the EU on soybean imports are addressed by Hörtenhuber et al. (2011), Weightman et al. (2011) and Sasu-Boakye (2014). They conclude that the utilization of protein-rich feedstuffs locally produced show clear advantages in terms of emissions. We broaden the analysis and show that higher prices resulting from reduced imports induce additional mineral fertilizer and land use changes, which in turn lead to increasing net GHG emissions.

[8] This number differs from Figure 7 as it includes some products that are not depicted in the Figure.

The effects of a cease of soybean imports from selected origins due to asynchronous approvals of GM crops are analysed by Henseler et al. (2013). The effects on agricultural markets in that analysis are less profound as substantial substitution results from imports from non-GMO origins, an effect not allowed in our analysis. The effects on global land use changes were also discussed in several other studies (e.g. Muller et al., 2017). The substitution possibilities of soybean meal and cereals in European livestock diets with bioethanol coproduct are well acknowledged (Weightman et al., 2011). With our analysis we economically quantify the degree of substitution which could take place and the relevance of the EU biofuels sector in the adjustment to a cease of imports. Not yet found in the literature is the loss of grassland, in regions where it is still possible, and the intensification of grassland due to higher agricultural prices. This has implications for biodiversity as extensively managed grassland declines as well as on other environmental dimensions (Weisser, 2017).

5 Conclusions

Genome edited crops are on the verge of being placed on the market and will thus be traded as agricultural products and embedded in processed foods on the world market. The EU classifies genome edited crops as genetically modified. Other major exporters like the US and Brazil do not regulate genome editing. As any shipment can be contaminated with genome edited goods, we argue that this provokes high economic risk to traders and that they will avoid importing to regulated markets like the EU. We acknowledge that small modifications are difficult to detect, but assume that approaches exist, e.g. documentation of specific trade flows from non-regulated markets to the EU carried out for example by NGOs opposing GMO, proving that certain shipments are contaminated. Therefore, a de facto complete cease of imports may result. We analyse the effect of a cease of EU imports for cereals and soy products with the comparative static partial equilibrium model CAPRI.

This section draws conclusions regarding first, the impact of a cease of imports for cereals and soy products on the EU agricultural sector, second, the potential and limitations of our analysis, and finally the implications for the regulation of genome editing.

Considering the effects of the scenario, we find that to replace protein and oil originally imported via soy for feed (for pig, poultry fattening and ruminants) and for oil (for bio-diesel production), the markets adjust by i) increasing EU production of pulses and soy, ii) increasing imports of substitutes, iii) substituting feed protein by increasing the intensity of EU grassland use and iv) a shift from biodiesel to bioethanol, as DDGs is a rich protein by-product. This triggers a conversion of grassland and an utilisation of non-agricultural land to crop land. Crop land is then used to increase the feed stock for bio-ethanol production, mainly cereals. The very strong price reactions reflect the strong dependence of the EU on soy product imports. As further consequences, increasing beef and sheep meat imports compensate for the reduction of poultry and pork meet production in the EU and palm oil imports increase to serve as a feedstock for EU biodiesel. EU exports are reduced for products which i) are not imported anymore (or for which soy or cereals is an input) and ii) which substitute soy products, e.g. rapeseed and sunflower seed. Particularly the strong increase in demand for rapeseed and sunflower seed invokes land use changes towards more crop land in other countries, except for Brazil where crop land is converted back to grassland induced by higher beef prices.

Particularly the intensification of agriculture (higher use of fertilizer) and the additional land use for agriculture result in higher nutrient surpluses in the EU per hectare as well as in total, although white meat production in the EU declines and hence the production of manure. Global greenhouse gas emissions increase, as protein productivity in the EU and animal productivity outside the EU is comparatively low and hence the new distribution of production is less efficient not only in terms of production cost, but also regarding GHG emissions. Overall the effects on markets as well as GHG emissions are large, and net effects are negative and agricultural prices increase in many regions of the world.

When analysing the economic and environmental impacts of the scenario, we need to acknowledge the limitations of our analysis. We did not consider genome edited animal products, other crops than cereals or soybeans or any further processed goods, all of which having the potential to contribute to even stronger effects than depicted in our analysis. Missing reliable information on specific properties of genome edited plants, we could not account for any productivity effect in non-regulated markets, e.g. resulting from pest resistance, higher yields or higher quality. Such effects would increase the competitiveness outside and increase relative production costs inside the EU. With respect to the model approach: As the market module uses the Armington approach and the supply model uses positive mathematical programming the so-called “small share problem” arises on the market and the supply side of the simulation. If the share of imports or supply is small in the baseline, the import or the supply will stay relatively small, even if major price changes occur. It is therefore possible that we overestimated the price effect. The problem of small shares and approaches to overcome this shortcoming are discussed for example in Kuiper and van Tongeren (2006). Furthermore, it should be mentioned that the income effect in this study are probably unequally distributed in the farming population, particular between cash crop and animal intensive farms. A quantification would require models operating at farm group scale such as proposed by Gocht et al. (2013).

To wrap up, countries are divided world-wide in their policies on genome edited crops, especially with regards to SDN-1, where no foreign DNA is introduced into the genome. Some main exporting countries of agricultural commodities do not regulate SDN-1, while others like the EU, do. Since at the moment, the link between a mutation and a certain breeding technique cannot be established, uncertainties for traders as well as regulatory agencies will arise. Currently, there is no way to combine the imports of crops or crop products for which genome edited varieties exist with the implementation of the verdict of the ECJ because compliance with GMO legislation can simply not be enforced due to identification problems. Accidental imports are likely to occur and will undermine the legislation in place (Wasmer, 2019). One could argue, that if no method for identification exists imports will flow into the EU without being recognized. We anticipate, however, that interested stakeholders will find a way to prove that genome edited crops enter the EU illegally. This will prevent traders from shipping from non-regulated markets. This has implications for the regulation of genome edited crops in the future. The EU Council, being beware of the potential economic consequences of current EU regulation, requested the Commission to submit an investigation until April 2021 in the light of the Court's judgment and, if necessary, to make a proposal for a new regulation. With this study we contribute to the assessment and point to the resulting market implications, the potential effects on GHG emissions and environmental aspects as well as the effects on land use in South America and income increases in the agricultural sector world-wide. Given the current initiative of the EU Council, we doubt that the EU’s timeline for finding a solution is sufficient to prevent a scenario as outlined in this paper. The scenario shows that as a result of asynchronous and divergent national legislations on genome edited crops, especially with regards to SDN-1, significant changes in the EU agricultural sector are likely to occur. Against the background of a) the challenge of non-identification, b) significant environmental as well as economic effects and supposed that the genome-edited products are safe it seems worthwhile to reconsider the current European regulatory framework. Recently, different options to either amend, supplement or replace Directive 2001/18/EC have been discussed (Wasmer, 2019). Generally spoken, any reform of the EU legislation on GMO should aim at being consistent with scientific principles, striving towards international coherence and also allow for agricultural innovation, such as genome editing (Eriksson et al., 2020).

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Annex

Table A1: Genome edited plants close to market launch

No.	Plant	Trait/Specification	Technological specification	Developer, producer, country	Probably traded as…
1	Potato	Product quality, non browning	TALENs SDN1	Calyxt, USA	IP
2	Potato	Product quality, reduced black spottiness	TALENs SDN1	Simplot Plant Science, USA (vermutlich jetzt Calyxt)	n.a.
3	Maize	Product quality, waxy corn	CRISPR/Cas9 SDN1	Du Pont Pioneer, USA in Koop. China	IP – grown under contract Might occur in processed products
4	Maize	Product quality, higher starch levels	Meganuklease SDN1	Agrivida, USA	IP
5	Maize	Product quality, reduced phytate production + herbicide tolerance	ZFN SDN3	DowAgroScience, USA	IP
6	Maize	Fungal resistance, Northern Leaf Blight (NLB)	CRISPR/Cas9 (Cisgenesis) SDN3	Du Pont Pioneer, USA	Commodity
7	Maize	Increased yield, increased photosynthesis efficiency	Meganuklease SDN3	Benson Hill Biosystems, USA	Commodity
8	Mushroom	Product quality, non-browning	CRISPR/Cas9 SDN1	Penn State University, USA	IP
9	Wheat	Product quality, increased nutritional value	TALENs SDN1	Calyxt, USA	IP
10	Wheat	Fungal resistance, resistance to powdery mildew	CRISPR/Cas9 TALENs SDN1	u.a. Calyxt, USA	Commodity
11	Soybean	Abiotic stress, drought and salt tolerance	CRISPR/Cas9 SDN1	USDA-ARS, USA	Commodity
12	Soybean	Product quality, high oleic content, low linoleic content	TALENs SDN1	Cellectis Plant Science, USA	IP
13	Rice	Fungal resistance, resistance to powdery mildew	TALENs SDN1	Iowa State University, USA	Commodity
14	Tomato	Growth characteristics, easy separation of fruit from stem	CRISPR/Cas9 SDN1	University of Florida, USA	n.a
15	Pennycress	Product quality, altered oil composition	CRISPR/Cas9 SDN1	Illinois State University, USA	n.a.
16	Tobacco	Product quality, reduced nicotine content	Meganuklease SDN1	North Carolina State University	n.a.
17	Rapeseed	Herbicide tolerance	ODM	Cibus, Kanada; USA	Commodity

Source: Kohl et al., 2018; Modrzejewski et al., 2019

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