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The economic, social and environmental value of plant breeding in the European Union

An ex post evaluation and ex ante assessment

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Content

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List of abbreviations

AWU	–	Annual Working Unit(s)
BCFN	–	Barilla Center for Food and Nutrition
BDP	–	Bund Deutscher Pflanzenzüchter
BLE	–	Bundesanstalt für Landwirtschaft und Ernährung
BSPB	–	British Society of Plant Breeders
CBD	–	Convention on Biological Diversity
CIS	–	Commonwealth of Independent States
DG Agri	–	Directorate-General for Agriculture and Rural Development
EC	–	European Commission
ETP	–	European Technology Platform 'Plants for the Future'
EU	–	European Union
FADN	–	Farm Accountancy Data Network
FAO	–	Food and Agriculture Organization
FNVA	–	Farm Net Value Added
GDP	–	Gross Domestic Product
GEF-BIO	–	Global Environment Facility Benefits Index of Biodiversity
GHG	–	Greenhouse Gases
GIPB	–	Global Partnership Initiative for Plant Breeding Capacity Building
HLPE	–	High Level Panel of Experts on Food Security and Nutrition
IMF	–	International Monetary Fund
KTBL	–	Kuratorium für Technik und Bauwesen in der Landwirtschaft
MENA	–	Middle East/North Africa
NBI	–	National Biodiversity Index
OBT	–	Observaçao da Terra
OECD	–	Organization for Economic Cooperation and Development
TFP	–	Total Factor Productivity
UBA	–	Umweltbundesamt
UNEP	–	United Nations Environment Programme
UNESCO	–	United Nations Educational, Scientific and Cultural Organization
UNSD	–	United Nations Statistics Division
USDA	–	United States Department of Agriculture
WRI	–	World Resources Institute

Executive summary

This study aims at providing science-based but well-understandable quantitative and qualitative information on the numerous benefits plant breeding is offering to societies. More particularly, this research is meant to make the socio-economic and environmental value of plant breeding in the EU and for a rather broad variety of crops quantifiable and, thus, apparent.

Based on the application of sophisticated modelling and calculation tools as well as on a rather comprehensive assessment of plant breeding contributions to land productivity and overall productivity enhancement in EU arable farming, it turns out that plant breeding innovations count a lot: On average and across all major arable crops cultivated in the EU, plant breeding contributes approximately 74 percent to overall productivity growth equal to an increase of yields by 1.24 percent per annum.

Based on this productivity growth, plant breeding activities towards major arable crops in the EU in the last 15 years (chapter 4.1 and chapter 4.2) resulted in numerous benefits for the economy and environment as well as the society at large. With plant breeding for major arable crops in the EU in the last 15 years yields per ha have considerably increased. On average, yields and consequently production of arable crops in the EU would be more than 16 percent lower without genetic crop improvements.

Higher yields per unit of arable land increase the supply of primary agricultural products on international markets. An additional 47 million tons of grains and 7 million tons of oilseeds can currently be produced in the EU with plant breeding for these crops in the last 15 years. This contributes to stabilising markets, reducing price volatility, and increasing potential world food supply.

Indeed, plant breeding in the EU is also indispensable for combating hunger and malnutrition and improves the world food security situation. Genetic crop improvements in the EU in the last 15 years assure the additional availability of carbohydrates, proteins and vegetable oils to feed between 100 and 200 million humans.

Plant breeding in the EU additionally generates economic prosperity by increasing the GDP. The entire agricultural value chain benefits from input suppliers to final consumers. Genetic crop improvements in EU arable farming since the turn of the millennium have generated in the agricultural sector alone an additional social welfare gain of almost EUR 9 billion and have added more than EUR 14 billion to the EU's GDP.

Breeding for yields in arable farming in the EU also secures employment and increases the income of farmers and agricultural employees. Approximately 7 000 EUR on average, i.e. 30 percent of the annual income of an arable farmer in the EU, have been induced by plant breeding in the last 15 years. Moreover, almost 70 000 jobs have been created in the arable sector as well as upstream and downstream the agricultural value chain in the EU.

However, plant breeding in the EU not only brings about positive economic and social effects, but it also generates substantial environmental effects. It helps save scarce land resources around the globe by generating higher yields per unit of area. This improves the EU agricultural trade balance. Without plant breeding in the last 15 years, the EU would have become a net importer in all major arable crops. Thus, plant breeding minimises the net virtual land imports of the EU, which currently amount to more than 17 million ha. In the absence of plant breeding for major arable crops in the EU in the last 15 years the global agricultural acreage would have to be expanded by more than 19 million ha.

This contributes to preserving natural habitats and to reducing GHG emissions resulting from an expansion of the global acreage. Plant breeding in the EU secures less CO_2 being emitted by helping avoid negative land use change. A total of about 3.4 billion tons of direct CO_2 emissions have been avoided by genetic improvements in major arable crops in the EU in the last 15 years. In addition, plant breeding in the EU generates a large positive biodiversity effect.

Without genetic crop improvements in the EU in the last 15 years, global biodiversity equivalent to 6.6 million ha of Brazilian rainforest or 9.4 million ha of Indonesian rainforest would have been lost. Plant breeding in the EU for major arable crops in the last 15 years has finally contributed to saving scarce water resources around the globe. Without plant breeding 55 million m^3 of water would be additionally needed.

Considering other than major arable crops, i.e. some selected fruits and vegetables as well as temporary forage crops on the one hand and other breeding objectives than breeding for yield on the other hand, even more benefits and values of EU plant breeding can be identified. The specific research findings portray genetic crop improvements offering more than a substantial contribution towards the availability of food and other agricultural raw materials per se, namely an entire tool-kit for meeting many, if not most, of the important global challenges agriculture is facing.

Looking ahead, the perspective changes only a bit. Most of the indicators which have been analysed with respect to plant breeding for major arable crops in the EU in the last 15 years show an even higher or rather stable value if applied to plant breeding in the upcoming 15 years, i.e. until 2030. This allows to summarise that successfully innovated genetic crop improvements in the EU have been and will be essential for economic, social and environmental benefits at large scale and should indeed be considered a highly effective measure for adapting to new and very dynamic settings.

Plant breeders in the EU, however, face a rather challenging policy and regulatory framework. They have to be encouraged to further and even more invest into new seed varieties and sophisticated breeding technologies instead of being hindered to spend the necessary resources. The obviously high societal rates of return plant breeding investments generate have to be broader acknowledged and politically supported through proper administration, sound legislation, higher financial support, or overall awareness raising.

The results of this study should help better inform and facilitate an unbiased public debate on the importance of historic, current and future genetic crop improvements for specific socio-economic and environmental objectives. As such, the study should be considered an initial. Further research has to follow. Analysing the various values and benefits from a more holistic point of view, e.g., would certainly help to identify additional promising measures targeted at desperately needed future productivity growth in EU and global agriculture.

1 Introductory remarks

Agriculture faces various challenges and change processes such as population growth, changing dietary habits (especially in emerging economies), globalisation of transport and communication (bringing about as well the transfer of regionally unwanted flora and fauna), climate change mitigation and adaptation (including changing patterns of heat, cold and precipitation), an increasing scarcity of fertile land and other natural resources, etc. (see e.g. Borlaug et al., 2010; Fan et al., 2011; USDA, 2015b). Having this dynamic perspective in mind, plant breeding as a science and business of developing and commercialising targeted new crop varieties is considered essential for successfully meeting the challenges ahead (BSPD, 2013) and as a major driver of agricultural productivity growth both in the European Union (EU) and on a global scale (Meyer et al., 2013; USDA, 2015b; for a definition of plant breeding, see additionally Acquaah, 2012; GIPB, 2010).

The associated benefits of plant breeding along with other productivity enhancing technologies and inputs are obvious. Increasing yields and agricultural productivity offer higher harvests, better income opportunities for farmers, more food and other agricultural raw materials for consumers at reasonable prices, the protection of natural resources and the broader environment, etc. Scientific research, public opinion and policy-makers have argued likewise (see e.g. Acquaah, 2012; Björnstadt, 2014; BSPB, 2013c; Evenson and Golin, 2003; Noleppa and Cartsburg, 2015a; b; Noleppa et al., 2013; Paulsen, 2014; USDA, 2015b). Science, however, has missed so far to comprehensively quantify the actual benefits genetic crop improvement undeniably offers.

Making the value of plant breeding clearly visible to the broader public and the society as a whole is certainly necessary since plant breeders do not only have to meet important objectives, but do face a challenging environment in terms of politics and regulations. Recent debates on the enforcement of the so-called Nagoya Protocol and its implementing EU Regulation no. 511/2014 point at additional administrative burdens that may jeopardise the free access to genetic resources for further breeding efforts (BDP, 2015b; Dieckhoff, 2015). Reluctance to invest into research in the field of new and better crop varieties may increase due to related uncertainties and actual costs. This might result in a decelerated breeding progress, especially as many EU plant breeders are small and medium-sized enterprises that may not be able to bear the costs for the necessary resources without severe adjustments.

Based on this background information the study aims at providing science-based but well-understandable quantitative and qualitative information on the numerous benefits plant breeding is offering to societies. More particularly, this research is meant to make the socio-economic and environmental value of plant breeding in the EU and for a rather broad variety of crops quantifiable and, thus, apparent.

The overall working hypothesis of this academic exercise states that modern plant breeding in the EU (and elsewhere) acts at:

a) increasing social welfare by generating additional income to farmers as well as in upstream and downstream industries related to the agricultural value chain,

b) providing a greater quantity of less expensive food to meet the rapidly growing needs of the world,

c) stabilising agricultural commodity markets,

d) adding jobs and social value to rural areas of the EU,

e) preserving valuable and scarce natural resources such as habitats and water reservoirs,

f) reducing greenhouse gas (GHG) emissions resulting from a decreased expansion of the global agricultural acreage, and

g) protecting biodiversity around the globe.

This rather complex hypothesis is tested by applying the following organisational concept of comprehensive assessment. The introductory remarks (chapter 1) are succeeded by highlighting important aspects of the methodologies applied and data used (chapter 2). Based on the explanation of prerequisites for a sound analysis, yield and productivity developments in European farming have to be determined and the relative importance of plant breeding for overall productivity growth in EU crop production has to be analysed and quantified (chapter 3). An *ex post* evaluation of the various values EU plant breeding in past 15 years has offered to farmers, the society and the environment follows (chapter 4). Looking not only back but also ahead, the potential benefits of future plant breeding activities (until 2030) are additionally discussed using an ex ante assessment approach (chapter 5). The report is completed with conclusions of the research and recommendations for decision-makers (chapter 6). In addition, various annexes are provided accumulating more valuable information and details of the research on very specific aspects of the entire analysis.

2 Methodological and data considerations

This study aims at providing quantitative data and additional qualitative arguments in favour of the benefits of plant breeding efforts carried out in the EU. Such benefits are considered to be numerous and related to various economic, social and environmental aspects. There is definitely neither a "one-fits-all"-methodology nor an accompanying data base available to satisfy this broad spectrum of particular analytical needs. Hence, a complex set of methodological tools has to be applied.

The operational concept chosen for this study basically consists of a standard market modelling approach for economic analysis and is accomplished by satellite models for proper social and environmental analysis. The most important features of these two different but interlinked methodological approaches including supplemented data requirements of these models are briefly described below.

2.1 Analysing elementary economic effects with a market equilibrium approach

A partial equilibrium market model allows to quantify supply, demand and trade effects of plant breeding in the EU for a variety of crops. Such an equilibrium model can be a powerful analytical tool in terms of country and market coverage as well as applicable target indicators – if properly applied. It can also be considered a resource-saving method and is, thus, frequently applied in agricultural economics (see e.g. Nelson et al., 2014; OECD and FAO, 2015; Renwick et al., 2013; Schwarz et al., 2011; Vannuccini, 2009).

The specific partial equilibrium model used here covers the major arable crops grown in the EU and has already been described in detail in Noleppa and Hahn (2013) as well as in Noleppa et al. (2013). Therefore, there is no need to repeat the entire model syntax and structure. However, a few modifications had to be made for this particular analysis in order to fit the model to the specific research questions. Major amendments and recent data inputs are as follows:

- The regional focus of the model is now attributed to the EU-28, i.e. it includes Croatia. The EU-28 is modelled as one single region consisting of five sub-regions. Agricultural supply (production) and demand (consumption) of the EU interact with other regions of the world to determine a market equilibrium.
- The five sub-regions of the applied EU model are mainly defined to analyse and determine plant breeding impacts on agricultural productivity in a more detailed way than it would be possible for the EU in general. These sub-

regions are described as (1) the “Mediterranean region” (Spain, Italy, Greece, Cyprus, and Malta), (2) the “Atlantic region” (Ireland, United Kingdom, the Netherlands, Belgium, Luxembourg, France, and Portugal), (3) the “Baltic region” (Sweden, Finland, Estonia, Latvia, Lithuania, and Denmark), (4) the “Central region” (Poland, Germany, Austria, Czech Republic, and Slovakia), and (5) the “South-East region” (Bulgaria, Romania, Hungary, Slovenia, and Croatia).

- The market coverage of the model is specified by a total of nine key arable crops (respectively groups of crops) grown in the EU, namely wheat, corn, other cereals, oilseed rape, sunflower seeds, other oilseeds, sugar beets, potatoes, and pulses. According to data of FAO (2015b; c) nearly 70 million ha of EU agricultural land are covered with these nine key arable crops. This accumulates to almost three quarters of the currently farmed arable land in the EU (see also Cole and Cole, 2013; Meyer et al., 2013). Thereby, each arable crop is considered to be homogenous in terms of its (average) quality; i.e. quality aspects such as the protein content of cereals potentially leading to food, feed or other uses are not distinguished in the following.
- The entire model has been calibrated based on most recent statistical information. In particular data of DG Agri (2014), Eurostat (2015b), FAO (2015a; c), and OECD and FAO (2015) have been used to determine market supply and demand quantities and the relevant market prices. It has been structured for the average of the years 2012-2014. This three-year average was used as calibration input in order to minimise the risk of random shocks (such as weather extremes) and to make sure that ad-hoc policy decisions (such as temporary trade restrictions) do not affect the results of the analysis.

This modelling approach allows to calculate the status quo of various target indicators of the analysis and their changes (due to genetic crop improvements in the EU) and comprises the volumes per market (crop) supplied, demanded and traded, the market prices, and additional social welfare indicators – i.e. producer surplus (or farmer income), consumer surplus (or purchaser savings), and monetary value added to society at market level.

The briefly described partial equilibrium market model is to some extent limited as it does not cover other than major arable crops and crops that are (usually) considered non-tradeable goods. However, plant breeding also targets other than key arable crops, for example fruits and vegetables as well as green fodder crops (maize, grasses, etc.). In order to include such crops (markets) in the analysis another type of an equilibrium model had to be applied – a set of single market models.

Single market models can be generated and developed by using a comparable data background and are able to provide almost similar indicator information as a partial equilibrium market model (see e.g. Noleppa and Cartsburg, 2014b). Applying single market models additionally allows for comparing and approximately aggregating the various (partial and single) model results to be calculated in this study.

Single market models were mainly developed for field and greenhouse tomatoes, strawberries, green maize, and temporary grasses. Including green fodder plants into the analysis of plant breeding effects allows to cover almost the entire arable land of the EU. Necessary input data and additional information were obtained from the same sources used to calibrate the partial equilibrium model and additional quotations (to be specified during the discussion of the various case studies below).

2.2 Determining other socio-economic effects with welfare and multiplier tools

The study does not only aim at analysing economic impacts of plant breeding on the agricultural market level, but also at assessing its benefits for the rural sector and the entire economy in the EU. This is attributed to farm input suppliers as well as downstream food and other industries depending on farmers' decisions. Changes of agricultural markets (e.g. variations in crop yields or in agricultural productivity) reflect more or less immediately in interlinked upstream and downstream sectors of an economy. Against this background, gross domestic product (GDP) effects (as an indicator for national income changes) and job effects (as an indicator for employment changes) are of particular interest.

Multiplier analyses permit the assessment of such effects. Multipliers are parameters which reflect the transmission of a particular sector change into an economy-wide change and have often been applied in agricultural economic analysis (see e.g. Breisinger et al., 2010; Mattas et al., 2009; Schwarz, 2010). Focussing on multipliers in rural areas of EU member states allows to analyse rural income and rural employment effects of productive (respectively plant breeding-driven) agriculture in the EU.

The analysis in this study uses an update of an earlier work on agricultural multipliers of the EU by Noleppa and Hahn (2013). The authors analysed more than 20 mainly peer-reviewed academic articles determining agricultural multipliers in terms of (rural) GDP and (rural) jobs in the EU and individual EU member states. Consequently, multipliers visualised in figure 2.1 and also depicted in Noleppa et al. (2013) will be used in this analysis.

Figure 2.1: Range of agricultural multipliers of the European Union used in this study

	Identified range of multipliers (from … to …)	'Average' multiplier used for own analysis
GDP multiplier(s)	1.50 – 1.90	1.70
Job multiplier(s)	1.10 – 1.40	1.25

Source: Own figure based on Noleppa and Hahn (2013) as well as Noleppa et al. (2013).

Thus, it is argued that EUR 1.00 created in EU agriculture due to an innovation in plant breeding creates an additional EUR 0.70 elsewhere in the rural economy of the EU. Likewise, one job – measured in annual working units (AWU) of approximately 1 800 working hours per year (Noleppa et al., 2013) – created in EU agriculture establishes an additional quarter of a job upstream or downstream the value chains in predominantly rural areas of EU member states.

As a methodologically consistent input of the GDP-related multiplier analysis, the producer surplus is endogenously calculated within the market models and the agricultural labour force engaged in EU arable farming is taken into consideration. To determine the latter, EC (2014) data based on most recent information from the Farm Accountancy Data Network (FADN) of the EU are used.

2.3 Calculating key environmental effects with satellite models and calculation tools

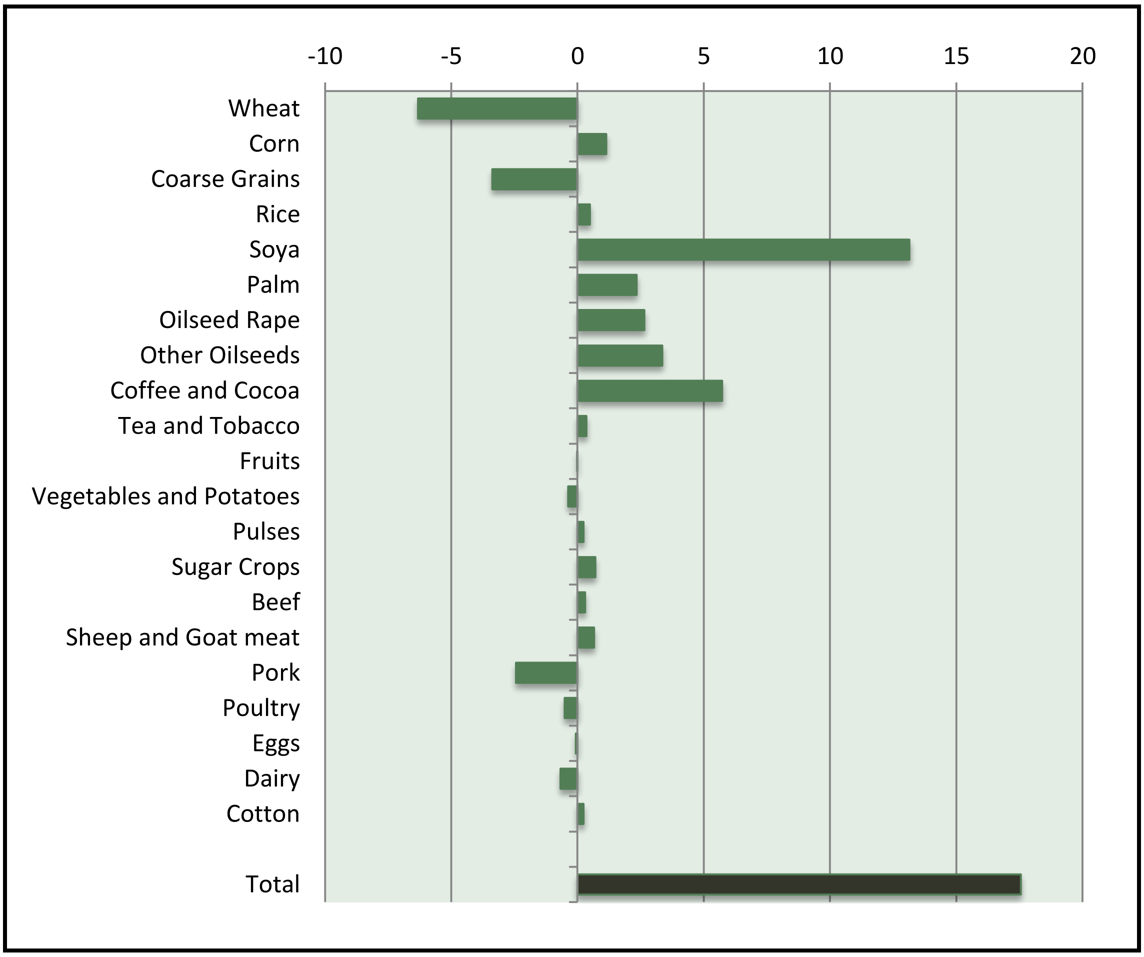
This study does not only define elementary economic and other socio-economic indicators as target variables but also environmental indicators. Changes in global resource (land and water) use, GHG emissions and biodiversity have been selected as relevant environmental parameters. Below they are detected in a stepwise approach using indicator-driven satellite models and calculation tools. These models and tools as well as related reference data had formerly been explained in detail and are, thus, just briefly discussed in the following sub-chapter referring to sources of full explanation.

Detecting changes in the use of global resources: land

The basis for calculating effects of plant breeding on a variety of environmental indicators is an analysis of the potential range of natural or nature-like habitats to be converted into agricultural land in the absence of plant breeding innovations in the EU. This particular analysis is based on a self-developed and meanwhile twice peer-reviewed virtual agricultural land trade approach (see Kern et al., 2012; Lotze-Campen et al., 2015). The latest version of this concept also used as a reference system in other research studies (see e.g., Meier et al., 2014; UNEP, 2015) and the underlying data are extensively documented in Noleppa and Cartsburg (2015a; 2014a) and do not need to be displayed here again.

The concept allows to calculate how much land the EU uses outside its own territory for agricultural purposes and how much land this would equal in case of a change in agricultural production and/or consumption in the EU. Against this background, figure 2.2 displays the status quo to be considered the average of the EU's virtual land net exports and imports per commodity of the years 2012-2014 (Noleppa and Cartsburg, 2015a). Accordingly, a total net import of roughly 17.6 million ha can be identified; and this outcome would look different without plant breeding.

Figure 2.2: Net imports (+) and net exports (–) in virtual agricultural land of the European Union by crop and livestock commodity, on average for 2012-2014 (in million ha)



Source: Own figure based on Noleppa and Cartsburg (2015a).

Detecting changes in the use of global resources: water

Calculating impacts of plant breeding efforts on agricultural water use requires to link available production and trade data (transferred from the market models) with information on regional water footprint data for EU and global agriculture. Such water footprint data are given by unit of production and reported in Mekkonen and Hoekstra (2011) for every crop in the focus of this study and each trading partner of the EU. Thus, the simple combination (multiplying) of trade (import vs. export) volumes with water footprint data leads to a statement on how much agricultural water is/will be used domestically and abroad in alternative scenarios (here: with vs. without genetic crop improvements in the EU).

Noleppa and Cartsburg (2015b) have already calculated the water embedded in EU agricultural production and trade. Figure 2.3 visualises the outcome for the average of the years 2010-2012 and will be used as a reference for further analysis.

Figure 2.3: Current water embedded in agricultural production and trade of the European Union, by major arable crops, on average for 2010-2012 (in billion m³)

Arable crop	Water used in domestic production	Virtual water internationally traded	Water embedded in agricultural production and trade
Wheat	151 048	–39 969	111 079
Corn	40 306	3 370	43 676
Other cereals	74 015	–17 611	56 404
Oilseed rape	31 428	10 061	41 489
Other oilseeds	20 862	19 402	40 264
Sugar crops	9 010	3 440	12 450
Potatoes	8 283	0 000	8 283
Pulses	4 167	0 691	4 858
All arable crops	**339 120**	**–20 617**	**318 503**

Source: Own figure based on Noleppa and Cartsburg (2015b).

Considering the arable crop clusters displayed above it becomes apparent that the EU needs almost 320 billion m³ of agricultural water. However, a distinction has to be made with respect to water importing and exporting commodities:

- Approximately one quarter of the agricultural water used in the domestic (EU) production of wheat and other cereals is exported to other world regions (58 billion m³ vs. 225 billion m³).

- In contrast one third of the domestic water used for cultivating corn, oilseeds, sugar crops, potatoes and pulses in the EU is additionally imported by the region at the cost of water resources of crop-specific trading partners (37 billion m^3 vs. 114 billion m^3).

Consequently, the EU virtually net exports some of the water (20.6 billion m^3) it uses in its own production processes (almost 340 billion m^3).

Detecting changes in global GHG emissions

All other things being equal and given the fact that worldwide – except in the EU (see Searchinger et al., 2008; and also below) – more and more land is being used for agricultural purposes, the extra land the EU would need without plant breeding innovation would have to come from additional land use changes elsewhere, in particular from converting natural habitats into acreage. Natural habitats which are not used for farming, however, still serve as a carbon sink. They sequester carbon and do not release CO_2. Knowing where and how much land to be converted, allows for calculating GHG effects. Regional yields and carbon release factors per converted ha are used for calculating these effects and are obtained from FAO (2015c) and Tyner et al. (2010). For more details on the entire calculation approach see again Noleppa et al. (2013).

Detecting global biodiversity losses

The conversion of natural habitats into agricultural land also leads to a loss of biodiversity (see e.g. Firbank et al., 2008; Hood, 2010; Tscharntke et al., 2012). Although measuring biodiversity and its changes is a challenging task (Croezen et al., 2011; Saling et al., 2014), a variety of methods have already been developed and a considerable number of biodiversity indicators has been published. All of them appear to have pros and cons and are still in their academic infancy while the scientific debate continues (e.g. HFFA Research, 2016; Wright, 2011). Hence, a generally accepted science-based indicator of mapping biodiversity and the loss thereof is not in sight. Therefore, this study applies a pragmatic approach. Two rather dissimilar indicators are used to cope with the inherent uncertainty in measuring biodiversity:

- First, the Global Environment Facility Benefits Index of Biodiversity (GEF-BIO) is used (see e.g. UNEP, 2009; Wright, 2011). It is scientifically sound and reasonable and can be combined with the economic and spatial approaches used here. The GEF-BIO captures the status quo of biodiversity as well as its changes, and it allows not only for a pure accounting of species but for mapping a regional distribution of species. Biodiversity, thus, can be calculated at the country as well as the world level. The indicator is frequently used meanwhile and starts to be accepted as a standard. It is consistent with the targets of the Convention on Biological Diversity (CBD) and widely used by research and international organisations (e.g. World Bank, 2013). The GEF-BIO originally developed by Dev Pandey et al. (2006) is a tested composite index of relative biodiversity for individual countries. It is based on the species represented in a country, their threat status, and the diversity of habitats. Moreover, the index is easy to handle. It is standardised on the interval {0; 100} (World Bank, 2013). Brazil is defined as the country with maximum biodiversity. Its natural habitats are rated 100. On the other end of the scale is Nauru, a small island nation in the Pacific Ocean, where only a few sea birds and insects live while the flora is characterised by coconut palm trees. Other countries are rated between these extremes.

- Second, the National Biodiversity Index (NBI) is applied. This index was developed by the CBD itself (CBD, 2001). It continues to be used in the Global Biodiversity Outlook Report (CBD, 2014). The NBI is based on estimates of a country's richness and endemism in four terrestrial vertebrate classes and vascular plants which have the same weight in the index. NBI values range from 1.00 (the maximum value is assigned to Indonesia) to 0.00 (the minimum value is allocated to Greenland). By multiplying all country-specific values with 100, the NBI can easily be compared to the GEF-BIO.

Deforestation and grassland conversion caused by productivity changes in EU agriculture due to missing plant breeding lead to changes in biodiversity. These changes can be analysed by multiplying the additional land use of the EU in other world regions with the GEF-BIO or NBI index value of that specific region (per ha).

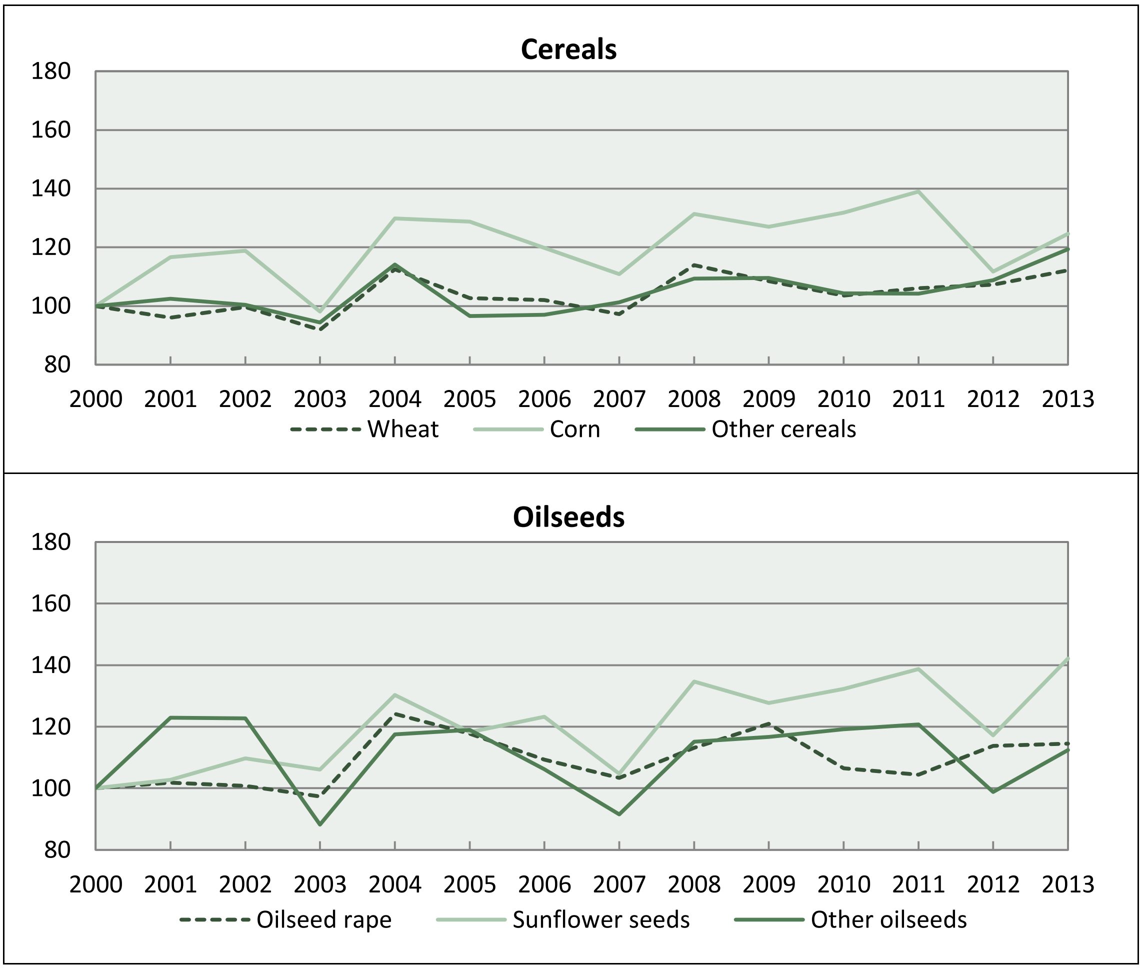
3 Productivity and plant breeding in European arable farming

Basic requirements for the entire analysis of this study are to examine the yield development in EU-28 agriculture and to determine a productivity impact solely caused by plant breeding in all EU member states for shifting agricultural supply. This can be achieved by using a gradual approach as described below.

3.1 Analysis of yield developments since the turn of the millennium

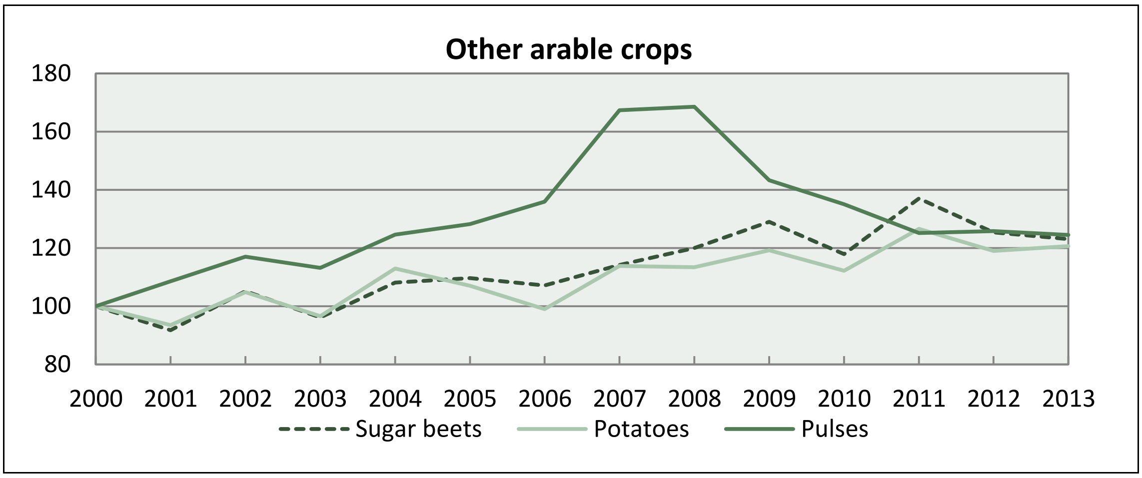
Based on FAO (2015c) data and for the nine core arable crops of this study, figure 3.1 displays the yield developments in EU farming since the year 2000 using comparable index values.

Figure 3.1: Yield developments in arable farming of the European Union, 2000-2013 (in index points, 2000 = 100) (to be continued)



Source: Own calculations and figure based on FAO (2015c).

Figure 3.1: Yield developments in arable farming of the European Union, 2000-2013 (in index points, 2000 = 100) (continued)



Source: Own calculations and figure based on FAO (2015c).

From the graphs and from annex A that provides similar information for each of the defined five sub-regions of the EU it becomes obvious that the yields of all crops have increased over time. However, high fluctuations per annum point at the volatility of crop production and its dependence on external factors such as weather conditions. Plotting an exponential trend line for each of the nine crops considered, however, allows to abstract from such influences and to determine an average annual percentage increase in yields. Figure 3.2 visualises the results for the EU as an aggregate of its 28 member states.

Figure 3.2: Yield growth in arable farming of the European Union, 2000-2013 (in percent per annum)

Wheat	Corn	Other cereals	Oilseed rape	Sunflower seeds	Other oilseeds	Sugar beets	Potatoes	Pulses
0.84	1.26	0.94	0.98	2.15	0.19	2.46	1.85	1.77

Source: Own calculations and figure based on FAO (2015c).

The current yield growth rates per annum for major arable crops in the EU vary between approximately 0.18 percent (other oilseeds) and 2.46 percent (sugar beets). Weighing the arable crops listed with their acreage, an average yield growth rate of just 1.10 percent can be specified for the EU since the turn of the millennium. This corresponds to other analyses for the EU and recent years with all of them stating that average yields tend to increase at rates of approximately 1.00 percent (see e.g.

Kirschke et al., 2011; Piesse and Thirtle, 2010; Spink et al., 2009). Hence, these rates are far away from what is globally needed (more than 2.0 percent per year) to satisfy current and forthcoming agricultural demands (see e.g. Jaggard et al., 2010; Ray et al., 2013).

Accordingly, it has to be noted that yield growth rates of the past are history and that the increase of crop yields is slowing down although land productivity in the EU is still increasing. This is consistent with other scientific findings, e.g. by de Ribou et al. (2013), Fan et al. (2011), Foley et al. (2011), Fuglie and Wang (2013), Gressel (2008), Laidig et al. (2014), and Meyer et al. (2013), who all argue that crop yield growth is diminishing, especially in developed countries such as the EU and its member states.

Yield growth rates in the EU not only differ per crop, but also per region. This becomes apparent by looking at figure 3.3. Accordingly, it can be stated that in the majority of the displayed cases positive yield growth rates can still be observed. Only three out of 45 crop-region combinations included in the matrix show a negative yield growth rate.

Figure 3.3: Yield growth in arable farming of the European Union, by sub-region, 2000-2013 (in percent per annum)

	Mediterranean region	Atlantic region	Baltic region	Central region	South-East region
Wheat	1.94	0.09	–0.02	0.99	1.87
Corn	0.38	0.69	1.05	0.81	2.27
Other cereals	0.87	0.31	1.07	1.07	1.71
Oilseed rape	3.32	0.96	1.56	0.96	3.40
Sunflower seeds	0.88	0.03	0.00	0.78	4.18
Other oilseeds	–0.60	2.30	9.91	1.64	2.30
Sugar beets	2.65	2.18	2.28	2.28	2.65
Potatoes	1.13	0.50	2.73	2.08	0.83
Pulses	6.92	–1.60	1.75	1.18	5.88

Source: Own calculations and figure based on FAO (2015c).

Yield growth rates for the five case-study crops – field and greenhouse tomatoes, strawberries, green maize, and temporary grasses – to be additionally included into this research shall briefly be discussed too. FAO (2015c) data also used above indicate that the yield of green maize has grown by 2.09 percent per annum in the EU since the turn of the millennium. Land productivity in strawberry production has risen on an annual base by 1.24 percent, and the yield of tomatoes has increased at a rate of almost zero (0.02 percent per year).

However, the FAO (2015c) data base does neither distinguish between greenhouse and open field tomatoes nor does it include temporary grasses. For these crops additional data had to be obtained from Eurostat (2015b), which provides a second best but unfortunately often incomplete and sometimes only fragmentary data base with respect to crop yields. From available data and information the following approximate conclusions can be drawn:

- The yields in field tomatoes production in the EU have increased by 0.06 percent per annum indicating that the yields in greenhouse tomatoes production have not grown at all. In fact, it is only a few EU member states that continuously provide statistical data on yields in greenhouse tomatoes production. Accordingly, it may be stated that the specific annual yields in most recent years have slightly grown in some countries, e.g. in France (0.9 percent) and the Netherlands (0.1 percent), while they remained stable in Ireland (0.0 percent) and have gone down to some extent in other countries, e.g. in Austria (0.1 percent). By and large neither a remarkable positive nor a significant negative yield trend has become apparent in EU's (greenhouse) tomatoes production.

- Due to very few data in Eurostat (2015b), annual yield growth rates for temporary grasses could only be assessed for 16 member states, but not for the EU as a whole. The results (expressed as annual yield growth rates) are listed in alphabetical order: Austria 0.7 percent, Belgium –0.6 percent, Bulgaria –1.0 percent, Croatia –0.6 percent, Denmark 2.3 percent, Estonia 0.9 percent, France 0.3 percent, Germany –1.6 percent, Hungary 6.9 percent, Lithuania 4.0 percent, Luxembourg 0.7 percent, Poland 4.3 percent, Romania 3.3 percent, Slovakia 4.4 percent, Slovenia 1.2 percent, and Spain 7.0 percent. Pragmatically using the arithmetic mean, an average yield growth of 1.9 percent per annum might be concluded.

Summarising the key findings with respect to the case study crops, the following yield growth rates will be used for further analyses taking into consideration the uncertainties associated with the comparably poor data background: field tomatoes 0.1 percent, greenhouse tomatoes 0.0 percent, strawberries 1.2 percent, green maize 2.1 percent, and temporary grasses 1.9 percent.

3.2 Calculation of total factor productivity growth

Considering the complexity of managerial and technological processes applied in agriculture, observable yield improvements are usually a multifactorial outcome. By using long-term observations the influence of weather phenomena can be minimised, but yields can still be induced by agricultural intensification or innovation respectively (see e.g. Sayer and Cassman, 2013). Considering the term "agricultural intensification" essentially referring to a process where inputs of capital and/or labour are increased to raise the productivity or yield of a fixed land area (see Börjeson, 2010), one might say in other words: Higher yields depend on more input per ha of land and/or better inputs applied on a given area.

Economic assessments use the "total factor productivity" (TFP) indicator to indicate which parts of observed changes in productivity are caused by innovation and should not be related to increased (or decreased) factor use intensities (see e.g. Lotze-Campen et al., 2015). Numerous theoretical and pragmatic applications of the TFP concept allow to state that this approach is standard in socio-economic science and particularly in agricultural economics (see e.g. Alston and Pardey, 2014; Ball et al., 2013; Fuglie and Toole, 2014; Fuglie, 2013; Piesse and Thirtle, 2010).

This study particularly counts on the peer-reviewed approach recently developed by Lotze-Campen et al. (2015) proving to be genuine since it allows to abstract from land as a production factor. Thus, it allows to directly compare TFP growth rates with changing yields per ha, to simplify the calculation process and to approximately determine TFP for specific crops. Accordingly, a ha-related TFP change rate can be calculated as follows:

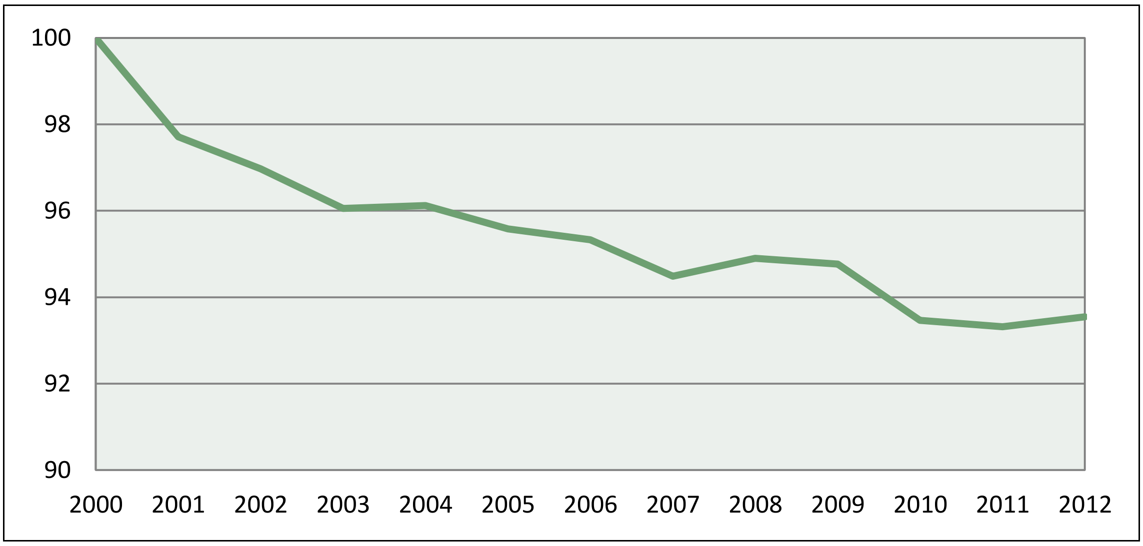
(1) $dTFP/TFP = dQ/Q - (DI/I) * SI - (dL/L) * SL$

with: Q = index of production (i.e. yield), I = index of all intermediate inputs used (e.g. volumes of fertilisers, plant protection products, machinery, etc.), L = index of labour input, and S = expenditure shares of the specific production factors (excluding land).

Looking at equation (1), it becomes apparent that weighted change rates with respect to the various input factors (other than land) need to be subtracted from yield changes in order to come up with meaningful TFP growth rates. Developments in factor use consequently need to be incorporated into the analysis.

Although not necessarily needed to calculate meaningful TFP growth rates in accordance with equation (1) but in order to be as comprehensive as possible within this study, the discussion starts with growth rates in the use of arable land, defined as all land under temporary agricultural crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (FAO, 2015b). Figure 3.4 displays the change in the use of arable land for the EU since the year 2000.

Figure 3.4: Use of arable land in the European Union, 2000-2012 (index, 2000 = 100)



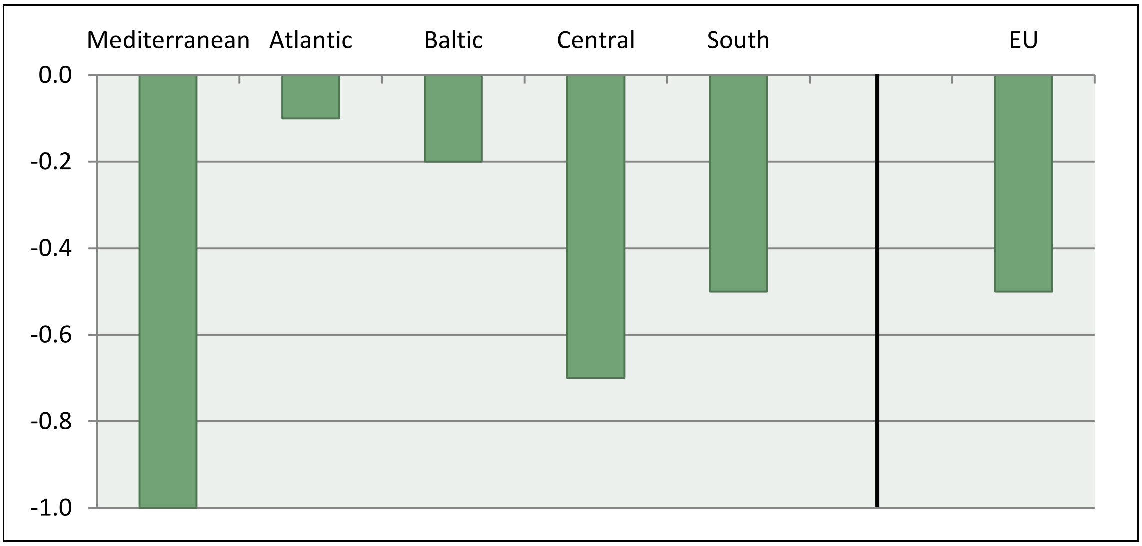
Source: Own calculations and figure based on FAO (2015b).

As visualised by the figure and stated above the use of arable land in the EU has decreased over time to more than six percent below the acreage managed by farms around the year 2000. This is different from other world regions, where acreage has continuously increased (see e.g. Searchinger et al., 2008), and may simply be related to at least three well-known facts:

- a strong impetus within the EU to maintain the share of permanent grassland,
- a publicly desired and policy-induced saving of land for various environmental schemes and
- a conversion of agricultural land towards infrastructure and urban settlements.

This means arable land has become a scarce resource in the EU. Since 2000 approximately 0.5 percent of arable land have been lost year by year. This trend, by the way, can be observed in all five sub-regions of the EU as figure 3.5 visualises and occurs despite a partial conversion of grassland into arable land in some regions due to bio-energy policies (see e.g. Pedroli et al., 2013). Accordingly, the negative trend in arable land use is the highest in the Mediterranean region (–1.0 percent); and it is obviously less pronounced in the Atlantic region (–0.1 percent). For compensating associated production losses, not only yields per se but particularly TFP generated by factor-related innovations, i.e. fully in accordance with the mathematical syntax of equation (1), need to be increased in the EU.

Figure 3.5: Change rates in the use of arable land in the European Union, 2000-2012 (in percent per annum)



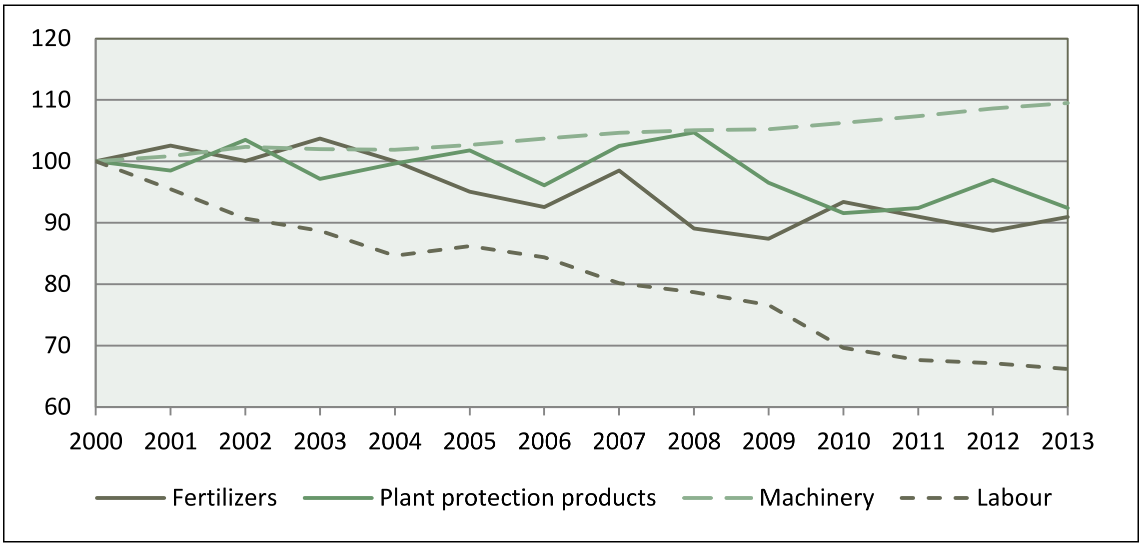
Source: Own calculations and figure based on FAO (2015b).

Based on official statistical data and additional expert knowledge as well as trend extrapolations for missing data, the use of intermediate inputs and labour in EU arable farming in recent years can be described as depicted in figure 3.6 (similar information for the five sub-regions of the EU is provided with annex B).

Altogether, the EU as a whole was able to considerably reduce its use of specific agricultural inputs. By plotting exponential trend lines it can be stated that labour use – measured in AWU engaged in arable farming – went down by 3.1 percent per annum. Fertiliser use – being the sum of consumed nitrogen fertilisers, phosphate fertilisers and potash fertilisers – decreased by 1.1 percent per year, and the use of plant protection products – covering herbicides, insecticides and fungicides – slightly fell at an annual rate of 0.6 percent. Contrary to that, machinery use increased a bit, i.e. by 0.7 percent per annum.

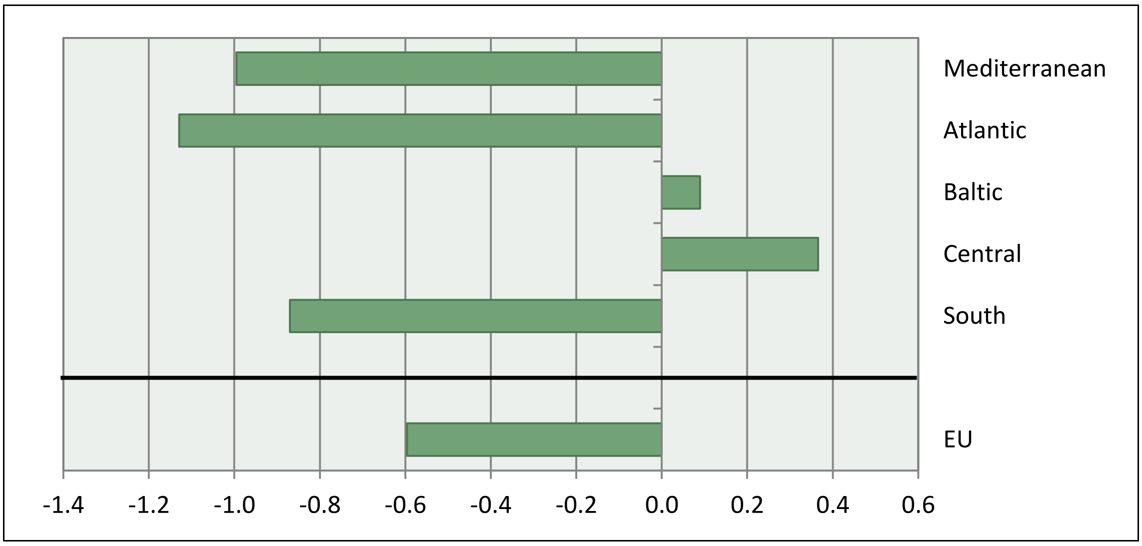
Weighting the various change rates of the specific intermediate inputs and labour with the individual input share of these production factors obtained from EC (2014) as well as Wang et al. (2012) results in the growth rates of overall input use (excluding land as an input) in arable farming of the EU and its sub-regions displayed in figure 3.7.

Figure 3.6: Use of intermediate inputs and labour in arable farming of the European Union, 2000-2013 (index, 2000 = 100)



Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), Fertilizers Europe (2014), and KTBL (2014a).

Figure 3.7: Growth rates of input use in arable farming of the European Union, 2000-2013 (in percent per annum)



Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), Fertilizers Europe (2015), KTBL (2014a) and Wang et al. (2012).

The use of production factors such as plant protection products, fertilisers, tractors and other machinery, as well as labour decreased at a rate of 0.6 percent per year in EU arable farming. This means, agricultural production on available acreage in the EU as a whole has not intensified since the turn of the millennium taking into consideration not only selected but all other major inputs, including labour. This is particularly noteworthy as public belief often claims an ongoing intensification of agriculture in the EU (see e.g. Hird et al., 2010; UBA, 2015b).

Using the statistical data and export knowledge available, it is also remarkable that not all the five defined sub-regions of the EU have reduced their overall use of intermediate inputs and labour. Region-specific and input-specific growth rates definitely differ a lot (see also annex B) and highlight that few inputs are nowadays used more intensively than in the past, at least in some EU member states. Analysing this obvious heterogeneity and the underlying procedures in more detail, however, exceeds the scope of this study.

According to equation (1), the share-weighted input growth rates displayed in figure 3.7 have to be subtracted from yield growth rates (see figures 3.2 and 3.3) to calculate meaningful TFP growth rates for EU arable farming. Figure 3.8 provides the result of such a data transformation for the EU as a whole and highlights that crop-specific TFP growth in recent years has varied between almost 0.8 percent and slightly more than 3.0 percent.

Figure 3.8: Total factor productivity growth in arable farming of the European Union, 2000-2013 (in percent per annum)

Wheat	Corn	Other cereals	Oilseed rape	Sunflower seeds	Other oilseeds	Sugar beets	Potatoes	Pulses
1.44	1.86	1.54	1.58	2.75	0.79	3.06	2.45	2.37

Source: Own calculations and figure.

Weighted by acreage, TFP growth in arable farming of the EU has amounted to around 1.7 percent per annum on average since the year 2000. Hence, the real productivity growth has been larger than increasing yields may indicate because not necessarily more but first of all better inputs have been used.

The just identified level of 1.7 percent TFP growth per annum can and should be compared with other recent scientific research findings:

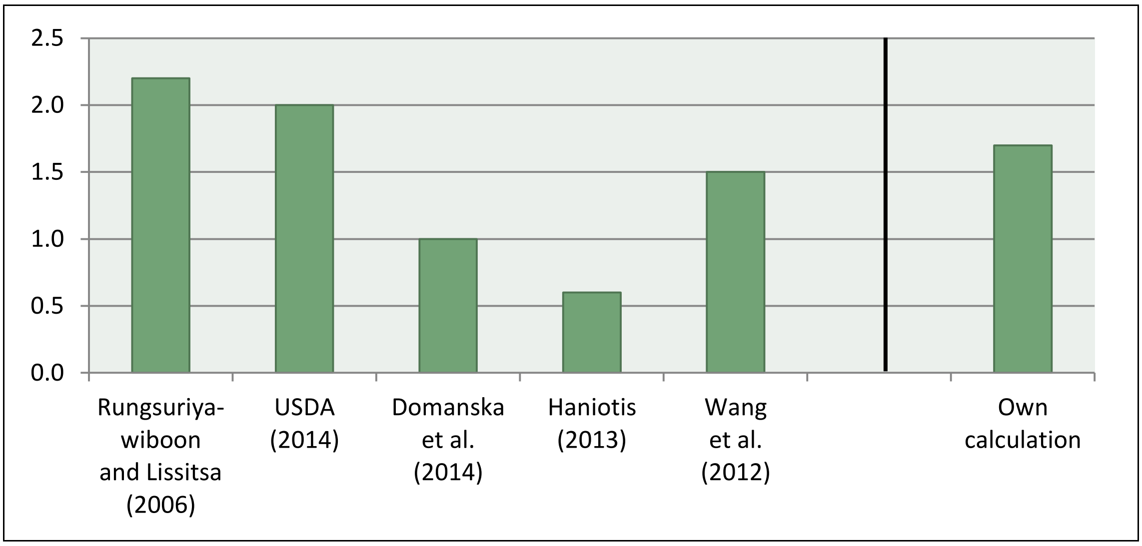
- Rungsuriyawiboon and Lissitsa (2006) calculated TFP growth rates for EU agriculture for the years 1992-2002. They suggest an average growth of 2.2

percent for the then EU-15 and 2.7 percent for the aggregate of the ten countries approaching the EU shortly after the millennium.

- Findings from USDA (2014) state a similar range. The authors arrived at the conclusion that the TFP growth rate in EU agriculture in the first decade of the 21st century was slightly higher than 2.0 percent.
- In contrast to that Domanska et al. (2014) argue that the TFP growth rate in EU agriculture for the years 2007-2011 amounted to 1.0 percent only.
- Even lower are most recent estimates of DG Agri presented by Haniotis (2013), who came to the conclusion that the TFP growth rate in EU agriculture over the past decade amounted to around 0.6 percent per year.
- Results obtained from Wang et al. (2012) finally highlight latest yearly agricultural TFP growth rates in EU member states of around 1.5 percent.

Considering this evidence a "stress test" of own calculation efforts, it can be stated that the "average" TFP growth rate computed here generally "fits" the broader academic consensus, which is still framed by methodological shortcomings and various data uncertainties (Matthews, 2014). It obviously ranges within the identified interval of other scientific findings as visualised in figure 3.9 and may, thus, be used as a robust result enabling further analysis.

Figure 3.9: Own and other scientists' total factor productivity growth rates for EU agriculture and arable farming (in percent per annum)



Source: Own calculations and figure.

3.3 Determination of the relative importance of plant breeding for productivity growth in agriculture

Considering the derived TFP growth rates an appropriate measure to discuss "real" productivity growth in EU arable farming, improvements in factor use are the key factor for explaining associated productivity gains. Focussing on the topic of this study, these improvements can still be borne by innovations in plant breeding on the one hand and by advances in crop nutrition, crop protection, irrigation, machinery, etc. on the other hand (see also Jaggard et al., 2010; Meyer et al., 2013; Rijk et al., 2013; Spielman and Pandya-Lorch, 2010). In order to allow for assessing the special importance of plant breeding for productivity growth in crop production it is necessary to distinguish the relative importance of plant breeding innovations from comparative contributions of other improved agronomic practices, i.e. better crop management through fertilisation, weeding, irrigation, etc.

There is scientific consensus that plant breeding played a major role in increasing yields and overall TFP in the past. Academics arrived at the following conclusions when it comes to assess the special importance of genetics for agricultural productivity in crop production in the EU or other developed countries until the turn of the millennium:

- Analysts of the Food and Agriculture Organization (FAO) of the United Nations argue that remarkable contributions in increasing yields came from plant breeding (GIPB, 2010). Approximately 50 percent of all crop productivity increases over the last century were attributed to better genotypes accordingly.

- Andersen et al. (2015) arrive at a similar conclusion referring to the second half of the 20th century only and to Denmark where plant breeding on the one hand and improved growing methods on the other hand have contributed equally to productivity growth in crop production.

- The 50 percent "criterion" referring to decades of the past century is also supported by scientific findings of Araus et al. (2008), Duvick and Cassman (1999), Friedt and Ordon (1998), McLaren (2000), and Monneveux et al. (2013) who analysed the particular importance of plant breeding in a European context and/or for U.S. arable cropping schemes.

- More specific figures on plant breeding impacts per crop are provided e.g. by Silvey (1994). In a United Kingdom context, the author arrived at the conclusion that the proportion of the land productivity changes attributable to plant breeding was nation-wide 47 percent for wheat and 55 percent for barley.

- With respect to maize in U.S. arable cropping systems, a 50 percent or 58 percent respectively contribution of plant breeding towards productivity increases was concluded following proper analysis by Reilly and Fuglie (1998) and Scott and Jaggard (2000). This dimension is supported as well by analyses discussed in Duvick (2005).
- However, the identified impact of plant breeding for productivity increases in sugar beets production in last decades of the past century is obviously slightly lower. According to Jaggard et al. (2007) as well as Scott and Jaggard (2000) better genotypes contributed between 30 and 47 percent in a United Kingdom context.

All in all, a 50 percent "ratio" with respect to the share of plant breeding in productivity growth in crop production may be assumed while looking at past decades of the last century. Bridging to the turn of the millennium, a few more recent academic studies and other reports provide additional and partly remarkable insights into ongoing developments:

- While arguing that plant breeding contributed around 50 percent to crop productivity gains in agriculture between the years 1947 and 1982 (focussing on yield increases of cereals in the United Kingdom), BSPB (2013c) also state that the contribution of plant breeding to cereal land productivity gains has increased to more than 90 percent since 1982.
- Referring to wheat, this dimension is also supported by Fischer and Edmeades (2010) as well as by Mackay et al. (2009) and Webb (2010).
- Fischer and Edmeades (2010) similarly argue for corn that genetics have most recently contributed around two thirds of observable productivity growth.
- An almost similar argument results from Björnstadt (2014). The author also argues that 50 percent of crop productivity growth in Nordic countries since the end of World War II have been attributed to better genotypes and the other 50 percent to better managerial options. However, Björnstadt (2014) has also shown that the particular importance of plant breeding vs. other innovations increased over time. In arable farming of Nordic countries such as Finland, Sweden and Norway it amounted to 29 percent between 1946 and 1960, 43 percent between 1960 and 1980, and noteworthy 89 percent in the time period 1980 to 2005.
- The increasing importance of plant breeding for productivity growth over time was also highlighted by Lege (2010) and Ahlemeyer and Friedt (2010).

- It also becomes visible when comparing the research of von Witzke et al. (2004) with its succeeding study (Noleppa and von Witzke, 2013) dealing with plant breeding in Germany. Before the millennium, an average importance of plant breeding for productivity in German crop production of 50 percent was concluded having increased to 75 percent by now.

Currently the importance of plant breeding is obviously ranked well above 50 percent by most scientists, who have mainly focused their specific research on the EU and its member states. The following findings of scientific literature are as well worth being emphasized:

- According to Carter et al. (2015), at least 88 percent of land productivity improvement in wheat should be considered a factor of breeding. Following the authors' arguments, genetic improvements are responsible for up to 92 percent of productivity growth in other small grains, but still only around 50 percent in sugar beets, pulses and forage crops.

- Crosbie et al. (2006) argue that 56 to 94 percent of productivity growth in maize shall be attributed to better genotypes.

- The relative importance of plant breeding is also high in Norway with respect to barley. According to Lillemo et al. (2010), it has amounted to around 78 percent in recent decades.

- Barley as a crop was also dealt with by Rijk et al. (2013) in a Dutch context. According to their research, an average contribution of plant breeding to productivity improvements in barley production of 67 percent should be envisaged. For other crops it is higher reaching 77 percent in wheat. However, it is lower with potatoes (65 percent) and sugar beets (52 percent).

- Another statement on the plant breeding importance for productivity growth in potatoes comes from Bradshaw (2009), who argues that 58 percent should be devoted.

Research findings of a study recently conducted by Laidig et al. (2014) are finally reviewed. The authors looked at genetic vs. agronomic innovations in crop performance distinguishing different levels of factor use intensity in a German context. Using the average of the manifold study outcomes, the following can be concluded:

- 99 percent of productivity progress in wheat are currently attributed to genetic improvements.

- These particular innovations account for 75 percent of productivity gains in barley production and 87 percent in rye production.

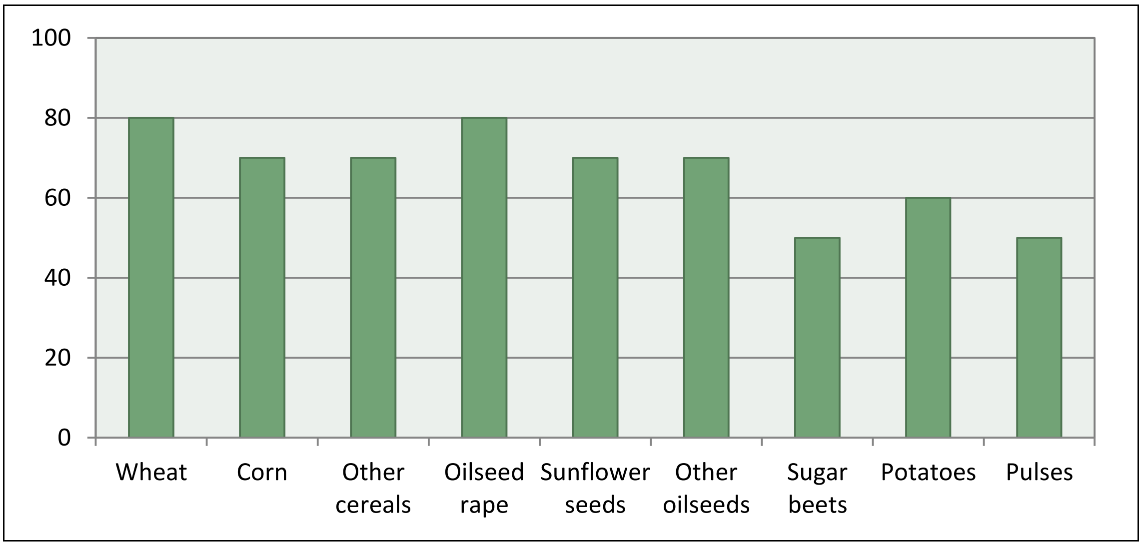
- Oilseed rape productivity as well is significantly affected by plant breeding efforts. The relative importance can be rated to 95 percent.
- Just in sugar beet production the importance of plant breeding for productivity gains is assessed lower, i.e. approximately 40 percent in recent years.

According to Björnstadt (2014) the role of genes will further increase with less inputs applied in precision agriculture. This statement is also supported by Meyer et al. (2013), Monneveux et al. (2013) as well as Wood et al. (2013). All of them claim the importance of plant breeding for further productivity progress to remain major and potentially increase.

Considering academic literature and the obviously broad consensus in science it becomes apparent that plant breeding across all arable crops in the EU has a tremendous impact on productivity in arable farming. In the last century, genetic improvements were responsible for at least half the progress made. Since the turn of the millennium this importance (ratio) has considerably increased.

Further analysis requires to summarise the various research findings listed above and make a decision on the TFP growth share of plant breeding taking into account still existing uncertainties. Using a simple scoring approach share values of 50, 60, 70, and 80 percent are attributed to the major arable crops in the focus of this study. Figure 3.10 displays the values selected, which are within the spectrum identified from academic literature and, thus, certainly do not tend to overestimate the importance of plant breeding for agricultural productivity in the EU.

Figure 3.10: Total factor productivity growth shares of plant breeding used in further analysis (in percent)



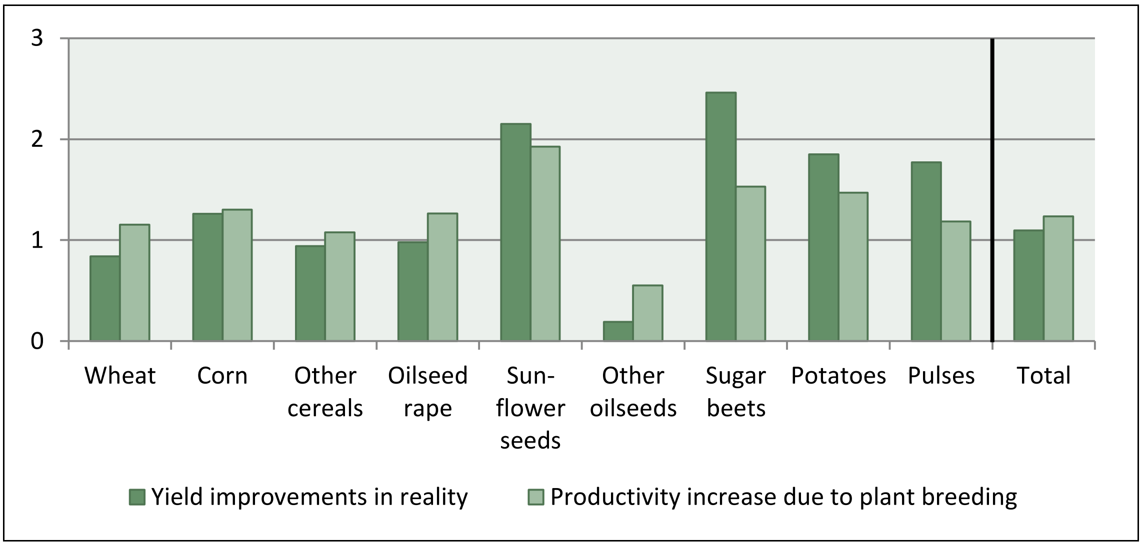
Source: Own calculations and figure.

To take an example: The TFP shares for small grains determined and consequently used here are 80 percent (for wheat) and 70 percent (for other cereals) respectively. However, the quotations listed above would have allowed to use 90 percent or 80 percent shares respectively.

Weighting the nine arable crops listed with their acreage, an average TFP growth share of plant breeding in the EU of 74 percent applies. This is fully in line with Lotze-Campen et al. (2015), who suggest a share of 75 percent (in a German context).

This fact-based decision allows to determine the annual impact of genetic crops improvement on overall productivity in arable farming of the EU. The TFP growth rates displayed in figure 3.8 need to be multiplied with the percentage shares just defined. Figure 3.11 visualises the outcome of this simple algebraic transformation and compares resulting impacts with real yield growth per crop in EU arable farming.

Figure 3.11: TFP growth due to plant breeding vs. yield growth in arable farming of the European Union, 2000-2013 (in percent per annum)



Source: Own calculations and figure.

It gets obvious that the average productivity growth in arable farming of the EU is slightly higher than the real yield growth, i.e. 1.24 percent vs.1.10 percent showing that occurring breeding progress could not fully be materialised on the field due to other circumstances and confirming the findings of e.g. Jaggard et al. (2010), Meyer et al. (2013), and Monneveux et al. (2013), who all argue that yield gaps are (partly) widening.

This study is not meant to find about these other framework conditions. However, it can be assumed that a mixture of different factors like changing climate conditions, policy conditions partly restricting the use of new seeds and other sophisticated and productivity enhancing technologies providing crop nutrients and disease control, a gradual move towards bigger acreage under ecological farming conditions (with considerably lower yields) has contributed. For wheat, e.g., showing the most remarkable difference between productivity growth obviously induced by plant breeding and real yield growth in the EU (1.15 percent vs. 0.84 percent) a substantial nutrient deficit in Eastern European member states of the EU was identified (Meyer et al., 2013); resistance problems may play a particular role herein, too, and might lead to the spatial use of varieties more resistant against fungi, e.g., but less strong in yield increase (Jones, 2015); in addition wheat acreage has remarkably increased probably leading to the fact that rather poor quality soils moved into wheat production (Eurostat, 2016).

For the five minor case study crops (field tomatoes, greenhouse tomatoes, strawberries, green maize, and temporary grasses) the study findings on the identified yield and TFP changes as well as contributions of plant breeding towards productivity gains can be summarised as follows:

- Chapter 3.1 has already given insights into yield developments. Accordingly, it can be stated that for the EU in total and per annum land productivity in the case of field (greenhouse) tomatoes has risen by 0.1 (0.0) percent, with strawberries by 1.2 percent, with green maize by 2.1 percent, and with temporary grasses by 1.9 percent since the year 2000.

- Specific input data for calculating TFP growth rates could neither be obtained from official statistical data nor was the academic literature review able to identify reliable information. Thus, it is defined in the following that TFP growth rates relating to the five minor crops are 0.6 percent higher than corresponding yield growth rates. This reveals what has been concluded above for the major arable crops and the EU on average.

- Plant breeding for all the five case-study crops is assessed to contribute a rather low 50 percent share to TFP growth. As mentioned above this has been backed up by science for forage crops (see again Carter et al, 2015). Also Lee and Tollenaar (2007) associate a value of not more than up to 60 percent to (green) maize. In addition, Fooland (2007) argues in terms of tomatoes that on average half of the increase in crop productivity is attributed to cultivar improvements through plant breeding. A share of almost 50 percent with respect to tomatoes is also mentioned by Nikolla et al. (2012). Reliable scientific data on strawberries have not been found.

Figure 3.12 summarises these findings and shows that plant breeding is assumed to contribute between 0.3 percent (tomatoes) and 1.3 percent (green maize) annually to specific crop productivity in the EU.

Figure 3.12: Yield, TFP growth and TFP growth due to plant breeding for case study crops of the European Union, 2000-2013 (in percent per annum)

	Yield growth	TFP growth	TFP growth due to plant breeding
Field tomatoes	0.10	0.70	0.35
Greenhouse tomatoes	0.00	0.60	0.30
Strawberries	1.20	1.80	0.90
Green maize	2.10	2.70	1.35
Temporary grasses	1.90	2.50	1.25

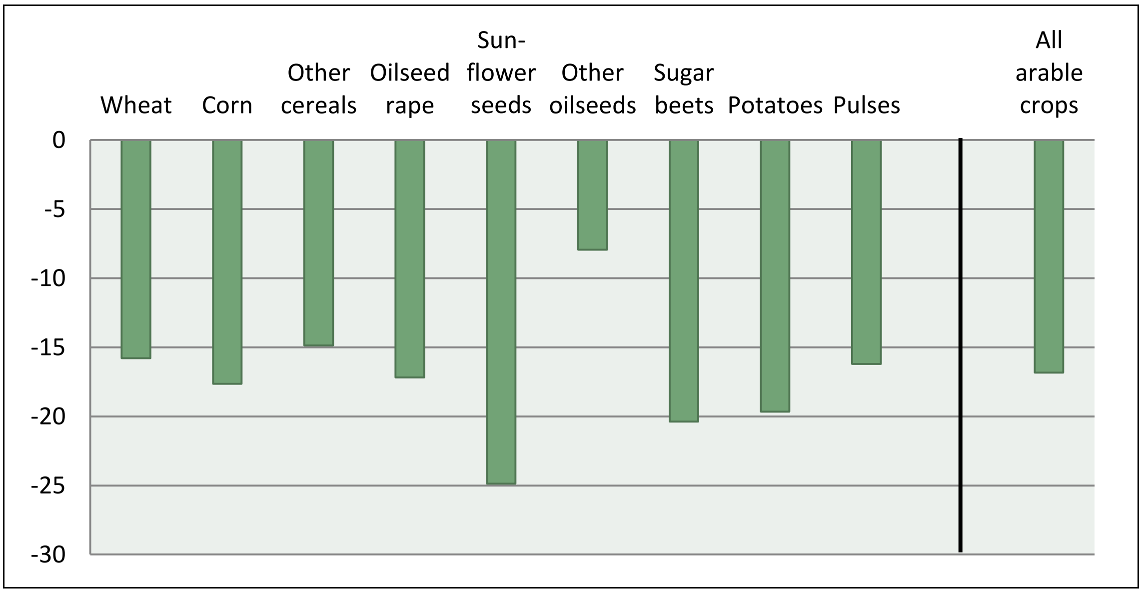
Source: Own calculations and figure.

4 The value of plant breeding in the European Union since the turn of the millennium

Analysing the value of plant breeding in and for the EU requires to specify a scenario on the status quo in arable farming without productivity increases due to plant breeding in the last 15 years (2000-2014). The methodology particularly insists the initial market models outlined in chapter 2 to be shocked with an impulse describing crop productivity without plant breeding. This shock or shift factor simulates a relative initial production loss and equals the productivity loss expressed as the percentage to be calculated by accumulating the average annual TFP growth due to plant breeding (see figures 3.11 and 3.12) for the entire time horizon (here: 2000-2014) and subtracting the resulting arithmetic product from 100 percent.

The various analyses based on this calculation are discussed for the nine core arable crops first. The other five case study crops – field tomatoes, greenhouse tomatoes, strawberries, green maize, and temporary grasses – are assessed at the end of chapter 4. Consequently, figure 4.1 displays the simulated initial production loss without plant breeding in the EU in the last 15 years for the major arable crops.

Figure 4.1: Simulated current production loss in arable farming of the European Union without plant breeding for major arable crops in the last 15 years (in percent)



Source: Own calculations and figure.

A remarkable drop in arable production equal to more than 16 percent of current production would have occurred across all arable crops. Inversely rated, EU agriculture today produces 20 percent more on arable land than without the plant breeding successes of last 15 years. Alternatively occurring production losses would have been highest with sunflower seeds (–25 percent), around one sixth in cereal production (approximately –16 percent), and comparably low with the other oilseeds (–8 percent).

4.1 Socio-economic values of plant breeding for major arable crops

Such initial production losses would certainly affect markets. International commodity prices would change and might set alternative incentives for domestic market supply and demand leading to changing monetary outcomes for farmers, consumers, but also the society on the whole. Social implications might be expected as well. Below, these effects are highlighted step by step for the nine core arable crops covered.

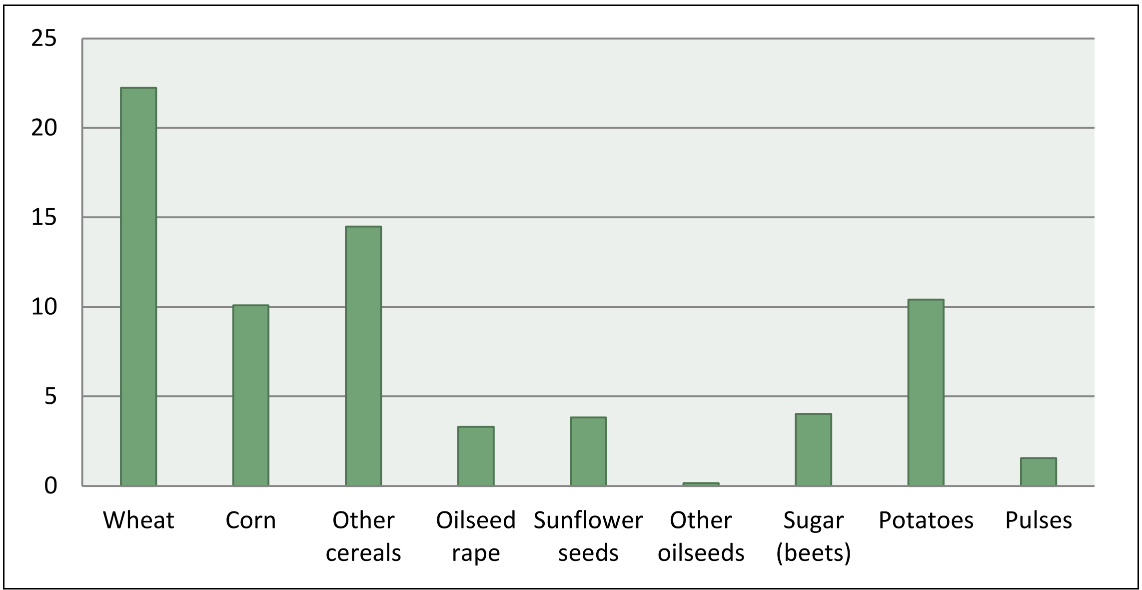
Before displaying the results it must be noted that the following discussion is arguing in positive terms, i.e. discussed effects are related to the fact that plant breeding in past 15 years allowed to increase agricultural productivity and gain more produce from arable land rather than debating what would have been lost in the absence of induced genetic crops improvements. The methodological approach using the potential loss to find a new market equilibrium within the models, thus, requires shifting the interpretation of respective results, namely negative signs get positive, positive signs get negative.

Additional crop supply

From the modelling exercise it can be concluded that plant breeding in the EU since the year 2000 has allowed to supply additional volumes of crops as depicted in figure 4.2:

- For grains on the whole the supply effect is almost 47 million tons.
- Approximately one half of it is accounted for by wheat, what is not that surprising as wheat is the most important crop in EU arable farming and heavily influenced by numerous plant breeding activities in various member states.
- Oilseeds aggregate to an additional 7 million tons.
- Sugar beets add 4 million tons of raw sugar, the volume of potatoes is 10 million tons larger and pulses additionally contribute more than 1 million tons.

Figure 4.2: Additional current arable crop supply of the European Union with plant breeding for major arable crops in the last 15 years (in million tons)



Source: Own calculations and figure.

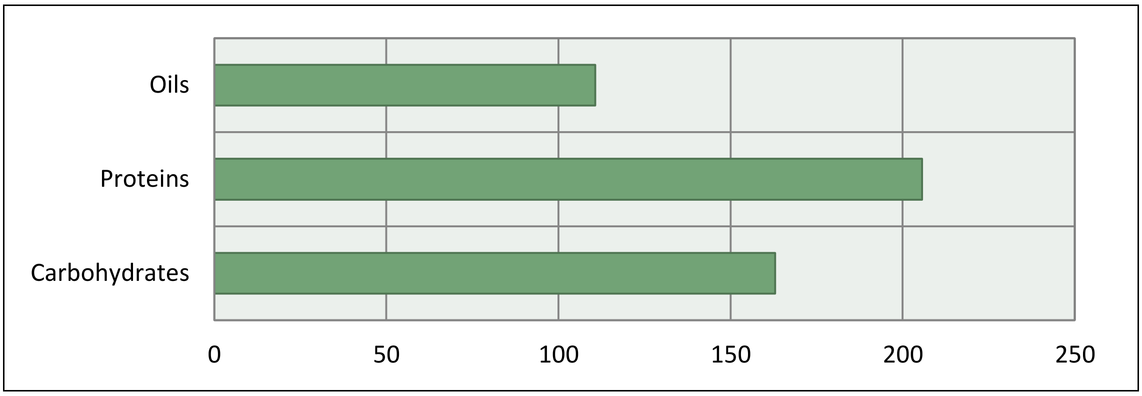
Increased world food availability

Looking at the nutrient content of the supply increase caused by plant breeding in the EU in the last 15 years enables to calculate an interesting social impact, i.e. the effect on global food availability (all other things – namely food access conditions – being equal).

According to FAO (2014), an average person on earth consumes 2868 kcal, 80 grams of vegetable proteins and 83 grams of vegetable oil per day. Given the crop-specific nutrient content (see again FAO, 2014) the additional supply displayed in figure 4.2 provides enough carbohydrates for more than 160 million humans, enough vegetable proteins for more than 200 million people, and vegetable oils for approximately 110 million humans as depicted in figure 4.3 – if the additionally produced volume becomes fully usable in world regions where it is really needed.

Being aware that currently almost 800 million people are malnourished in terms of calories and 1.9 billion people suffer from one or the other (micro-)nutrient deficit (Heddad, 2015), plant breeding in the EU is stated to have considerably contributed to improve this very unsatisfactory situation.

Figure 4.3: Additional current potential global food supply for world population with plant breeding for major arable crops in the European Union in the last 15 years (in million humans)



Source: Own calculations and figure.

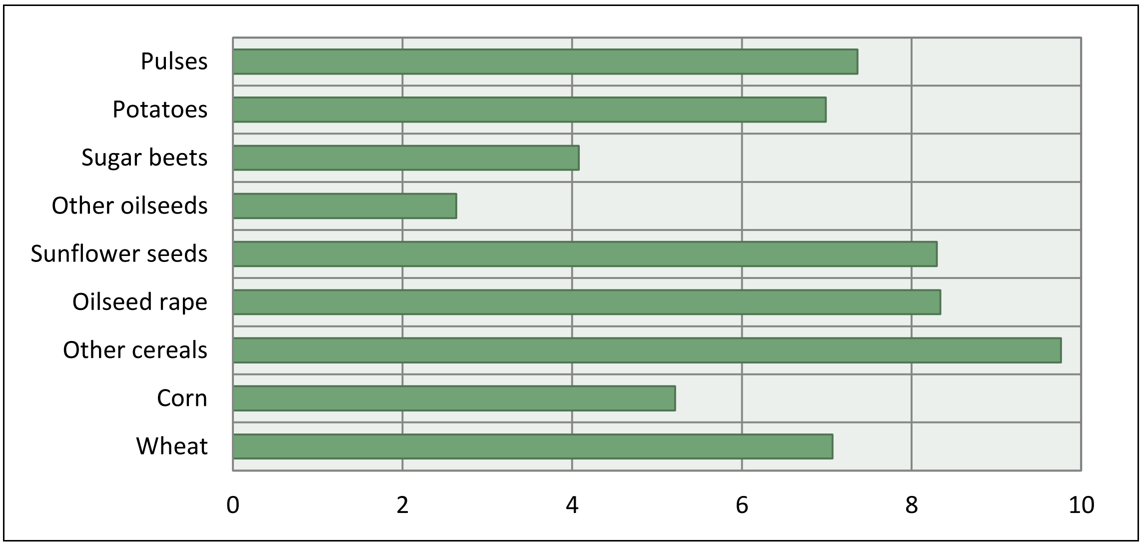
Avoided price increases

A rather high market supply volume does not only create a benefit in terms of world food security, but additionally enables consumers around the globe to buy food and agricultural raw materials at affordable prices. It is generally accepted that the long-term trend of declining agricultural commodity prices has come to an end and that future prices of agricultural commodities and, thus, food will be (much) higher than in the past (see e.g. Irwin and Good, 2015; Kirschke et al., 2011; USDA, 2015a). Against this background, figure 4.4 depicts the market price effect of plant breeding in the EU since the turn of the millennium, i.e. the avoided price increases.

By and large, prices at international agricultural commodity markets would have been 3 to 10 percent higher without plant breeding in the EU during the last one and a half decades than they are at present. The avoided price increase is highest (9.8 percent) in other cereals, a rather narrow world market with the EU as a major player involved (keyword: barley). It is lowest (2.6 percent) in other oilseeds (mainly soybeans), which should be considered a rather huge market in terms of traded volumes with comparably little affected supply coming from the EU. This tendency of lowering prices, however, should not be considered a negative farming incentive occurring from plant breeding activities. Despite lower prices, revenues increase with genetic crop improvements due to the fact that increasing production volumes overcompensate (see figure 4.1 above and figure 4.7 below).

Additionally it may be stated that in times of increasing agricultural commodity prices plant breeding contributes to price stabilisation. Larger tradeable volumes (with plant breeding in the EU in the last 15 years) tend to lower market volatility. Comparably full stocks function as shock absorbers and could be better built once larger production volumes are principally available. In fact, agricultural commodity prices tend to be rather volatile for a number of reasons (inelastic markets, weather phenomena, plant diseases, ad-hoc policy decisions such as export stops and import bans, etc.). In such an environment genetic improvements and, thus, higher market volumes help keep price volatility low (see also Wright, 2010).

Figure 4.4: Avoided price increases on world agricultural markets with plant breeding for major arable crops in the European Union in the last 15 years (in percent)



Source: Own calculations and figure.

Additional gross value added

From a national account point of view, changes in societal welfare may serve as a proxy for discussing changes of the gross value added. The current social welfare effect – from an analytical and modelling perspective the sum of so-called producer surpluses and consumer surpluses – of plant breeding in the EU between the years 2000 and 2014 for the arable crops included in the analysis and in total is listed in figure 4.5. The total social welfare gain for the analysed crops amounts to almost EUR 9.0 billion. Wheat does have the largest effect again. More than one third of the total social welfare gain is attributable to this crop. Other grains and sugar beets contribute more than EUR 2.0 billion each. Oilseed crops add a total of more than EUR 1.0 billion.

Figure 4.5: Current social welfare gains in the European Union with plant breeding for major arable crops in the last 15 years (in billion EUR)

Wheat	Corn	Other cereals	Oilseed rape	Sunflower seeds
3.286	0.926	1.087	0.594	0.348
Other oilseeds	**Sugar beets**	**Potatoes**	**Pulses**	**Total**
0.185	2.006	0.248	0.228	8.908

Source: Own calculations and figure.

According to latest available information, the gross value added in agriculture of the EU totals approximately EUR 160 billion (Eurostat, 2015a) implying that this number would have been almost 6 percent lower without plant breeding just for major arable crops in the EU since the turn of the millennium. This approximately equals the gross value added of the agricultural sector in Poland (Eurostat, 2015a).

It becomes clear that genetic crops improvements have a strong economic impact what is also supported by conclusions of other scientists (see e.g. Andersen et al., 2015; Björnstadt, 2015). According to their findings investments into plant breeding activities definitely payoff in economic terms, i.e. offer (very) high returns on investments not only from a private but also from a societal perspective (BSPB, 2013c; GIPB, 2010; Lotze-Campen et al., 2015; Noleppa and von Witzke, 2013).

Rural income (GDP) and employment (jobs) effects

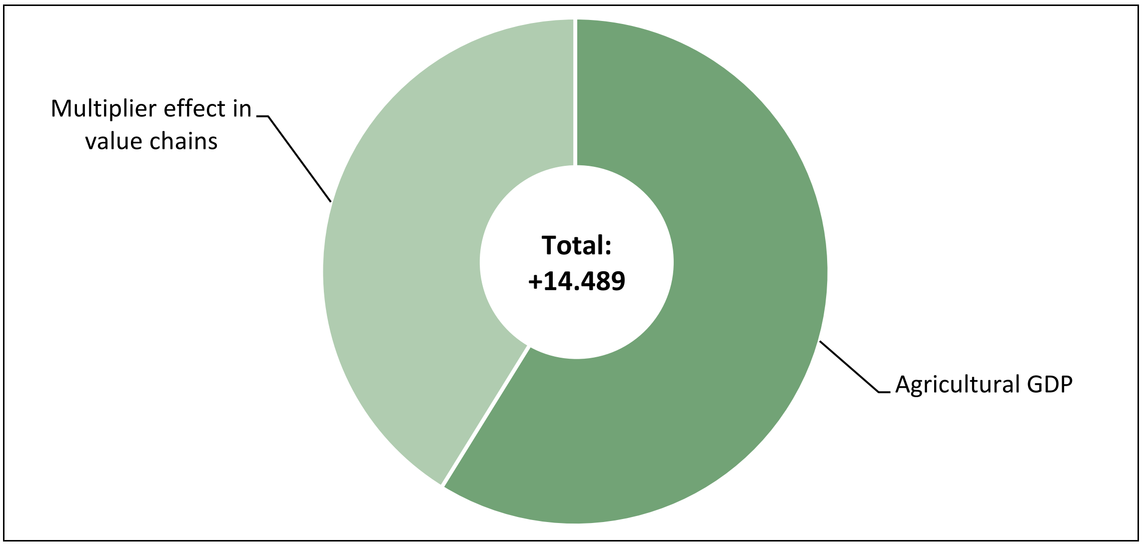
Plant breeding does not only benefit the society on the whole. It particularly creates an economic value for farmers and rural citizens since it tends to increase income and labour in rural areas. This is emphasised by the following qualitative arguments and quantitative calculation results.

Starting point for the income analysis to be conducted is the producer surplus additionally generated through plant breeding. To be methodologically consistent, this surplus is considered an approximation of the agricultural GDP. According to the modelling exercise it should be valued slightly above EUR 8.5 billion.

Applying now the GDP multiplier presented in figure 2.1, monetary effects upstream and downstream the agricultural value chains can be defined and the calculation of the impact of plant breeding on the entire GDP of the EU becomes operational. Figure 4.6 depicts this additional economy-wide GDP at present generated by better crop varieties since the turn of the millennium.

This additional economy-wide GDP is the sum of the additional agricultural GDP (EUR 8.523 billion) and the GDP additionally generated in upstream and downstream industries of the various agricultural value chains mainly located in rural areas of the EU (EUR 5.966 billion). It amounts to almost EUR 14.5 billion. This monetary value approximately equals the GDP of Albania (IMF, 2015), a country trying to approach the EU in not too many years from now.

Figure 4.6: Current annual gross domestic product impact on the European Union with plant breeding for major arable crops in the last 15 years (in billion EUR)



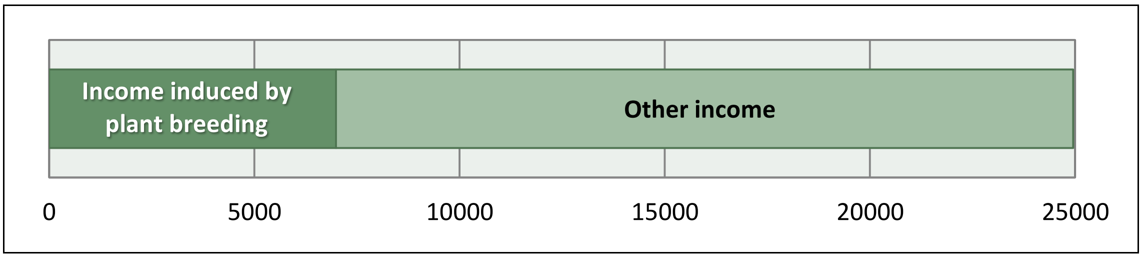
Source: Own calculations and figure.

In the context of socio-economic effects of plant breeding, the income effect of genetic crops improvements shall finally be analysed for labour directly engaged in arable farming and cultivating the crops under consideration. Such crop-specific activities comprise tillage, sowing and drilling, monitoring, applying fertilisers, irrigation, pest management, harvesting, transport of primary and secondary products from the field, and other area-related management efforts. For calculating the effect, information obtained from the FADN based on EC (2014) is used and double checked by KTBL (2014a) information.

Growing the nine arable crops under consideration in the EU affects approximately 1.2 million AWU. Dividing above-mentioned producer surplus of slightly more than EUR 8.5 billion by these 1.2 million AWU yields the following result. Plant breeding for arable crops in the EU since the turn of the millennium has generated an additional annual income of almost 7 000 EUR/AWU compared to a situation with no plant breeding for years.

This is quite remarkable since latest information on the annual farm net value added (FNVA) (the comparable income indicator within the FADN) suggests an average income in crop cultivation of 24 950 EUR/AWU in the EU (EC, 2014). Hence, without plant breeding in the EU since the year 2000 the FNVA would have been around 18 000 EUR/AWU or 70 percent of the current income even if present direct payments had continuously been transferred and other income components had remained stable. This is visualised in figure 4.7.

Figure 4.7: Income induced by plant breeding for major arable crops in the European Union in the last 15 years and other income in arable farming of the European Union (farm net value added in EUR/AWU)



Source: Own calculations and figure.

Harvesting less in the EU in the absence of plant breeding would additionally imply devoting a lower amount of man-power to farming since less harvest, transport and storage activities on-farm would be necessary. The resulting labour effect, however, is small. Using KTBL (2014a) data, it can be concluded that just 4.4 percent of all AWU engaged in the cultivation of the core arable crops of this study would be unnecessary. The percentage of AWU not needed in the case of missing plant breeding in the last 15 years is comparably low in cereals and oilseed rape, but rather high in potatoes and sugar beets as these are crops where a lot of working time needs to be devoted to harvest and transport activities. Figure 4.8 provides the full picture of this very particular analysis.

Figure 4.8: Annual working units currently not needed in arable farming of the European Union without plant breeding for major arable crops in the last 15 years (in percent)

Wheat	Corn	Other cereals	Oilseed rape	Sunflower seeds
3.7	5.4	3.7	3.5	5.4
Other oilseeds	**Sugar beets**	**Potatoes**	**Pulses**	**Total**
4.5	8.4	13.8	3.9	4.4

Source: Own calculations and figure.

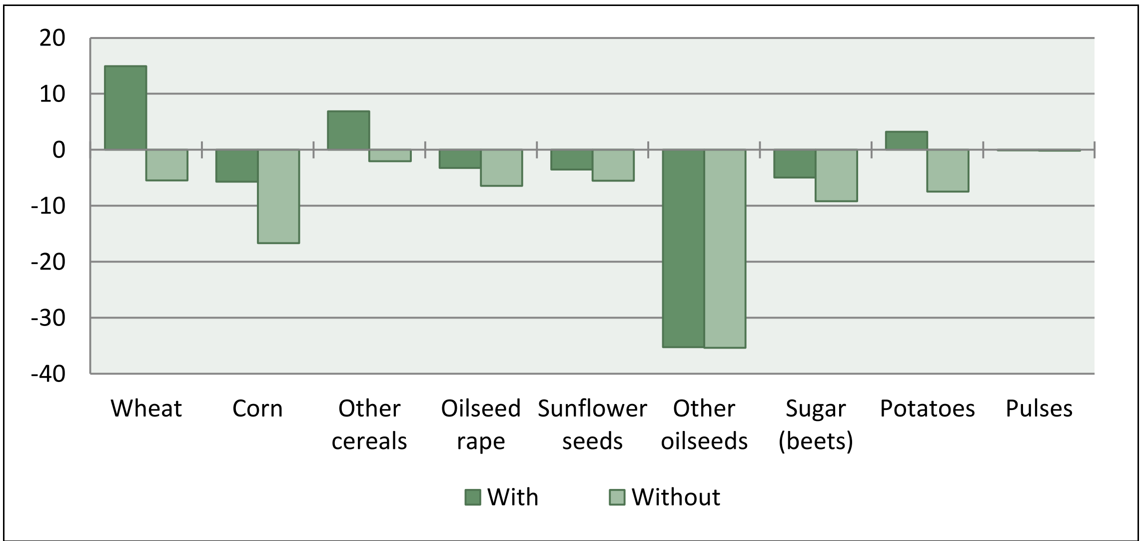
This means more than 54 000 AWU, i.e. an equal amount of paid or unpaid labour force in arable farming of the EU, would be endangered to lose their jobs. The corresponding decrease in production and buying-in of inputs would additionally cause some turbulences upstream and downstream the agricultural value chains. Using the job multipliers displayed in figure 2.1 more than 13 500 extra jobs would be lost in the case of missing genetic crops improvements. Hence, this number of jobs has been created by plant breeding activities since the year 2000.

However, this marks the lower bound of labour market effects to be expected and requires missing production volumes to be fully substituted through trade. Otherwise numerous additional jobs in storing, processing, and packaging, internationally trading and retailing the missing crop volumes of absent plant breeding in the EU would be endangered.

4.2 Environmental values of plant breeding for major arable crops

Changing market conditions do affect trade volumes. The resulting changes in the case of missing plant breeding progress in the EU as defined in above scenario are depicted in figure 4.9. The displayed trade volumes, however, do not show agricultural commodity trade only. They also include trade (imports and exports) of processed and semi-processed products re-converted to the commodity level (for an in-depth explanation of the calculation concept see Noleppa and Cartsburg, 2015a; 2014a).

Figure 4.9: Agricultural trade volumes with and without plant breeding for major arable crops in the European Union in the last 15 years (in million tons)



Source: Own calculations and figure based on Noleppa and Cartsburg (2015a; 2014a).

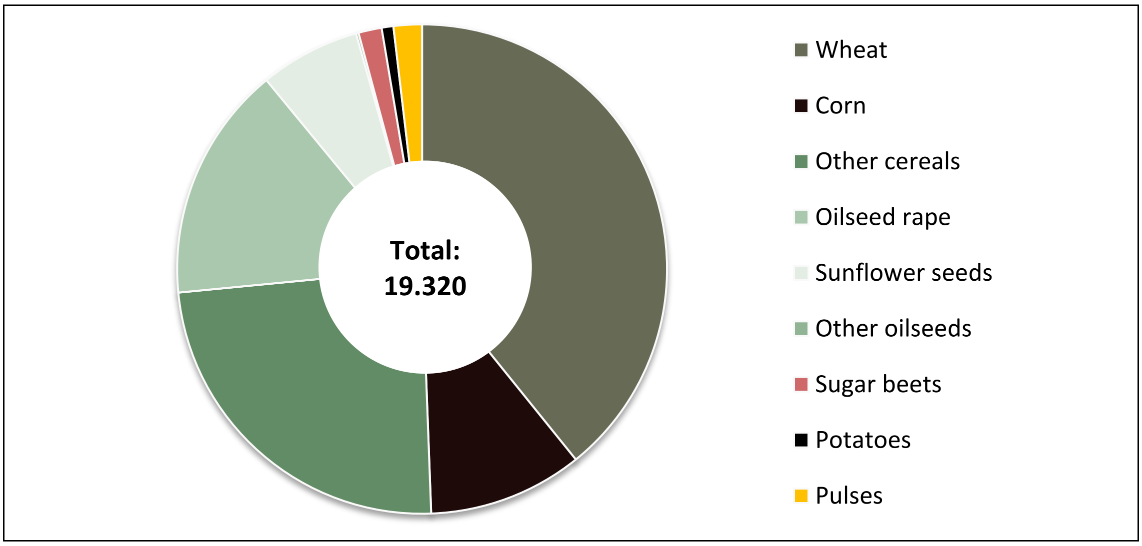
The figure reveals that European plant breeding allows the EU to export major arable crops such as wheat, other cereals and potatoes. If progress in crop genetics had not occurred in the past one and a half decades, the EU would have been a net importer of all arable crops including wheat and other small grains as well as potatoes. Hence, the EU agricultural trade deficit with the aggregated self-sufficiency being 92 percent in terms of carbohydrates and 85 (87) percent in terms of proteins (and fats) (see Noleppa and Cartsburg, 2015a) would considerably have deteriorated.

Saving land resources

The obvious reductions in exports and the apparent increases in imports in case of missing plant breeding activities would also change the balance of EU net imports of virtual agricultural land. Instead of just using the already substantial area of 17.6 million ha abroad (see also figure 2.2 for the current situation), 36.9 million ha in other world regions would be needed to satisfy the domestic demand. This equals the territory of Germany (UNSD, 2012).

The resulting avoided net virtual land trade of the EU due to successful plant breeding in its member states since the turn of the millennium is visualised in figure 4.10.

Figure 4.10: Avoided net virtual land trade with plant breeding for major arable crops in the European Union in the last 15 years (in million ha)



Source: Own calculations and figure.

Considering all other factors than land to be unchanged (e.g. yields in the other world regions), more than 19 million ha arable land would globally have been needed in addition to what is already used if plant breeding in the EU had been terminated in 2000. This would have meant an increase of more than 100 percent representing an area almost as large as the entire territory of Belarus (UNSD, 2012). The bulk of the potential growth in net land imports would be caused by wheat and other cereals followed by oilseed rape and corn. Just the additional area needed to cultivate extra wheat (7.6 million ha) is larger than the entire territory of Bavaria in Germany (Destatis, 2014) or almost as large as the Czech Republic (UNSD, 2012). The regional distribution of the additional imports of virtual agricultural land is listed in figure 4.11.

Figure 4.11: Regional distribution of avoided net virtual land imports with plant breeding for major arable crops in the European Union in the last 15 years (in million ha)

North America	Asia	Sub-Sahara Africa	CIS
1.476	1.346	2.120	5.102
South America	**MENA region**	**Oceania**	**Rest of Europe**
2.215	4.843	1.873	0.345

Source: Own calculations and figure.

Around 5.0 million ha would come each from the Commonwealth of Independent States (CIS) and the Middle East/North Africa (MENA) region. More than 2.0 million ha would be located in South America and also in Sub-Sahara Africa, while well above 1.0 million ha would need to be additionally occupied in North America, Asia, and Oceania.

Protecting the climate

This arable land needed extra globally without plant breeding in the EU in the last 15 years is not available per se. In a situation where estimates suggest global acreage to be expanded by 45 million ha between the years 2010 and 2020 (Laborde, 2011; Marelli et al., 2011) this land foremost needs to be additionally converted from grassland or natural habitats.

All this land is sequestering carbon both above and below ground. A tremendous part of this carbon would be released into the atmosphere in the form of CO_2 if the land was used for farming. The amount to be emitted in such a situation, yet avoided due to lasting genetic crops improvements, can be calculated by using the approach described in chapter 2.3 and yields the avoided CO_2 emissions. The resulting effect is visualised in figure 4.12.

Figure 4.12: Avoided regional CO_2 emissions with plant breeding for major arable crops in the European Union in the last 15 years (in million tons)

North America	Asia	Sub-Sahara Africa	CIS
215	398	413	862
South America	**MENA region**	**Oceania**	**Rest of Europe**
334	944	212	58

Source: Own calculations and figure.

Plant breeding successes in the EU since the year 2000 avoid an extra emission of CO_2 of more than 3.4 billion tons. This is equal to what the EU-15, the old member states, currently emit as GHG in total or half the climate gas emissions of the USA (WRI, 2014).

However, this is a one-time-only effect and putting these savings into perspective is challenging. Such non-recurring emissions are usually annualised by dividing total emissions by 20 (see e.g. Laborde, 2011). The avoided "annualised" CO_2 emissions of plant breeding in the EU in the past one and a half decades would consequently amount to approximately 170 million tons.

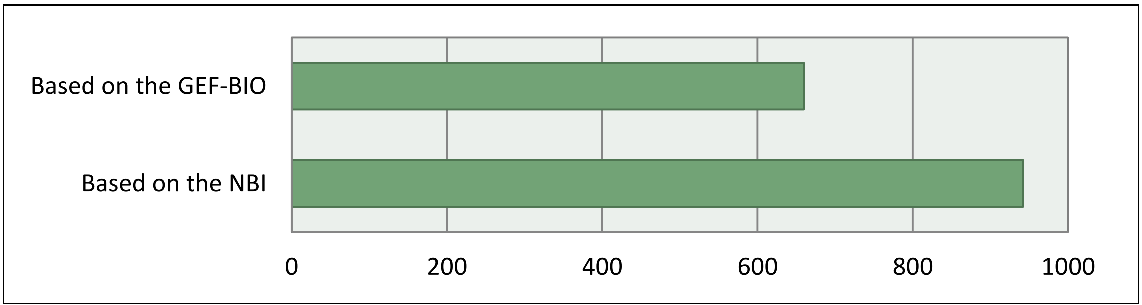
This is as much as the GHG emission reduction achieved by a rather ambitious country, namely Germany, between the years 1997 and 2014 (UBA, 2015a; 2010). At the same time it is similar to the CO_2 still emitted via traffic in Germany (UBA, 2015a) or total CO_2 emissions in a country like the Netherlands (Coenen et al., 2013). This implies that noteworthy and long-lasting efforts to reduce GHG emissions in EU member states would be counteracted in a rather short period of time without plant breeding.

Preserving global biodiversity

Remembering that plant breeding efforts in the EU since the year 2000 have avoided a conversion of grassland and natural habitats of more than 19 million ha worldwide with eco-zones rather rich in species compared to more or less intensely used arable land (Croezen et al., 2014; von Zeijts et al., 2011) it is also worth quantifying the associated "biodiversity preserving" effect of genetic crops improvements. As outlined in chapter 2, two methods for capturing this effect are applied.

One is the GEF-BIO approach and the other one is the NBI concept. The results of the two separate analyses are depicted in figure 4.13.

Figure 4.13: Globally preserved biodiversity with plant breeding for major arable crops in the European Union in the last 15 years (in million biodiversity index points)



Source: Own calculations and figure.

Based on the GEF-BIO, 660 million biodiversity index points would have been lost by neglecting plant breeding in the EU since the turn of the millennium on top of what has already been lost in terms of global species richness. This is equivalent to the biodiversity found in 6.6 million ha of Brazilian rainforest and savannahs. Assuming a current cutting rate in the Brazilian Amazon Forest of 0.54 million ha per year (OBT, 2013), this implies that plant breeding for arable crops in the EU between the years 2000 and 2014 has compensated for more than 12 years of deforestation in the Amazon region at current pace.

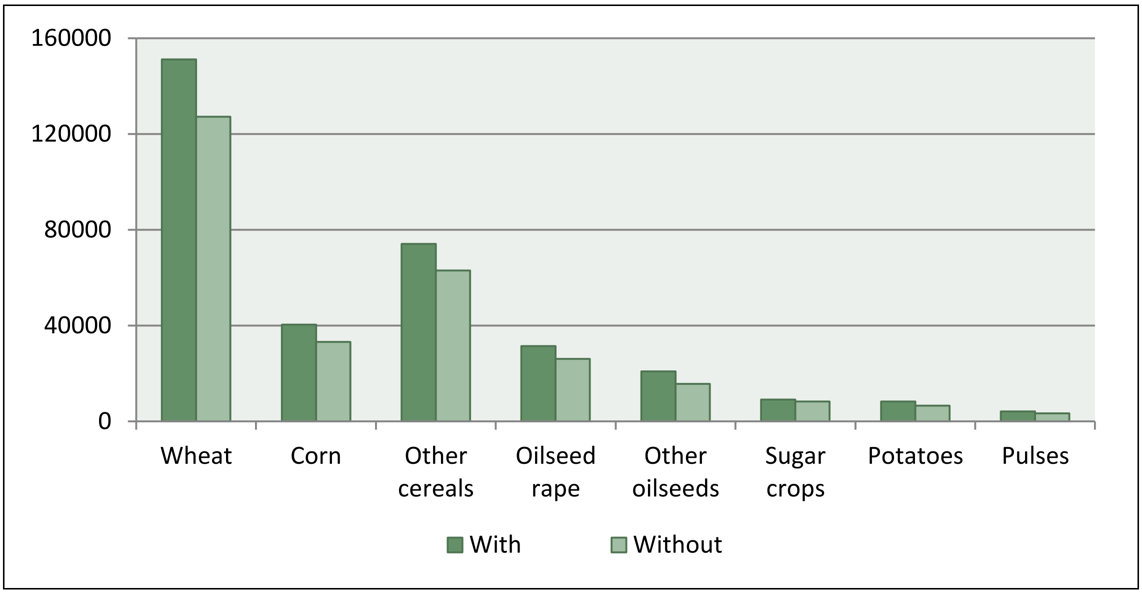
However, the NBI suggests an even larger loss in global biodiversity. It would have declined by an additional 942 million index points without genetic crops improvements in the EU since the turn of the millennium. Latest available figures for Indonesia, the country for which the NBI counts 100 index points per ha, indicate a loss of almost 30 million ha of rainforest from 1990 to 2005 (Leigh, 2011). If plant breeders in the EU had given up their jobs 15 years ago, global biodiversity would have been reduced to an equivalent of species richness on an additional 9.4 million ha of Indonesian rain forest.

Reduction of global water demand

Analysing the impact of plant breeding in the EU on global water demand requires a twofold approach. It has to be analysed (1) how water use in domestic production is stimulated and (2) how virtual water trade (via trade of agricultural commodities and products thereof) is affected.

Looking at domestic water use, first, it has to be noted that the subsequent analysis is still based on the imperfect assumption that equal amounts of water are needed to produce one unit of harvestable biomass. This counteracts the argument that water productivity rises with higher yield supported by various scientists (e.g. Zwart and Bastiaanssen, 2004; Lamm et al., 2009; Yuan and Shen, 2013). However, applying this academic knowledge simply fails because of data limitations. Thus, yield-independent water footprint data provided by Mekonnen and Hoekstra (2011) generate a higher domestic water use (since more crops are produced). The result considered as marking the top of current water use in EU arable farming is visualised in figure 4.14 (which does not separate sunflower seeds from other oilseeds due to given numbers for the reference situation, see figure 2.3).

Figure 4.14: Domestic water use in the European Union with and without plant breeding for major arable crops in the European Union in the last 15 years (in million m³)

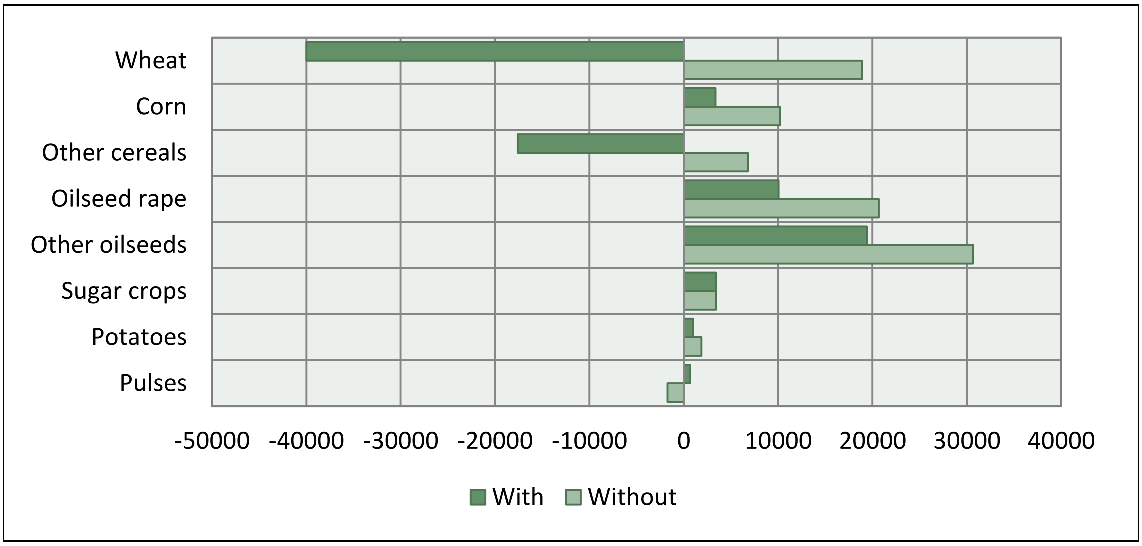


Source: Own calculations and figure.

Higher yields due to genetic crops improvements achieved in the last 15 years have raised the annual water use in EU arable farming by more than 55 billion m³ or 20 percent. At first glance, this very particular study outcome might be considered a negative effect of plant breeding. However, this additional water use (which is probably lower in reality as outlined above) has to be contrasted with substitution effects due to an alternative trade situation.

It has already become obvious that plant breeding was able to reduce agricultural commodity imports and expand respective exports (see figure 4.9). This means more virtual water is exported and less virtual water is imported via agricultural commodities and products thereof. The crop-specific outcome of this "water trade" impact is visualised in figure 4.15.

Figure 4.15: Net water imports (+) and exports (–) with and without plant breeding for major arable crops in the European Union in the last 15 years (in million m^3)



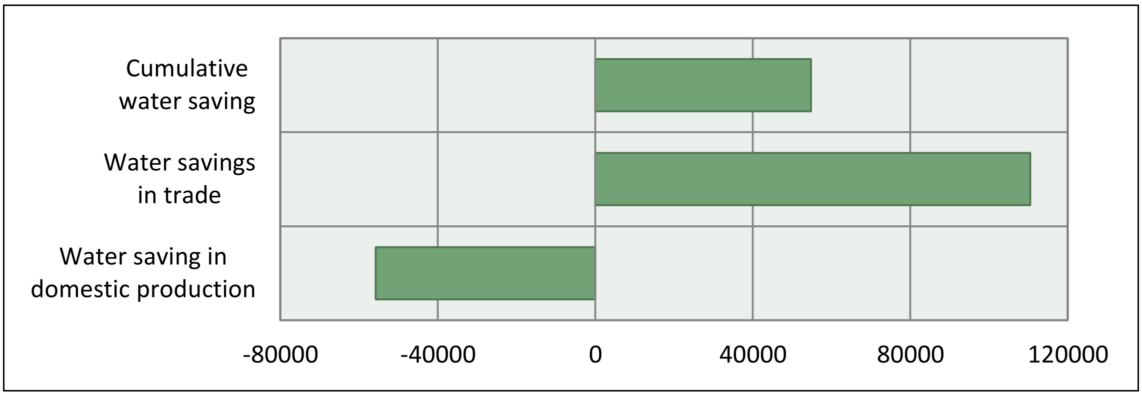
Source: Own calculations and figure.

Summing up the crop-specific water volumes displayed in the graph leads to the following conclusions:

- Instead of net exporting approximately 20 billion m^3 of agricultural water embedded in major arable crops and products thereof the EU would have had to have imported more than 90 billon m^3 of water due to missing plant breeding since the turn of the millennium.
- An additional amount of 110 billion m^3 virtual water would have had to have been net imported in the EU in case of a complete abolition of plant breeding since the year 2000. This is almost as large as the water volume of Lake Lucerne or Lake Müritz (Marsh et al., 2012).

This "saved" net agricultural water import overcompensates the additional water currently embedded in domestic arable farming due to plant breeding in past years. The current water "saving" of genetic crops improvements in the EU since the year 2000 accumulates to almost 55 billion m^3 as figure 4.16 displays.

Figure 4.16: Current cumulative water savings with plant breeding for major arable crops in the European Union in the last 15 years (in million m^3)



Source: Own calculations and figure.

This is as much as the water volume of Lago Maggiore and Lago di Como. These particular results support other scientific findings on more efficient agricultural systems saving water resources (Dalin et al., 2014) and are mainly based on the EU using water more productively than other world regions (Noleppa and Cartsburg, 2015b; Zwart et al., 2010). This becomes visible by finally looking at figure 4.17 depicting average crop-specific water productivity in the EU and in other world regions.

Figure 4.17: Average water productivity in the European Union and in other world regions for major arable crops (in kg per m^3)

Crop	Global (ex EU)	EU
Wheat	0.55	0.90
Corn	0.93	1.53
Barley	0.32	1.23
Oilseed rape	0.47	0.62
Sunflower seed	0.29	0.42
Sugar beets	6.62	12.66
Potatoes	4.02	6.94
Peas	1.02	4.07

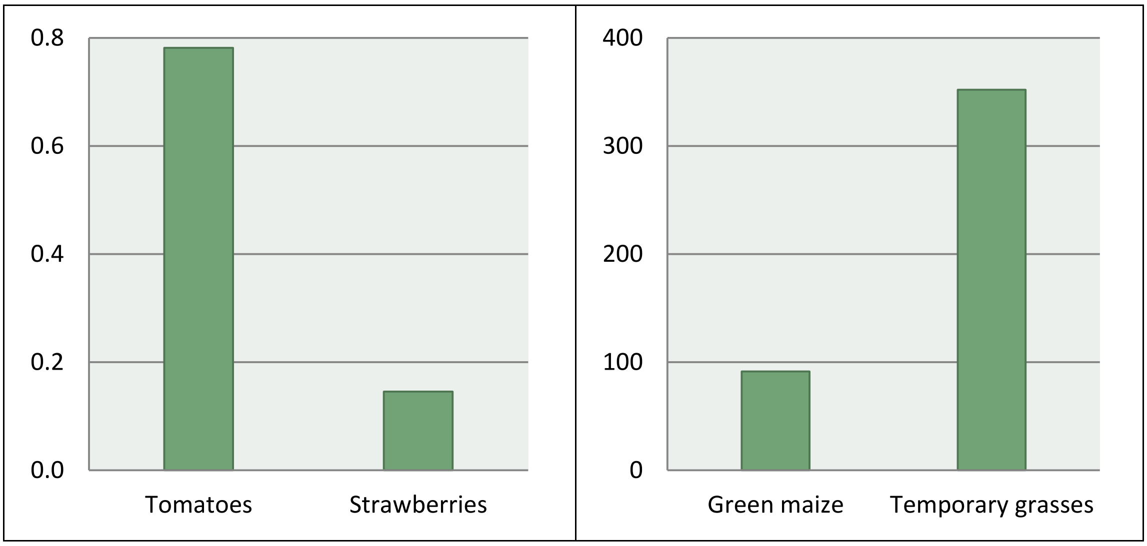
Source: Own calculations and figure based on Noleppa and Cartsburg (2015b) as well as Mekonnen and Hoekstra (2011).

4.3 Selected socio-economic and environmental values of plant breeding for other than major arable crops and specific benefits of plant breeding

The calculation of the socio-economic as well as environmental values of plant breeding in the EU for other than major arable crops is challenging. Severe data limitations and information gaps hinder conducting a thorough analysis. Therefore only selected effects can be highlighted hereafter.

The discussion starts with an assessment of the production increase with plant breeding in the EU in the last 15 years in cultivating tomatoes – distinguishing field tomatoes and greenhouse tomatoes is not possible because of unsatisfactory statistical data –, strawberries and the two predominant forage crops on arable land (green maize and temporary grasses). The impacts are visualised in figure 4.18.

Figure 4.18: Additional current supply of tomatoes, strawberries and forage crops on arable land in the European Union with plant breeding in the last 15 years (in million tons)



Source: Own calculations and figure.

The numbers need to be put into perspective. With plant breeding for tomatoes in the last 15 years, an additional production quantity of 781 000 tons annually is generated in the EU. This is similar to the tomatoes production of France (Eurostat, 2015b). An additional amount of 145 000 tons of strawberries almost equals the production of this fruit in Germany (Steinbacher and Schlossberger, 2015), Italy or Morocco, which is a major strawberries exporting country outside the EU (Appeltans, 2010).

Furthermore it has to be noted that without plant breeding in the last 15 years more than 90 million tons of green maize and more than 350 million tons of temporary grasses for forage (measured in fresh mass) would also be missing in the EU today. According to KTBL (2014b), both together correlate with approximately 235 million tons of silage. Only fed to bovine animals using average feed ratios (KTBL, 2009), this volume of silage is enough to provide forage to at least 16 million heads or 18 percent of all bovine animals in agricultural holdings across the EU (see Eurostat, 2015b).

This highlights a particular importance of plant breeding which might easily be overlooked if only considering crops: Plant breeding in the EU is not only essential for crop production but also a vital component of a competitive livestock sector within EU agriculture. For forage crops such as Italian ryegrass and maize and especially for hybrids thereof plant breeding is very important and has led to varieties adopted to a wide range of diverse geographical conditions (von Huyghe et al., 2014). Green maize, e.g., is nowadays also grown in comparably wet and cool environments of Western and Northern Europe.

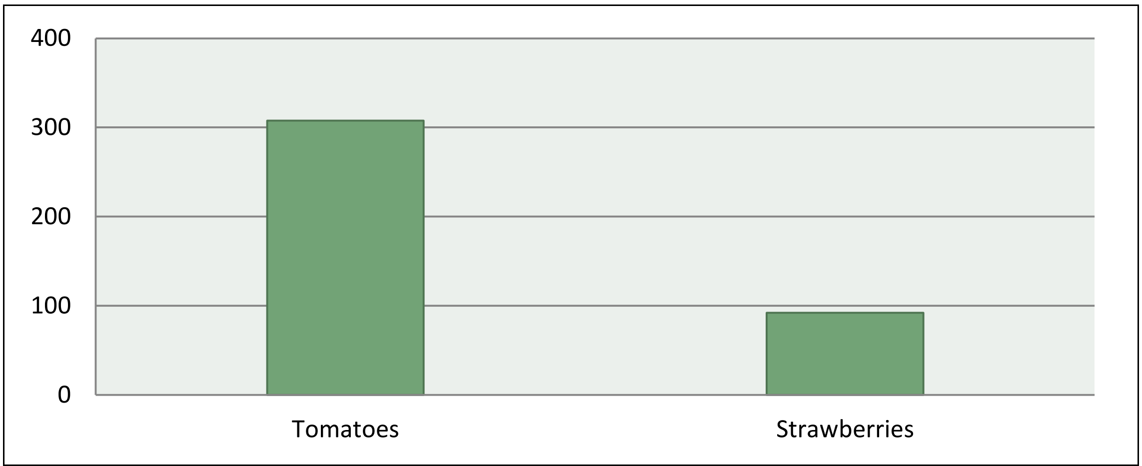
Quantitative information for tomatoes and strawberries allow to additionally analyse monetary impacts. Using single market models as briefly discussed in chapter 2 and calibrated with data gathered from Appeltans (2010), BLE (2015), Eurostat (2015b), FAO (2015a; c), Statista (2015), Steinbacher and Schlossberger (2015), and Sutor et al. (2015) leads to the following conclusions regarding the additional monetary value added in value chains in the EU with plant breeding for tomatoes and strawberries in the last 15 years.

This value added is consistently measured at the wholesale/retail sale level (for which meaningful and comparable prices are available) and depicted in figure 4.19. It turns out that a rather high economic impact occurs:

- In tomatoes production alone, the economic impact added along the value chain with plant breeding in the last 15 years accumulates to approximately EUR 300 million.
- Along the value chain of strawberries, almost EUR 100 million are added.

Thus, the importance of plant breeding for high-value crops such as fruits and vegetables should obviously not be underestimated and is considered an advisable investment – at least from a macroeconomic point of view.

Figure 4.19: Current extra value added in the European Union with plant breeding for tomatoes and strawberries in the last 15 years (in million EUR)



Source: Own calculations and figure.

Remarks on a few but interesting environmental benefits concerning the case study crops of this study finalise this specific quantitative assessment. Again, the missing production volumes (see figure 4.18) can be translated into acreage which would be additionally needed to compensate. For tomatoes and strawberries, the respective analysis integrates international trade and is thus similar to what has been applied above when analysing major arable crops. However, for the two non-tradeable forage crops usually grown on arable land a shift from grassland (or non-temporary set-aside land) to arable land in the EU would be the only meaningful option. Figure 4.20 displays the results of such a transformation.

Figure 4.20: Avoided net virtual land trade with plant breeding for tomatoes, strawberries and forage crops on arable land in the European Union in the last 15 years (in million ha)

	Tomatoes	Strawberries
Additional arable land abroad	0.023	0.008
	Green maize	**Temporary grasses**
Additional arable land in EU	2.285	4.191

Source: Own calculations and figure.

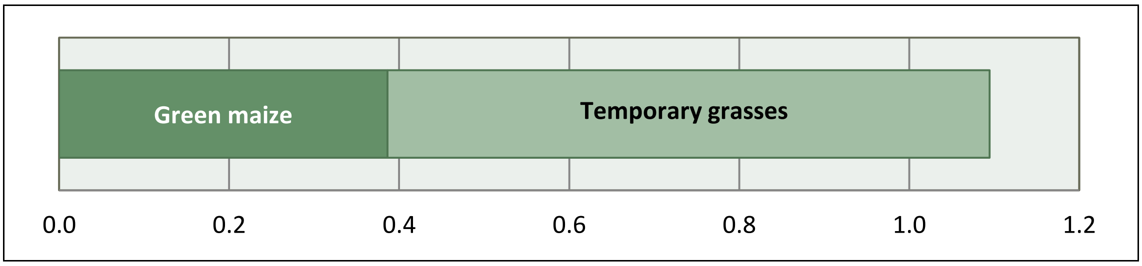
At first glance, the numbers are not very spectacular with respect to tomatoes and strawberries. An additional area of 23 000 ha grown with tomatoes and an extra

8 000 ha cultivated with strawberries would be used by EU trading partners. However, knowing from Noleppa and Cartsburg (2014a) that a few years ago no land cultivated with berries was virtually net traded by the EU and only 25 000 ha cultivated with tomatoes were virtually net exported, the indicated change could be considered a tremendous deterioration of the specific trade and virtual land trade balances.

Looking at forage crops, the value of plant breeding in terms of the actually avoided grassland conversion towards arable land is impressive. Without plant breeding in the last 15 years, an additional area of almost 6.5 million ha of grassland would have to be ploughed in the EU in order to compensate for production losses in green maize and temporary grasses. This corresponds to approximately 10 percent of the EU's entire permanent grassland (Eurostat, 2009) still serving as a carbon sink and being rich in biodiversity, what is a conservative assessment since subsequently missing forage from grassland could not be taken into account with the approach chosen.

Finally, resulting GHG emission and biodiversity impacts of plant breeding in the EU for forage crops in the last 15 years are discussed keeping in mind that figures might be higher if the probably missing forage from grassland was analysed too. Figure 4.21 highlights the CO_2 emission effect and figure 4.22 visualises the biodiversity outcome:

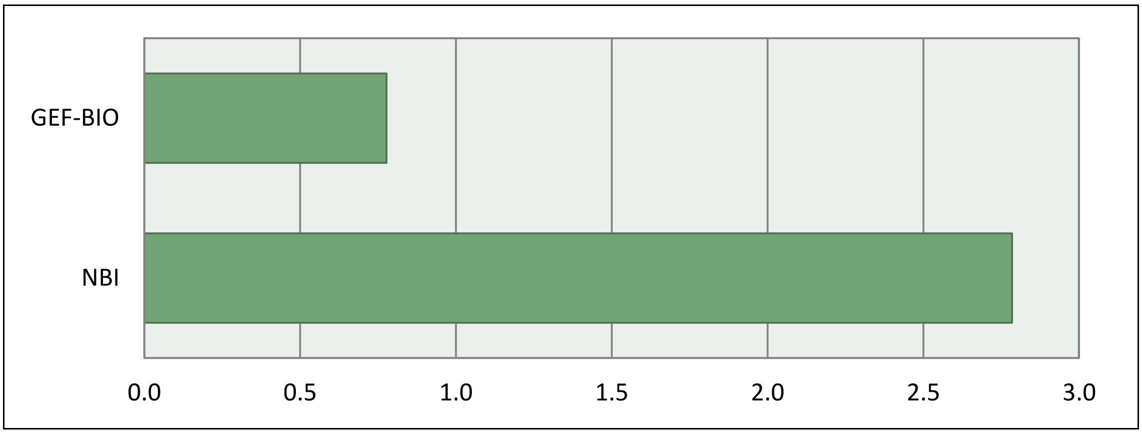
Figure 4.21: Avoided CO_2 emissions with plant breeding for forage crops on arable land in the European Union in the last 15 years (in billion tons)



Source: Own calculations and figure.

With plant breeding for green maize and temporary grasses in the last 15 years, the EU has been able to avoid more than 1.0 billion tons of additional CO_2 emissions. This is more than the volume of annual GHG emissions of a country like Germany or twice as much as the annual GHG emissions of France (see WRI, 2014). Divided through 20, i.e. annualised, it is as large as the GHG emissions occurring in EU member states like Denmark or Bulgaria (see also WRI, 2014).

Figure 4.22: Preserved biodiversity with plant breeding for forage crops on arable land in the European Union in the last 15 years (in million tons)



Source: Own calculations and figure.

The same plant breeding efforts have additionally preserved biodiversity in the EU which can be compared to species richness currently available on 0.7 million ha of Brazilian ecosystems or 2.7 million ha of Indonesian environments.

The discussion has concentrated on the yield effect of plant breeding in the EU and values resulting from this yield effect. However, plant breeding does not only tackle land productivity. Genetic crop improvements also aim at better quality and other parameters. In a period when the agricultural value chains face manifold challenges such as population growth, changing eating habits, scarce land and water resources, climate change impacts, food waste, etc., the development of new varieties mirrors approaches towards meeting these challenges. Discussing all these attempts would exceed the scope of this study. Nevertheless, a few examples particularly dealing with breeding for (a) better water use, (b) combating food waste, and (c) providing more healthy and convenient food shall finally be discussed accentuating the analysis above and demonstrating that modern plant breeding is much more than looking for higher yields. Instead, it provides many more beneficial values for the society at large.

Increasing global water scarcity is a fact (Hanjra and Qureshi, 2010), and agriculture considerably contributes to this shortage by using up to 70 percent of the anthropogenic freshwater consumption (Biewald et al., 2014; UNESCO, 2014). Breeding for higher yields per se helps mitigate the problem (see above). However, plant adaptation to water stress and in particular towards drought and water logging tolerance is also a must. Therefore, the development of plants with increased survivability and growth during water stress is a major objective in plant breeding (Osakabe et al., 2014), especially in relation to climate change.

Respective efforts concentrate amongst others on the stomatal and membrane transport during water stress (see e.g. Geiger et al., 2009), the identification and use of transcription factors (see e.g. Aprile et al., 2009; Jogaiah et al., 2012), a better understanding of early water stress response and signal transduction pathways (see e.g. Christmann et al., 2013; de Lorenzo et al., 2009), and on protecting photosynthesis during water stress (see e.g. Estavillo et al., 2011). The utilisation of these and other underlying technologies makes it possible to modify the regulation of water through genes leading to region-specific crop varieties having an improved stress tolerance in terms of drought or water logging while maintaining crop productivity (Herzog et al., 2015; Osakabe et al., 2014).

While water is becoming increasingly scarce, food at least in developed countries is still too often considered an almost non-restricted and cheap resource leading to a tremendous amount of waste. On global scale and independent on being a developed or less developed country, 30 to 40 percent of all the potentially availably food is wasted along the value chain and at consumer level (see, e.g., Abeliotis et al., 2014; Fox und Fimeche, 2013; Gustavsson et al., 2011). Consequently, BCFN (2012) as well as Caronna (2011) came to the conclusion that approximately 180 kg of food per capita are wasted in the EU. Avoiding food waste is now on the political agenda and publicly debated (Bagherzadeh et al., 2014; EC, 2015; HLPE, 2014; Lipinski et al., 2013; Monier et al., 2010; Schneider, 2013).

Plant breeders are engaged in minimizing food waste what is found in numerous examples. Efforts in the EU are often targeted at potatoes, fruits and vegetables and concentrate on maintaining and improving quality throughout the post-harvest production chain to prevent spoilage (see Bovy, 2015; Cullen et al., 2015; NBT, 2015). Post-harvest decay of fruits and vegetables is considered a major challenge (Abano and Buah, 2014). The following listing exemplary highlights three of such efforts made in the EU:

- Plant breeding activities in the Netherlands target potatoes to have the right shape for crisps or chips. This avoids unnecessary losses during peeling and cutting (Larsson, 2015).
- Scientists in England managed to extend the shelf life of lettuce by breeding for smaller leaves with lots of cells packed closely together. Thus, the leaves remain green and crisp for longer, i.e. for more than a week (Lim, 2014).
- Scottish plant breeders have investigated the genetics of fruit softening. Markers which have been found can now be added to breeding tools speeding

up the development of new varieties with desirable traits, e.g. in the case of raspberries (Cullen et al., 2015).

Global food availability faces two major challenges: providing sufficient food and delivering of more healthy and convenient food. While food insecurity in some parts of the world can partially be overcome by providing more food (e.g. through higher yields), it is at the same time a matter of single nutritious components such as vitamins and other micronutrients in the available food. In parallel, people especially in more wealthy countries demand food characterised by consumer quality traits, such as flavour, nutritional value, colour, easy handling, and firmness (Bovy, 2015). Breeding for such quality issues directly targets an improvement of consumers' health and wellbeing.

Discussing current plant breeding efforts towards such innovations in crops numerous examples can be found. Newell-McGloughlin (2008) alone summarised more than 50 case studies aimed at providing health benefits. Others are listed in Kaput et al. (2015). NBT Platform (2015), e.g., highlights EU breeding efforts focussing on enhancing vitamin levels and reducing allergens as well as on changing colour, odour, flavour and texture of crops. Other attempts target an increase of so-called phytonutrients in crops assumed to mitigate chronic diseases and cancer (see e.g. Eckardt, 2011; Martin, 2011; Traka and Mithen, 2011). Noteworthy are also breeding successes displayed in BSPB (2015a; c) and BDP (2015a): Oilseed crops with healthier oil profiles, brassica crops with increased levels of beneficial nutrients and hitherto unknown uniformity, improvements in disease resistance reducing levels of harmful mycotoxins in small cereals and corn, barley varieties with reduced ingredients causing potentially toxic metabolites while malting, cauliflower with meal-sized florets, seedless peppers, potatoes for every culinary purpose, tomatoes not losing juice when sliced, etc. are now on the market and substantially improve specific health problems as well as the general well-being of consumers in the EU and beyond.

These very few examples complete the picture drawn with respect to the numerous benefits modern plant breeding offers for yield growth in the EU. They additionally portray genetic crop improvements today offering more than a substantial contribution towards the availability of food and other agricultural raw materials per se, namely an entire tool-kit for meeting many, if not most, of the important challenges EU and global agriculture is facing.

5 Potential benefits of future plant breeding activities

Part of this study previews and assesses the share continuous plant breeding efforts in the EU could contribute in terms of the various socio-economic and environmental target indicators discussed from an *ex post* point of view. However, such a comprehensive and future-oriented assessment first of all requires to define the following guiding principles:

- The projections to be made shall focus on the year 2030, i.e. a fifteen-year time horizon (2016-2030 instead of 2000-2014) is again analytically envisaged. Major arable crops are covered hereafter. Respective simulations for the five case study crops have failed due to severe data limitations.
- Within this period, plant breeding will have the same importance for TFP growth in EU agriculture as in the past, i.e. the annual growth rates with plant breeding displayed in figures 3.11 and 3.12 once again apply.
- Consequently, the potential agricultural market situation in the EU around the year 2030 has to be set as reference scenario for analyses. For describing such a reference scenario available OECD and FAO (2015) forecasts have been used and extrapolated for the target year 2030.
- However, these available projections only allow to distinguish wheat and coarse grains as well as oilseeds and roots and tubers. Pulses are not included. To be methodologically consistent, changes over time in production, prices and trade volumes according to OECD and FAO (2015) and subsequent extrapolation are set to be equal for (a) corn and other cereals, (b) oilseed rape, sunflower seeds and other oilseeds, and (c) sugar beets and potatoes. Respective changes in pulses are assumed to be zero.

Change rates resulting from comparing the years 2030 vs. 2016 are displayed in figure 5.1.

Figure 5.1: Major assumptions for the ex ante assessment of plant breeding benefits (in percent for 2030; 2016 = 100 percent)

	Production change	Market price change	Trade volume change
Wheat	110.3	110.6	130.5
Coarse grains	109.0	139.2	20.0
Oilseeds	108.6	136.7	95.4
Roots and tubers	105.0	93.9	10.0
Pulses	100.0	100.0	100.0

Source: Own assumptions and figure based on OECD and FAO (2015) and own extrapolations.

In addition, the following assumptions had to be made allowing for a more realistic projection of potential future plant breeding benefits.

- Labour in arable farming of the EU is assumed to continuously decrease as in the past, i.e. at a rate of around 3.0 percent per annum.
- Labour productivity in upstream and downstream industries of the agricultural value chains is supposed to increase at a rate of 2.0 percent.
- Land productivity increases, i.e. yield growth rates, in the other world regions are presumed to average 1.5 percent per year.
- Global water productivity is finally considered to grow at a rate of 1.0 percent per annum.
- All other factors, e.g. carbon release factors per ha of newly cultivated agricultural land, biodiversity index values, etc. are held constant.

These assumptions lead to the following potential future benefits of plant breeding in the EU starting with the socio-economic effects.

5.1 Potential future socio-economic benefits of plant breeding in the European Union for arable crops

Figure 5.2 visualises the magnitude of benefits with plant breeding in the next 15 years, i.e. for the target year 2030, and compares these potential ex ante benefits with achieved ex post values as discussed in chapter 4. Accordingly, it can be concluded that additional arable crop supply due to plant breeding in the EU will even be higher in the 15 years to come than in the last one and a half decades. Instead of an extra 70.0 million tons of cereals, oilseeds, roots and tubers, as well as pulses with plant breeding in the last 15 years, 76.0 million tons of these commodities will be able to be produced on top of what will be achievable without plant breeding in the next 15 years. This amount would be sufficient to additionally feed almost 180 million humans with carbohydrates, more than 220 million people with vegetable proteins, or 120 million humans with vegetable oils.

Future monetary benefits are also higher compared to the particular plant breeding benefits of the last 15 years. Social welfare on agricultural markets might increase in future by EUR 11 billion and GDP by EUR 18 billion compared to a scenario without plant breeding in the EU in the next 15 year. Thus, the future monetary gain is 25 percent higher than what is contributed to EU societies at present. These monetary indicators tend to change more significantly than tonnages mainly due to the expected ongoing increase of agricultural market prices.

Figure 5.2: Analytical results of the ex ante assessment (plant breeding in the next 15 years) for socio-economic indicators in relation to the ex post evaluation (plant breeding in the last 15 years)

	Ex post evaluation	*Ex ante* assessment	Ratio (in percent)
Additional arable crop supply (in million tons)	70.042	75.997	109
Additional global food supply (for million humans)			
- Carbohydrates	163	178	109
- Proteins	206	224	109
- Fats/oils	111	120	109
Additional social welfare (in billion EUR)	8.908	11.167	125
Additional economy-wide GDP (in billion EUR)	14.489	18.163	125
Farm income induced by plant breeding (in EUR/AWU)	6 989	14 263	204
Additional AWU in arable farming	54 441	38 963	72
Additional labour force upstream and downstream the value chains	13 540	11 166	83

Source: Own calculations and figure.

Furthermore, the potential development of labour impacts reveals interesting but twofold results. On the one hand, the additional future farm income due to plant breeding can be expected to be immense because the additional producer surplus to be used for income generation will rise at similar pace as societal welfare while labour engaged in farming tends to decrease at a rate of 3.0 percent per annum. On the other hand, it is exactly the decrease in labour engaged in arable crop production and associated gains in labour productivity along the agricultural value chains that cause a rather low future impact of plant breeding on agricultural jobs as well as jobs in upstream and downstream industries.

5.2 Potential environmental benefits of plant breeding in the European Union for arable crops

Figure 5.3 reveals slightly decreased future environmental benefits of plant breeding (with an average rate of approximately 5 percent) compared with current benefits.

Figure 5.3: Analytical results of the ex ante assessment (plant breeding in the next 15 years) for environmental indicators in relation to the ex post evaluation (plant breeding in the last 15 years)

	Ex post evaluation	*Ex ante* assessment	Ratio (in percent)
Avoided net virtual land trade (in million ha)	19.320	18.305	95
Avoided global CO_2 emissions (in billion tons)	3.438	3.258	95
Globally preserved biodiversity (in million biodiversity index points)			
- GEF-BIO	660	625	95
- NBI	942	893	95
Global water savings (in million m^3)			
- Additional water use in domestic production	55 758	52 980	95
- Water savings in trade	110 496	105 570	96
- Cumulative water savings	54 738	52 590	96

Source: Own calculations and figure.

However, this particular outcome of the study is caused by changing framework conditions only, in particular the fact that land productivity in all other world regions will still improve despite an investment stop in plant breeding innovation in the EU for the period of the next 15 years. This and the defined increase in global water productivity over time would allow the EU to use less land and other environmental resources (such as biodiversity) abroad than without such an "external" productivity growth independent of plant breeding innovation in the past and the next 15 years.

If this "autonomous" productivity enhancement was neglected, above-listed environmental benefits of plant breeding for major arable crops in the EU in the next 15 years would be approximately 10 percent higher than with plant breeding in the past 15 years.

6 Concluding remarks

The overall working hypothesis of this academic study stated that modern plant breeding in the EU acts at (a) increasing social welfare by generating additional income to farmers as well as in upstream and downstream industries related to the agricultural value chain, (b) providing a greater quantity of less expensive food to meet the rapidly growing needs of the world, (c) stabilising agricultural commodity markets, (d) adding jobs and social value to rural areas of the EU, (e) preserving valuable and scarce natural resources such as land habitats and water reservoirs, (f) reducing GHG emissions resulting from a decreased expansion of the global agricultural acreage, and (g) protecting biodiversity around the globe.

As shown in the paper, plant breeding in the EU contributes to various economic, social and environmental values. The picture drawn is based on sophisticated modelling and calculation tools (chapter 2) as well as a rather comprehensive assessment of plant breeding contributions to land productivity and overall productivity enhancement in EU arable farming (chapter 3). It turns out that plant breeding innovations count a lot: On average and across all major arable crops cultivated in the EU, plant breeding contributes approximately 74 percent to overall productivity growth (figure 3.10) equal to an increase of yields by 1.24 percent per annum (figure 3.11).

Based on this productivity growth, plant breeding activities towards major arable crops in the EU in the last 15 years (chapter 4.1 and chapter 4.2) resulted in benefits which can be characterised, quantified and summarised with the following ten key statements:

1. Increasing yields

   With plant breeding for major arable crops in the EU in the last 15 years yields per ha have increased. On average and across all major arable crops harvested in EU member states, yields and consequently production would be more than 16 percent lower without genetic crop improvements (figure 4.1).

2. Improving market conditions

   Higher yields per unit of arable land increase the supply of primary agricultural products on international markets. For example, an additional 47 million tons of grains and 7 million tons of oilseeds can currently be produced in the EU with plant breeding for these crops in the last 15 years. This contributes to stabilising markets and reducing price volatility (figure 4.2 and figure 4.4).

3. Increasing potential world food supply

   Plant breeding in the EU is also indispensable for combating hunger and malnutrition and improves the world food security situation. Given current global per capita rates of nutrient consumption, genetic crop improvements in the EU in the last 15 years assure the additional availability of carbohydrates, proteins and vegetable oils to feed between 100 and 200 million humans (figure 4.3) – if the additionally produced volume becomes fully usable in world regions where it is really needed.

4. Generating economic prosperity and increasing social welfare

   Plant breeding in the EU generates additional economic prosperity by increasing the GDP. The entire agricultural value chain benefits from input suppliers to final consumers. Genetic crop improvements in EU arable farming since the turn of the millennium have generated in the agricultural sector alone an additional social welfare gain of almost EUR 9 billion and have added more than EUR 14 billion to the EU's GDP (figure 4.5 and figure 4.6).

5. Creating additional farm income and securing agricultural jobs

   Breeding for yields in arable farming in the EU also secures employment and increases the income of farmers and agricultural employees. Approximately 7 000 EUR/AWU on average, i.e. 30 percent of the income of an arable farmer in the EU, have been induced by plant breeding in the last 15 years (figure 4.7). Moreover, almost 70 000 jobs have been created in the arable sector (figure 4.8) as well as upstream and downstream the agricultural value chain in the EU.

6. Improving the agricultural trade balance

   Plant breeding in the EU not only brings about positive economic and social effects, but it also generates substantial environmental effects. It helps save scarce land resources around the globe by generating higher yields per unit of area. This improves the EU agricultural trade balance. Without plant breeding in the last 15 years, the EU would have become a net importer in all major arable crops (figure 4.9).

7. Minimising net virtual land imports

   In addition, plant breeding minimises the net virtual land imports of the EU, which currently amount to more than 17 million ha. In the absence of plant breeding for major arable crops in the EU in the last 15 years the global agricultural acreage would have to be expanded by more than 19 million ha (figure 4.10 and figure 4.11).

8. Reducing CO_2 emissions

   This contributes to preserving natural habitats and to reducing GHG emissions resulting from an expansion of the global acreage. Plant breeding in the EU secures less CO_2 being emitted by helping avoid negative land use change. A total of about 3.4 billion tons of direct CO_2 emissions have been avoided by genetic improvements in major arable crops in the EU in the last 15 years (figure 4.12).

9. Preserving biodiversity

   In addition, plant breeding in the EU generates a large positive biodiversity effect. Without plant breeding in the EU in the last 15 years, global biodiversity equivalent to 6.6 million ha of Brazilian rainforest or 9.4 million ha of Indonesian rainforest would have been lost (figure 4.13).

10. Saving agricultural water resources

    Plant breeding in the EU for major arable crops in the last 15 years has finally contributed to saving scarce water resources around the globe. Without plant breeding 55 million m^3 of water would be additionally needed (figure 4.16). This is as much as the water volume of Lago Maggiore and Lago di Como.

Considering other than major arable crops, i.e. some selected fruits and vegetables as well as temporary forage crops on the one hand and other breeding objectives than breeding for yield on the other hand, even more benefits and values of EU plant breeding can be identified (chapter 4.3). The specific research findings portray genetic crop improvements offering more than a substantial contribution towards the availability of food and other agricultural raw materials per se, namely an entire tool-kit for meeting many, if not most, of the important global challenges agriculture is facing.

Looking ahead, the perspective changes only a bit (chapter 5). Most of the indicators which have been analysed with respect to plant breeding for major arable crops in the EU in the last 15 years, i.e. since the turn of the millennium, show an even higher or rather stable value if applied to plant breeding in the upcoming 15 years, i.e. until 2030. This allows to summarise that successfully innovated genetic crop improvements in the EU have been and will be essential for economic, social and environmental benefits at large scale and should indeed be considered a highly effective measure for adapting to new and very dynamic settings.

Plant breeders in the EU, however, face a rather challenging policy and regulatory framework, as made clear in the introductory remarks of this study (chapter 1). They have to be encouraged to further and even more invest into new seed varieties and sophisticated breeding technologies instead of being hindered to spend the necessary resources on urgently needed future productivity and efficiency growth. The obviously high societal rates of return plant breeding investments generate have to be broader acknowledged and politically supported be it through proper administration, sound legislation, higher financial support (e.g. by boosting public investment in basic research), or overall awareness raising.

This study has tried to increase such an awareness by providing evidence of the multiple benefits of plant breeding in agriculture and beyond based on reproducible findings and scientific facts for arable crops in the EU. In particular, the results of the study should help better inform and facilitate an unbiased public debate on the importance of historic, current and future genetic crop improvements for specific socio-economic and environmental objectives. As such, the study should be considered an initial. Further research has to follow.

Potential points of departure are obvious: The rather general discussion of EU plant breeding could be further focussed and might be fine-tuned towards individual EU member states, specific crops and/or current as well as upcoming breeding technologies; qualitative arguments discussed (e.g. breeding for water stress tolerance, combating food waste, nutritional and health value) but also others not at all mentioned above might be quantifiable as well; plant breeding could also be seen as just one – of course important – technology which is able to create even more benefits in symbiosis with other technologies such as modern fertilisation, irrigation, plant protection, tillage, etc.; in addition, new agricultural approaches such as integrated production systems and smart agriculture closely linked to plant breeding should analytically be considered. Analysing the various values and benefits from such a more holistic point of view would certainly help to identify additional promising measures targeted at desperately needed future productivity growth in EU and global agriculture.

Reference list

Abano, E.E.; Buah, J.N. (2014): Biotechnological approaches to improve nutritional quality and shelf life of fruits and vegetables. In: International Journal of Engineering and Technology 4, p. 660-672.

Abeliotis, K.; Chroni, C.; Kyriacou, A.; Lasaridi, K. (2014): Food waste within households: a review on the generated quantities and potential for prevention. Athens: Harokopio University.

Acquaah, G. (2012): Principles of plant genetics and breeding. 2nd edition. Hoboken, NJ: John Wiley & Sons.

Ahlemeyer, J.; Friedt, W. (2010): Entwicklung der Weizenerträge in Deutschland: Welchen Anteil hat der Zuchtfortschritt? Giessen: Justus-Liebig-Universität.

Alston, J.M.; Pardey, P.G. (2014): Agriculture in the global economy. In: Journal of global perspectives 28, p. 121-146.

Andersen, S.B.; Thomsen, T.H.; Jensen, C.S.; Rasmussen, M.; Gylling, M.; Haastrup, M.; Bertelsen, I.; Jahoor, A.; Sander, B. (2015): An analysis of the potential for breeding better plant varieties. Copenhagen: FVM.

Appeltans, P. (2010): Strawberries in Europe. Antwerp: VBT.

Aprile, A.; Mastrangelo, A.M.; De Leonardis, A.M.; Galiba, G.; Roncaglia, E.; Ferrari, F. (2009): Transcriptional profiling in response to terminal drought stress reveals differential responses along the wheat genome. In: BMC Genomics 10. Doi: 10.1186/1471-2164-10-279.

Araus, J.L.; Slafer, G.A.; Royo, C.; Serret, M.D. (2008): Breeding for yield potential and stress adaptation in cereals. In: Critical Reviews in Plant Science 27, p. 377-412.

Bagherzadeh, M.; Inamura, M.; Jeong, H. (2014): Food waste along the food chain. OECD Food, Agriculture and Fisheries Papers No. 71. Paris: OECD.

Ball, E.; Schimmelpfenning, D.; Wang, S.L. (2013): Is U.S. agricultural productivity growth slowing? In: Applied Economic Perspectives and Policy 35, p. 435-450.

BCFN (Barilla Center for Food and Nutrition) (2012): Food waste: causes, impacts and proposals. Parma: BCFN.

BDP (Bund Deutscher Pflanzenzüchter) (2015a): Plant breeding – crops – vegetables. Bonn: BDP.

BDP (Bund Deutscher Pflanzenzüchter) (2015b): Zukunft der Pflanzenzüchtung am Scheideweg: Züchtungsausnahme drastisch gefährdet. Bonn: BDP.

Biewald, A.; Rolinski, S.; Lotze-Campen, H.; Schmitz, C.; Dietrich, J.P. (2014): Valuing the impact of trade on local blue water. In: Ecological Economics 101, p. 43-53.

Björnstadt, A. (2014): Impact on Nordic plant production from the use of genetic resources in plant breeding – past, present and future: As: NMBU.

BLE (Bundesanstalt für Landwirtschaft und Ernährung) (2015): Marktbericht – Obst – Gemüse – Südfrüchte. Verschiedene Volumina. Bonn: BLE.

Börjeson, L. (2010): Agricultural intensification. In: Warf, B. (ed.): Encyclopedia of geography. DOI: http://dx.doi.org/10.4135/9781412939591. London: SAGE Publications.

Borlaug, N.E.; Buchanan, G.; Herdt, R.W.; Tweeten, L.G. (2010): Agricultural productivity strategies for the future: addressing U.S. and global challenges. In: CAST Issue Paper 45, p. 1-16.

Bovy, A.G. (2015): Breeding for quality. Wageningen: Wageningen UR.

Bradshaw, J.E. (2009): Potato breeding at the Scottish plant breeding station and the Scottish crop research institute: 1920-2008. In: Potato Research 52, p. 141-172.

Breisinger, C.; Thomas, M.; Thurlow. J. (2010): Food security in practice: social accounting matrices and multiplier analysis: an introduction with exercises. Washington, DC: IFPRI.

BSPB (British Society of Plant Breeders) (2013a): Plant breeding matters: health. Ely: BSPB.

BSPB (British Society of Plant Breeders) (2013b): Plant breeding matters: lifestyle. Ely: BSPB.

BSPB (British Society of Plant Breeders) (2013c): Science and technology: written evidence submitted by the British Society of Plant Breeders. Ely: BSPB.

Caronna, S. (2011): Bericht über das Thema „Schluss mit der Verschwendung von Lebensmitteln – Strategien für eine effiziente Lebensmittelversorgungskette in der EU“. Brüssel: Europäisches Parlament.

Carter, R.; Clarke, J.; Tompkins, S. (2015): Review of the objectives of modern plant breeding and their relation to agricultural sustainability. Cambridge: ADAS.

CBD (Convention on Biological Diversity) (2014): Global Biodiversity Outlook 4. Montreal: CBD.

CBD (Convention on Biological Diversity) (2001): Global Biodiversity Outlook 1. Montreal: CBD.

Christmann, A.; Grill, E.; Huang, J. (2013): Hydraulic signals in long-distance signaling. In: Current Opinion in Plant Biology 16, p. 293-300.

Coenen, P.W.H.G.; van der Maas, C.W.M.; Zijlema, P.J.; Arets, E.J.M.M.; Baas, K.; van den Berghe, A.C.W.M.; te Biesebeek, J.D.; Brandt, A.T.; Geilenkirchen, G.; van der Hoek, K.W.; te Molder, R.; Dröge, R.; Montfoort, J.A.; Peek, C.J.; Vonk, J. (2013): Greenhouse gas emissions in the Netherlands 1990-2011: National Inventory Report 2013. Bilthoven: National Institute for Public Health and the Environment.

Cole, J.; Cole, F. (2013): A geography of the European Union. London: Routledge.

Croezen. H.; Head, M.; Bergsma, G.; Odegard, I. (2014): Overview of quantitative biodiversity indicators. Delft: CE Delft.

Croezen, H.; Bergsma, G.; Clemens, A.; Sevenster, M.; Tulleners, B. (2011): Biodiversity and land use: a search for suitable indicators for policy use. Delft: CE Delft.

Crosbie, T.M.; Eathington, S.R.; Johnson Sr., G.R.; Edwards, M.; Reiter, R.; Stark, S.; Mohanty, R.G.; Oyervides, M.; Buehler, R.E.; Walker, A.K.; Dober, R.; Delannay, X.; Pershing, J.C.; Hall, M.A.; Lamkey, K.R. (2006): Plant breeding: past, present and future. In: Lamkey, K.R.; and Lee, M. (eds.): Plant breeding: the Arnel R. Hauer international symposium, p. 3-50. Oxford: Blackwell Publishing.

Cullen, D.W.; Woodhead, M.; Ross, H.A.; Simpson, C.G.; Hallett, P.D.; Hacklett, C.A.; Graham, J. (2015): Developing breeding and selection tools to reduce spoilage of soft fruit and wastage in the supply chain. Dundee: The James Hutton Institute.

Dalin, C.; Hanasaki, N.; Qiu, H.; Mauzerall, D.L.; Rodriguez-Iturb, I. (2014): Water resources transfers through Chinese interprovincial and foreign food trade. In: PNAS 111, p. 9774-9779.

de Lorenzo, L.; Merchan, F.; Laporte, P.; Thompson, R.; Clarke, J.; Sousa, C. (2009) : A novel plant leucine-rich repeat receptor kinase regulates the response of roots to salt stress. In: Plant Cell 21, p. 668-680.

de Ribou, S.B.; Douam, F.; Hamant, O.; Frohlich, M.W.; Negrutiu, I. (2013): Plant science and agricultural productivity: why are we hitting the yield ceiling? In: Plant Science 210, p. 159-176.

Destatis (2014): Bundesländer mit Hauptstädten nach Fläche, Bevölkerung und Bevölkerungsdichte am 31.12.2013. Wiesbaden: Destatis.

Dev Pandey, K.; Buys, P.; Chomitz, K.; Wheeler, D. (2006): New tools for priority setting at the global environment facility. World Bank Development Research Group Working Paper. Washington, DC: World Bank.

DG Agri (Directorate-General for Agriculture and Rural Development) (2014): Prospects for agricultural markets and income in the EU 2014-2024. Brussels: European Commission.

Dieckhoff, P. (2015): Komplexe Umsetzungsvorschriften gefährden Ziele des Nagoya-Protokolls. Berlin: Bioökonomierat.

Domanska, K.; Kijek, T.; Nowak, A. (2014): Agricultural total factor productivity change and its determinants in European Union countries. In: Bulgarian Journal of Agricultural Sciences 20, p. 1273-1280.

Duvick, D.N.; Cassman, K.G. (1999): Post green revolution trends in yield potential of temperate maize in north-central USA. In: Crop Sciences 39, p. 1622-1630.

Duvick, D.N. (2005): The contribution of breeding to yield advances in maize. In: Advanced Agronomy 86, p. 83.145.

EC (European Commission) (2015): Food waste. Brussels: EC.

EC (European Commission) (2014): EU cereal farms report 2013. Brussels: EC.

Eckardt, N.A. (2011): Plant science in the service of human health and nutrition. In: Plant Cell 23, p. 2476.

Estavillo, G.M.; Crisp, P.A.; Pornsiriwong, W.; Wirtz, M.; Collinge, D.; Carrie, C. (2011): Evidence for a SAL1-PAP chloroplast retrograde pathway that functions in drought and high light signaling in Arabidopsis. In: Plant Cell 23, p. 3992-4012.

Eurostat (2016): Agricultural production – crops. Luxembourg: Eurostat.

Eurostat (2015a): Agricultural output and gross value added at producer prices, 2010-14. Luxembourg: Eurostat.

Eurostat (2015b): Database: agriculture. Luxembourg: Eurostat.

Eurostat (2009): Permanent grassland: number of farms and areas by size of farm (UAA) and size of permanent grassland area. Luxembourg: Eurostat.

Evenson, R.E.; Gobin, D. (eds.) (2003): Crop variety improvement and its effect on productivity: the impact of international agricultural research. Wallingford: CABi.

Fan, M.; Shen, J.; Yuan, L.; Jiang, R.; Chen, X.; Davies, W.J.; Zhang, F. (2011): Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. In Journal of Experimental Botany 2011, p. 1-12.

FAO (Food and Agriculture Organization) (2015a): FAOSTAT: food balance sheets. Rome: FAO.

FAO (Food and Agriculture Organization) (2015b): FAOSTAT: inputs. Rome: FAO.

FAO (Food and Agriculture Organization) (2015c): FAOSTAT: production. Rome: FAO.

FAO (Food and Agriculture Organization) (2014): FAOSTAT: food supply. Rome: FAO.

Fertilizers Europe (2015): EU-27 fertilizer consumption (agric. use). Brussels: Fertilizers Europe.

Firbank, L.G.; Petit, S.; Smart, S.; Blain, A.; Fuller, R.J. (2008): Assessing the impacts of agricultural intensification on biodiversity: a British perspective. In: Philosophical Transactions of the Royal Society B 363, p. 777-787.

Fischer, R.A.; Edmeades, G.O. (2010): Breeding and cereal yield progress. In: Crop Science 50, p. 85-98.

Foley, J.A.; Ramankutty, N.; Brauman, K.A.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O'Connell, C.; Ray, D.K.; West, P.C.; Balzer, C.; Bennett, E.M.; Carpenter, S.R.; Hill, J.; Monfreda, C.; Polasky, S.; Rockström, J.; Sheehan, J.; Siebert, S.; Tilman, D.; Zaks, D.P.M. (2011): Solutions for a cultivated planet. In: Nature 478, p. 337-342.

Fooland, M.R. (2007): Genome mapping and molecular breeding of tomato. In: International Journal of Plant Genomics 2007, Article ID 64358.

Fox, T.; Fimeche, C. (2013): Global food: waste not, want not. London: Institution of Mechanical Engineers.

Friedt, W.; Ordon, F. (1998): Von Mendel zum Gentransfer. Bonn: Verlag Thomas Mann.

Fuglie, K.O.; Toole, A.A. (2014): The evolving institutional structure of public and private agricultural research. In: American Journal of Agricultural Economics, 96, p. 862-883.

Fuglie, K.O.; Wang, S.L. (2013): New evidence points to robust but uneven productivity growth in global agriculture. In: Global Journal of Emerging Market Economies 5, p. 23-30.

Fuglie, K.O. (2013): U.S. agricultural productivity. Washington, DC: USDA.

Geiger, D.; Scherzer, S.; Mumm, P.; Stange, A.; Marten, I.; Bauer, H. (2009): Activity of guard cell anion channel SLAC1 is controlled by drought-stress signaling kinase-phosphate pair. In: Proceedings of the National Academy of Science U.S.A. 106, p. 21425-21430.

GIPB (Global Partnership Initiative for Plant Breeding Capacity Building) (2010): Plant breeding impacts and current challenges. Rome: GIPB.

Gressel, J. (2008): Glass ceilings: transgenics for crop biodiversity. Baltimore, MD: John Hopkins University Press.

Gustavsson, J.; Cederberg, C.; Sonesson, U.; van Otterdijk, R.; Meybeck, A. (2011): Global food losses and food waste. Rome: FAO.

Haniotis, T. (2013): Agricultural productivity: introductory comments. Paper presented at the International Agricultural Trade Research Consortium meeting on “Productivity and its impacts on global trade”, June 2-4, 2013, Seville.

Hanjra, M.A.; Qureshi, M.E. (2010): Global water crisis and future food security in an era of climate change. In: Food Policy 35, p. 365-377.

Heddad, L. (2015): The scale of malnutrition. In: Independent Expert Group (ed.): Global nutrition report: actions and accountability to advance nutrition and sustainable development. p. 3-4. Washington, DC: IFPRI.

Herzog, M.; Striker, G.G.; Colmer, T.D.; Pedersen, O. (2015): Mechanisms of waterlogging tolerance in wheat: a review of root and shoot physiology. In: Plant Cell and Environment Nov. 13. Doi: 10.1111/pce.12676.

HFFA Research (2016): Pflanzenschutz in Deutschland und Biodiversität: Eine Analyse der Effekte eines wirksamen chemischen Pflanzenschutzes auf die regionale und globale Artenvielfalt. HFFA Research Paper 01/2016. Berlin: HFFA Research GmbH.

Hird, V.; Holder, H.; Chandrasekaran, K.; Benning, R.; Schimpf, M.; Becheva, S.; Burley, H. (2010): A new food and agriculture policy for the European Union: position paper on the 2013 reform of the Common Agricultural Policy. Brussels: Friends of the Earth.

HLPE (High Level Panel of Experts on Food Security and Nutrition) (2014): Food losses and waste in the context of sustainable food systems. Rome: FAO.

Hood, L. (2010): Biodiversity: facts and figures. In: SciDevNet, 08th October 2010.

IMF (International Monetary Fund) (2015): World economic outlook database. Washington, DC: IMF.

Irwin, S.; Good, D. (2015): Long term corn, soybeans, and wheat price: forecasts and the farm bill program choice. Urbana-Champaign, IL: University of Illinois.

Jaggard, K.W.; Qi, A.; Ober, E.S. (2010): Possible changes to arable crop yields by 2050. In: Philosophical Transactions of the Royal Society B 365, p. 2835-2851.

Jaggard, K.W.; Qi, A.; Semenov, M.A. (2007): The impact of climate change on sugar beet yield in the UK: 1976-2004. In Journal of Agricultural Sciences 145, p. 367-375.

Jogaiah, S.; Govind, S.R.; Tran, S.L. (2012): Systems biology-based approaches toward understanding drought tolerance in food crops. In: Critical Review of Biotechnology 33, p. 23-39.

Jones, D. (2015): Wheat growers swing to varieties with better disease resistance. In: Farmers Weekly, Tuesday 10 February 2015.

Kaput, J.; Kussmann, M.; Mendoza, Y.; Le Coutre, R.; Cooper, K.; Roulin, A. (2015): Enabling nutrient security and sustainability through systems research. In: Genes and Nutrition 2015, Doi: 10.1007/s12263-015-0462-6.

Kern, M.; Noleppa, S.; Schwarz, G. (2012): Impacts of chemical crop protection applications on related CO_2 emissions and CO_2 assimilation of crops. In: Pest Management Science 68, p. 1458-1466.

Kirschke, D.; Häger, A.; Noleppa, S. (2011): Rediscovering productivity in European agriculture: theoretical background, trends, global perspectives, and policy options. HFFA Working Paper 01/2011. Berlin: HFFA.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) (2014a): Betriebsplanung Landwirtschaft 2014/15. Darmstadt: KTBL.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) (2014b): Futterbau: Produktionsverfahren planen und kalkulieren. Darmstadt: KTBL.

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) (2009): Faustzahlen für die Landwirtschaft. Darmstadt: KTBL.

Laborde, D. (2011): Assessing the land use change consequences of European biofuel policies. Final Report October 2011. Washington, DC: IFPRI.

Laidig, F.; Piepho, H.P.; Drobek, T.; Meyer, U. (2014): Genetic and non-genetic long-term trends of 12 different crops in German official variety performance trials and on-farm yield trends. In: Theoretical and Applied Genetics 127, p. 2599-2617.

Larsson, T. (2015): Preventing food wastage in the food and drink sector: Europe's food and drink manufacturers take action to prevent food wastage. Brussels: fooddrinkeurope.

Lamm, F.R.; Aiken, R.M.; Abai Kheira, A.A. (2009): Corn yield and water use characteristics as affected by tillage, plant density, and irrigation. In: Transactions of the ASABE 52, p. 133-143.

Lee, E.A.; Tollenaar, M. (2007): Physiological basis of successful breeding strategies for maize grain yield. In: Crops Sciences 47, p. 202-215.

Lege, A. (2010): Gibt es (k)einen Zuchtfortschritt? Leistungspotenziale neuer Weizensorten. In: Getreide Magazin 15, p. 252-253.

Leigh, M. (2011): Indonesian rainforest statistics: a timeline of statistics relating to the degradation of Indonesian rainforests. In: Internet [http://prezi.com/bi4r3t6rpxbv/indonesian-rainforest-statistics/; access: September, 18th, 2015].

Lillemo, M.; Reitan, L.; Bjornstadt, A. (2010): Increasing impact of plant breeding on barley yields in central Norway from1946 to 2008. In: Plant Breeding 129, p. 484-490.

Lim, X.Z. (2014): Genetics keep salads fresh and reduce food waste. In: Genetic Literacy Project, April 15, 2014.

Lipinski, B.; Hanson, C.; Lomax, J.; Kitinoja, L.; Waite, R.; Searchinger, T. (2013): Installment 2 of "Creating a Sustainable Food Future": reducing food losses and waste. Washington, DC: World Resource Institute.

Lotze-Campen, H.; von Witzke, H.; Noleppa, S.; Schwarz, G. (2015): Science for food, climate protection and welfare: an economic analysis of plant breeding research in Germany. In: Agricultural Systems 136, p. 79-84.

Mackay, I.; Philpott, H.; Horwell, A.; Garner, J.; White, J.; McKee, J. (2009): A contemporary analysis of the contribution of breeding to crop improvement. Final report. Cambridge: NIAB.

Marelli, L.; Ramos, F.; Hiederer, R.; Koeble, R. (2011): Estimate of GHG emissions from global land use change scenarios. Luxembourg: Publications Office of the European Union.

Marsh, W.M.; Kaufman, M.M. (2012): Physical geography: great systems and global environments. Cambridge: Cambridge University Press.

Martin, C.; Butelli, E.; Petroni, K.; Tonelli, C. (2011): How can research on plants contribute to promoting human health? In: Plant Cell 23, p. 1685-1699.

Mattas, K.; Arfini, F.; Midmore, P.; Schmitz, M.; Surry, Y. (2009): CAP's impacts on regional employment: a multi-modelling cross country approach. Thessaloniki Aristotle University of Thessaloniki.

Matthews, A. (2014): What is happening to EU agricultural productivity growth? Blog post at capreform.eu.

McLaren, J.S. (2000): The importance of genomics to the future of crop production. In: Pest Management Science 56, p.573-579.

Meier, T.; Christen, O.; Semler, E.; Jahreis, G.; Voget-Kleschin, L.; Schrode, A.; Artmann, M. (2014): Balancing virtual land imports by a shift in the diet. Using a land balance approach to assess the sustainability of food consumption. Germany as an example. In: Appetite 75, p. 20-34.

Mekonnen, M.; Hoekstra, A. (2011). National water footprint accounts: the green, blue and grey water footprint of production and consumption. Volume 1: Main Report. Delft: IHE Delft.

Meyer, R.; Ratinger, T.; Voss-Fels, K.P. (2013): Technology options for feeding ten billion people: plant breeding and innovative agriculture. Brussels: STOA.

Monier, V.; Mudgal, S.; Escalon, V.; O Connor, C.; Gibon, T.; Anderson, G.; Montoux, H.; Reisinger, H.; Dolley, P.; Ogilvie, S.; Morton, G. (2010): Final report: Preparatory study on food waste across EU 27. Brussels: EC.

Monneveux, P.; Ortiz, P.; Merah, O. (2013): Is crop breeding the first step to fill the yield gap? Understanding the impact and constraints of developing new improved varieties. In: Secheresse 24, p. 254-260.

NBT Platform (2015): Fact sheet: The socio-economic impact of new breeding techniques on the food supply chain in the European Union: N.N.: NBT Platform.

Nelson, G.C.; Valin, H.; Sands, R.D.; Havlík, P.; Ahammad, H.; Deryng, D.; Elliott, J.; Fujimori, S.; Hasegawa, T.; Heyhoe, E.; Kyle, P.; von Lampe, M.; Lotze-Campen, H.; Mason d'Croz, D.; van Meijl, H.; van der Mensbrugghe, D.; Müller, C.; Popp, A.; Robertson, R.; Robinson, S.; Schmid, E.; Schmitz, C.; Tabeau, A.; Willenbockel, D. (2014): Climate change effects on agriculture: economic responses to biophysical shocks. In: PNAS: 111, p. 3274-3279.

Newell-McGloughlin, M. (2008): Nutritionally improved agricultural crops. In: Plant Physiology 147, p. 939-953.

Nikolla, M.; Kapaj, A.; Mulliri, J.; Harizaj, A. (2012): Measuring the effect of production factors on yield of greenhouse tomato production using multivariate models. In: European Scientific Journal 8, p. 93-104.

Noleppa, S.; Cartsburg, M. (2015a): The agricultural trade of the European Union; consequences for virtual land trade and self-sufficiency. HFFA Research paper 03/2015. Berlin: HFFA Research GmbH.

Noleppa, S.; Cartsburg, M. (2015b): The social, economic and environmental value of agricultural productivity in the European Union: Part II: Impacts on water trade and water use. HFFA Research paper 01/2015. Berlin: HFFA Research GmbH.

Noleppa, S.; Cartsburg, M. (2014a): Another look at agricultural trade of the European Union: virtual land trade and self-sufficiency. HFFA Research paper 01/2014. Berlin: HFFA Research GmbH.

Noleppa, S.; Cartsburg, M. (2014b): Die gesamtwirtschaftliche Bedeutung des Einsatzes von Pendimethalin: diskutiert am Beispiel von Möhren und Zwiebeln in Belgien, Deutschland, den Niederlanden und Österreich. agripol research paper 2014-01. Berlin: agripol GbR.

Noleppa, S.; Hahn, T. (2013): The value of neonicotinoid seed treatment in the European Union: a socio-economic, technological and environmental review. HFFA Working Paper 01/2013. Berlin: HFFA e.V.

Noleppa, S.; von Witzke, H.; Cartsburg, M. (2013): The social, economic and environmental value of agricultural productivity in the European Union: Impacts on markets and food security, rural income and employment, resource use, climate protection, and biodiversity. HFFA Working Paper 03/2015. Berlin: HFFA e.V.

Noleppa, S.; von Witzke, H. (2013): Die gesellschaftliche Bedeutung der Pflanzenzüchtung in Deutschland: Einfluss auf soziale Wohlfahrt, Ernährungssicherung, Klima- und Ressourcenschutz. HFFA Working Paper 02/2013. Berlin: HFFA e.V.

OBT (Observaçao da Terra) (2013): Monitoramento da Floresta Amazonica Brasileira por Satelite. São José dos Campos: OBT.

OECD (Organization for Economic Cooperation and Development); FAO (Food and Agriculture Organization) (2015): OECD-FAO agricultural outlook 2015-2024. Paris: OECD Publishing.

Osakabe, Y.; Osakabe, K.; Shinozaki, K.; Tran, L.M.P. (2014): Response of plants to water stress. In: Frontiers of Plant Science 5. Doi: 10.3389/fpls.2014.00086.

Paulsen, M. (2014): Plant breeding can help meet food challenges. In Features, 23 April 2014.

Pedroli, B.; Elbersen, B.; Frederiksen, P.; Grandin, U.; Heikkilä, R.; Krogh, P.H.; Izakovičová, Z.; Johansen, A.; Meiresonne, L.; Spijker, J. (2013): Is energy cropping in Europe compatible with biodiversity? Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. In: Biomass and Bioenergy 55, p. 73-86.

Piesse, J.; Thirtle, C. (2010): Agricultural R&D, technology and productivity. In: Philosophical Transactions of the Royal Society B 365, p. 3035-3047.

Ray, D.K.; Mueller, N.D.; West, P.C.; Foley, J.A. (2013): Yield trends are insufficient to double global crop production by 2050. In PLOS one 8 (6): e66428.

Reilly, J.M.; Fuglie, K.O. (1998): Future yield growth in field crops: what evidence exists? In: Soil Tillage Research 47, p. 275-290.

Renwick, A.; Jansson, T.; Verburg, P.; Revoredo-Giha, C.; Britz, W.; Gocht, A.; McCracken, D. (2013): Policy reform and agricultural land abandonment in the EU. In: Land Use Policy, 30, 446-457.

Rijk, B.; van Ittersum, M.; Withagen, J. (2013): Genetic progress in Dutch crop yields. In: Field Crops Research 149, p. 262-268.

Rungsuriyawiboon, S.; Lissitsa, A. (2006): Total factor productivity growth in European agriculture. Halle/S.: IAMO.

Saling, P.; Schöneboom, J.; Künast, C.; Ufer, A.; Gipmans, M.; Frank, M. (2014): Assessment of biodiversity within the holistic sustainability evaluation method of AgBalance. In: Schenck, R.; Huizenga, D (eds.): Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food-Sector. San Francisco, CA: American Center for Life Cycle Assessment. p. 1144-1153.

Sayer, J.; Cassman, K.G. (2013): Agricultural innovation to protect the environment. In: PNAS 110, p. 8345-8348.

Schneider, F. (2013): Review on food waste prevention on an international level. In: Waste and Resource Management 166, p. 187–203.

Schwarz, G.; von Witzke, H.; Noleppa, S. (2011): Impacts of future energy price and biofuel production scenarios on international crop prices and trade. In: Schmitz, A.; Wilson, N. (eds.): Economics of alternative energy sources and globalization. p. 76-90, Oak Park, FL: Bentham Science Publishers.

Schwarz, G. (2010): Contributions of LFA agriculture to the Scottish economy: A SAM based analysis of inter-sectoral linkages. In: Management Theory and Studies for Rural Business and Infrastructure Development 22. Research Paper #3. Braunschweig: TI.

Scott, R.K.; Jaggard, K.W. (2000): Impact of weather, agronomy and breeding on yields of sugar beets grown in the UK since 1970. In: Journal of Agricultural Science 134, p. 341.352.

Searchinger, T.; Heimlich, R.; Houghton, A.; Dong, F.; Elobeid, A.; Fabiosa, J.; Togkoz, S.; Hayes, D.; Yu, T.-H. (2008): Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Princeton, NJ: Princeton University.

Silvey, V. (1994): Plant breeding in improving crop yields and quality in recent decades. In Acta Horticulturae 35, p.19-24.

Spielman, D.J.; Pandya-Lorch, R. (2010): Proven success in agricultural development: a technical compendium to millions fed. Washington, DC: IFPRI.

Spink, J.; Street, P.; Sylvester-Bradley, R.; Berry, P. (2009): The potential to increase productivity of wheat and oilseed rape in the UK. Report to the Government Chief Scientific Adviser. Hereford: ADAS.

Statista (2015): Durchschnittlicher Verbraucherpreis von Tomaten in ausgewählten Ländern in Europa im Jahr 2013 (in Euro pro Kilogramm). Hamburg: Statista.

Steinbacher, N.; Schlossberger, F. (2015): Obst. In: LEL und LfL (Hrsg.): Agrarmärkte 2015, S. 92-117. Schwäbisch Gmünd: LEL.

Sutor, P.; Neuberger, S.; Steinbacher, N. (2015): Gemüse. In: LEL und LfL (Hrsg.): Agrarmärkte 2015, S. 118-137. Schwäbisch Gmünd: LEL.

Traka, M.H.; Mithen, R.F. (2011): Plant science and human nutrition: challenges in assessing health-promoting properties of phytochemicals. In: Plant Cell 23, p. 2483-2497.

Tscharntke, T.; Clough, Y.; Wanger, T.C.; Jackson, L.; Motzke, I.; Perfecto, I.; Vandermeer, J.; Whitbread, A. (2012): Global food security, biodiversity conservation and the future of agricultural intensification. In: Biological Conservation 151, p. 53-59.

Tyner, W.E.; Taheripour, F.; Zhuang, Q.; Birur, D.; Baldos, U. (2010): Land use changes and consequent CO_2 emissions due to US corn ethanol production: a comprehensive analysis. West Lafayette, IN: Purdue University.

UBA (Umweltbundesamt) (2015a): UBA-Emissionsdaten 2014 zeigen Trendwende beim Klimaschutz: Emissionen sinken auf niedrigsten Wert seit 2010. Dessau-Roßlau: UBA.

UBA (Umweltbundesamt) (2015b): Umweltbelastungen der Landwirtschaft. Dessau-Roßlau: UBA.

UBA (Umweltbundesamt) (2010): Entwicklung der THG-Emissionen in Deutschland nach Sektoren. Dessau-Roßlau: UBA.

UNEP (United Nations Environment Progamme) (2015): International trade in resources: a biophysical assessment. Report of the International Resource Panel. Nairobi: UNEP.

UNEP (United Nations Environment Programme) (2009): Science panel review of the GEF Benefits Index (GBI) for biodiversity. Nairobi: UNEP.

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2014): The United Nations world water report 2014. Paris: UNESCO.

UNSD (United Nations Statistics Division) (2012): Demographic yearbook – table 3: population by sex, rate of population increase, surface area and density. New York: UN.

USDA (United States Department of Agriculture) (2015a): USDA agricultural projections to 2024. Washington, DC: USDA.

USDA (United States Department of Agriculture) (2015b): USDA roadmap for plant breeding, March 11, 2015. Final report. Washington, DC: USDA.

USDA (United States Department of Agriculture) (2014): International agricultural productivity. Washington, DC: USDA.

Vannuccini, S. (2009): The OECD-FAO AGLINK-COSIMO projection system. Rome: FAO.

van Zeijts, H.; Overmars, K.; van der Bilt, W.; Schulp, N.; Notenboom, J.; Westhoek, H.; Helming, J.; Terluin, I.; Janssen, S. (2011): Greening the Common Agricultural Policy: impacts on farmland biodiversity on an EU scale. The Hague: PBL Netherlands Environmental Assessment Agency.

von Huyghe, C.; De Vliegher, A.; van Gils, B.; Peeters, A. (2014): Grasslands and herbivore production in Europe and effects of common policies. Versailles: Quae Editor.

von Witzke, H.; Jechlitschka, K.; Kirschke, D.; Lotze-Campen, H.; Noleppa, S. (2004): Social rate of return to plant breeding research in Germany. In: Agrarwirtschaft 53, p. 206-210.

Wang, S. L.; Schimmelpfennig, D.; Fuglie, K.O. (2012): Is agricultural productivity growth slowing in Western Europe? In: Fuglie, K.O.; Wang, S.L.; Ball, V.E. (eds.): Productivity growth in agriculture: an international perspective. p. 109-125. Wallingford: CAB International.

Webb, D. (2010): Economic impact of plant breeding in the UK. Manchester: DTZ.

Wood, T.; Teakle, G.; Mackay, I. (2013): An introduction to the contemporary breeding of oilseed rape. In: Lipid Technology 25, p. 251-254.

World Bank (2013): Data: GEF benefits index for biodiversity. Washington, DC: World Bank.

WRI (World Resources Institute) (2014): Climate analysis indicators tool (CAIT) version 2.0. Washington, DC: WRI.

Wright, B.E. (2011): Measuring and mapping indices of biodiversity conservation effectiveness. Worcester, MA: Clark University.

Wright, B.D. (2010): Recent agricultural price volatility and the role of grain stocks. Washington DC: IFPRI.

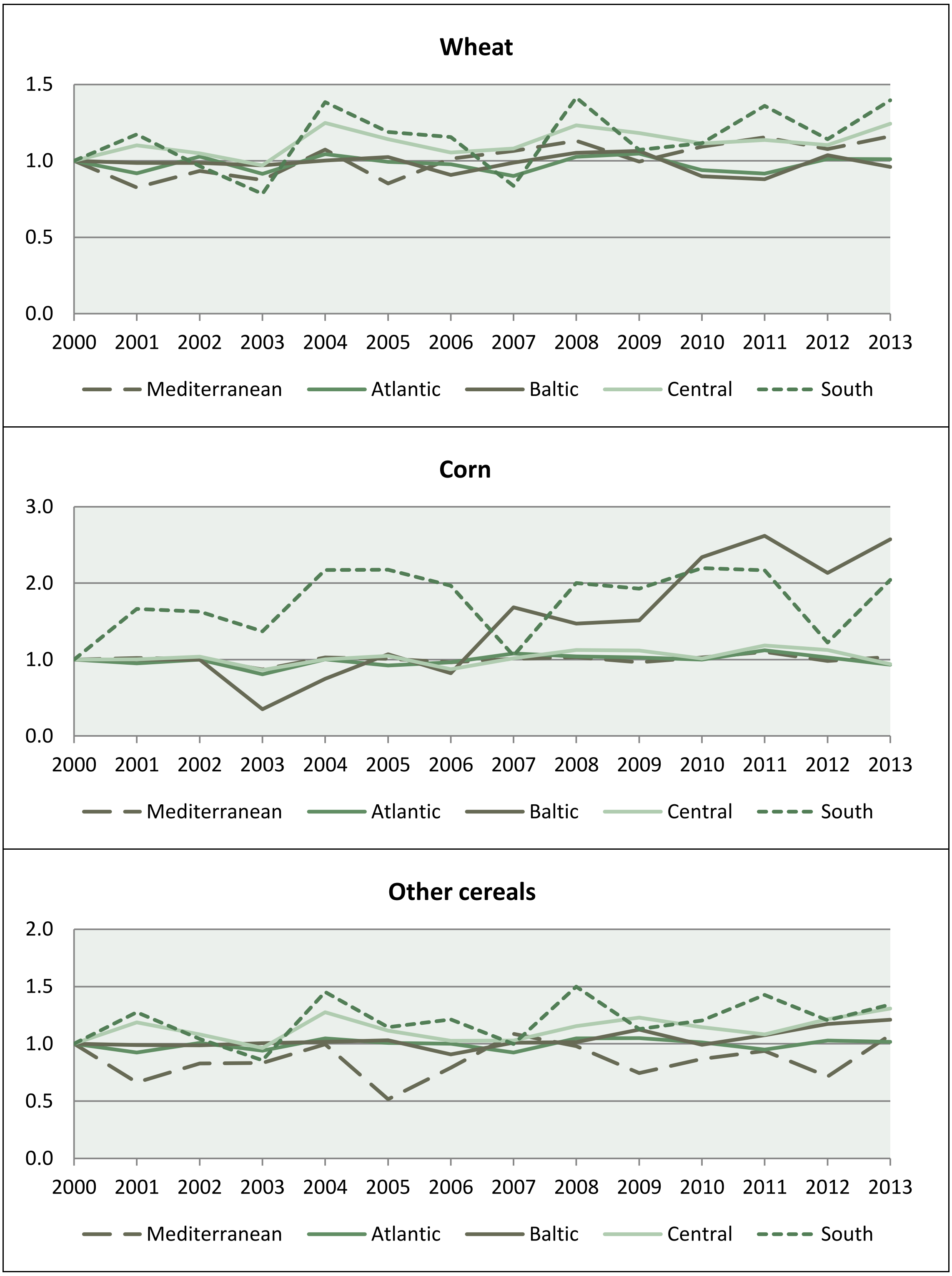
Yuan, Z.; Shen, Y. (2013): Estimation of water consumption from meteorological and yield data: a case study of Hebei, North China. In: PLOS ONE 8, e58685. doi: 10.1371/journal.pone.0058685.

Zwart, S.J.; Bastiaanssen, W.G.M.; De Fraiture, C.; Molden, D.J. (2010): A global benchmark map of water productivity for rain-fed and irrigated wheat. In: Agricultural Water Management 97, p. 1617-1627.

Zwart, S.J.; Bastiaanssen, W.G.M. (2004): Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. In: Agricultural Water Management 69, p. 115-133.

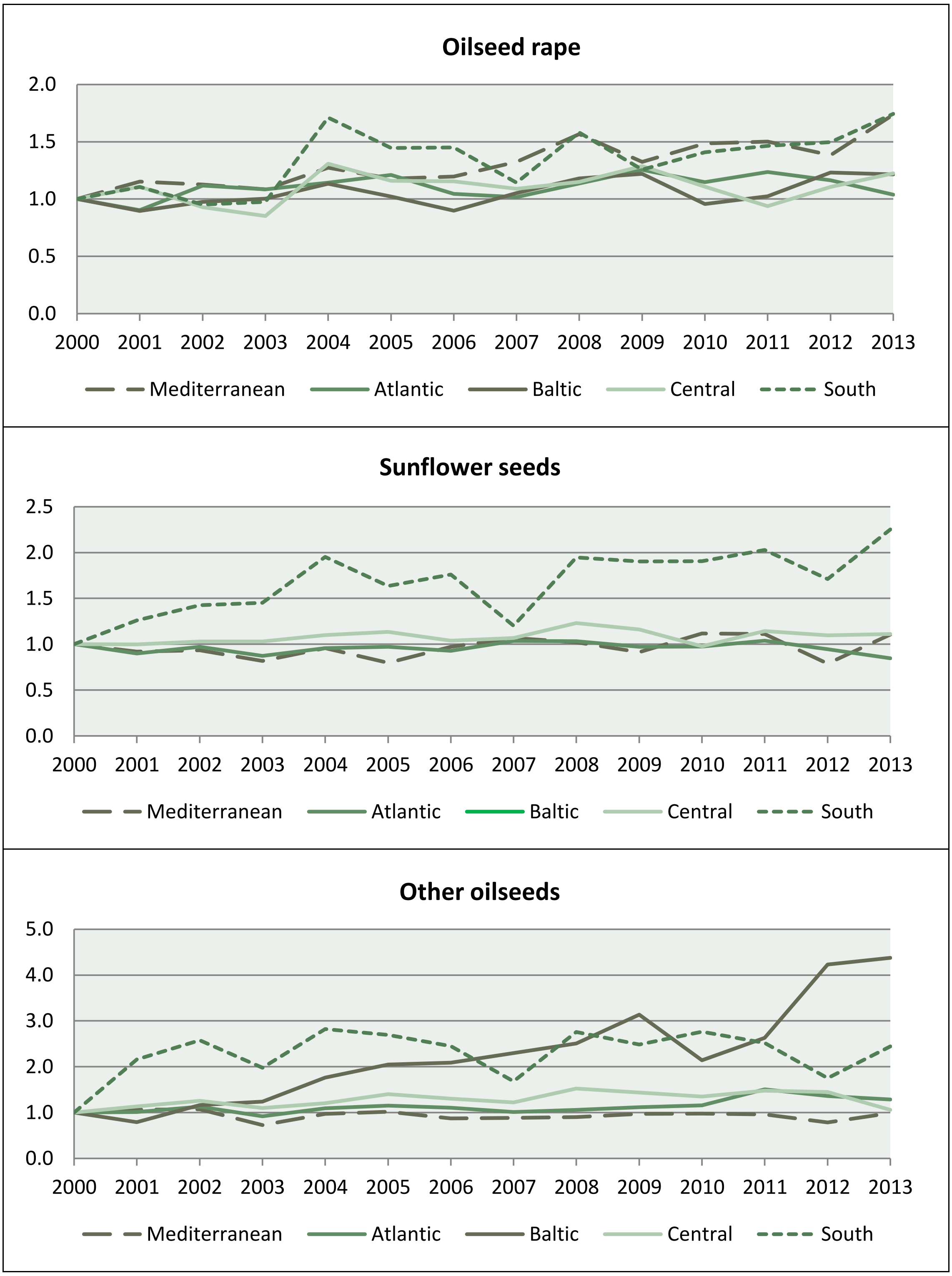
Annex

Annex A01: Yield developments in cereals for sub-regions of the European Union, 2000-2013 (in index points, 2000 = 100)



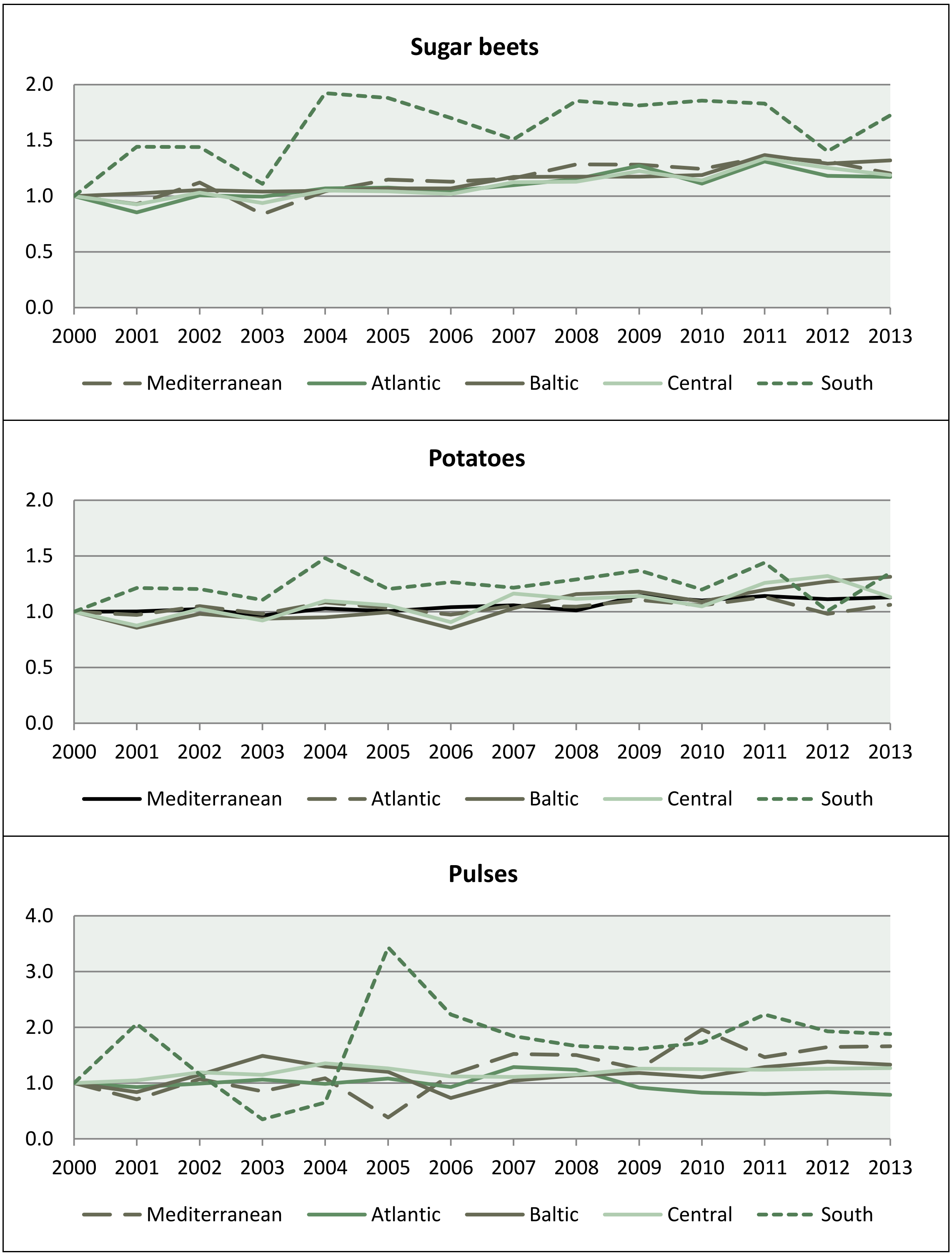
Source: Own calculations and figure based on FAO (2015c).

Annex A02: Yield developments in oilseeds for sub-regions of the European Union, 2000-2013 (in index points, 2000 = 100)



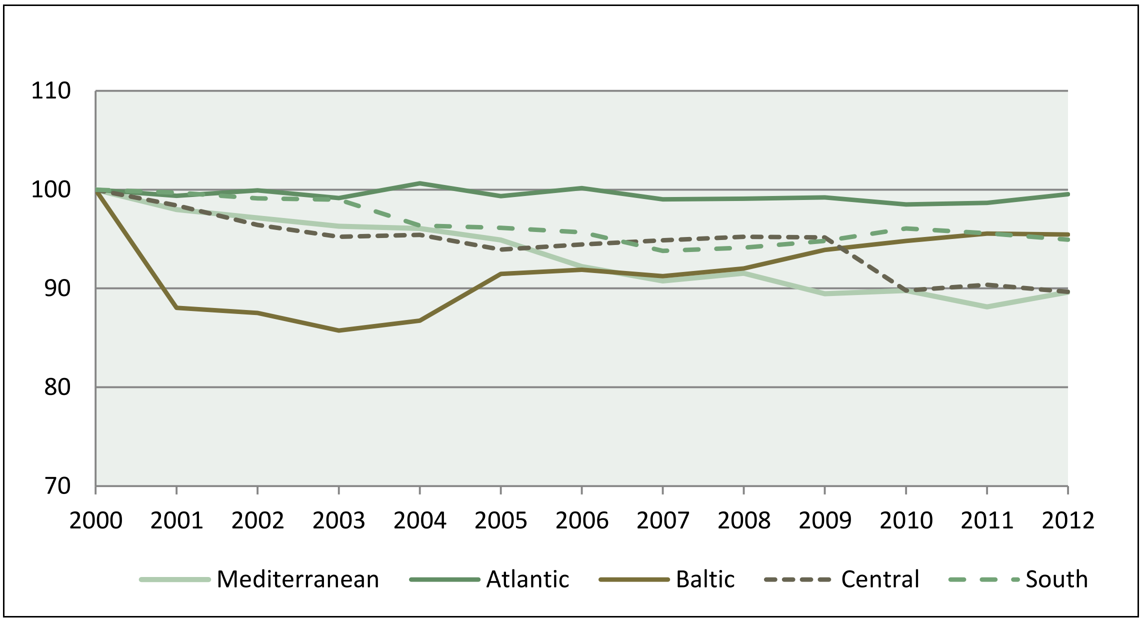
Source: Own calculations and figure based on FAO (2015c).

Annex A03: Yield developments in roots and tubers as well as pulses for sub-regions of the European Union, 2000-2013 (in index points, 2000 = 100)



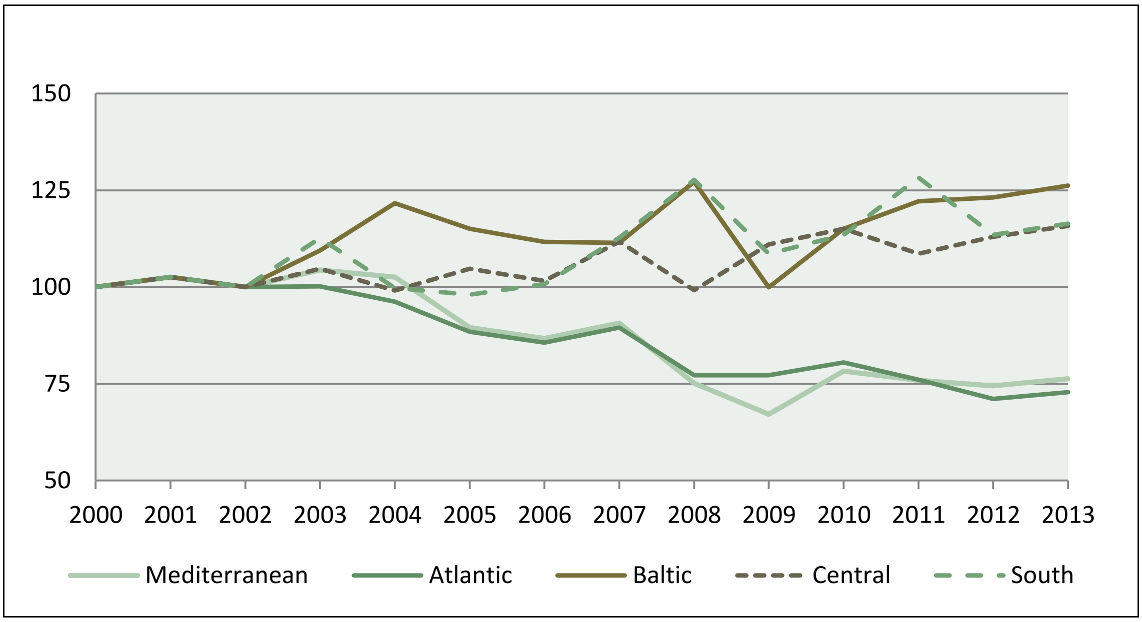
Source: Own calculations and figure based on FAO (2015c).

Annex B01: Use of arable land in sub-regions of the European Union, 2000-2012 (index, 2000 = 100)



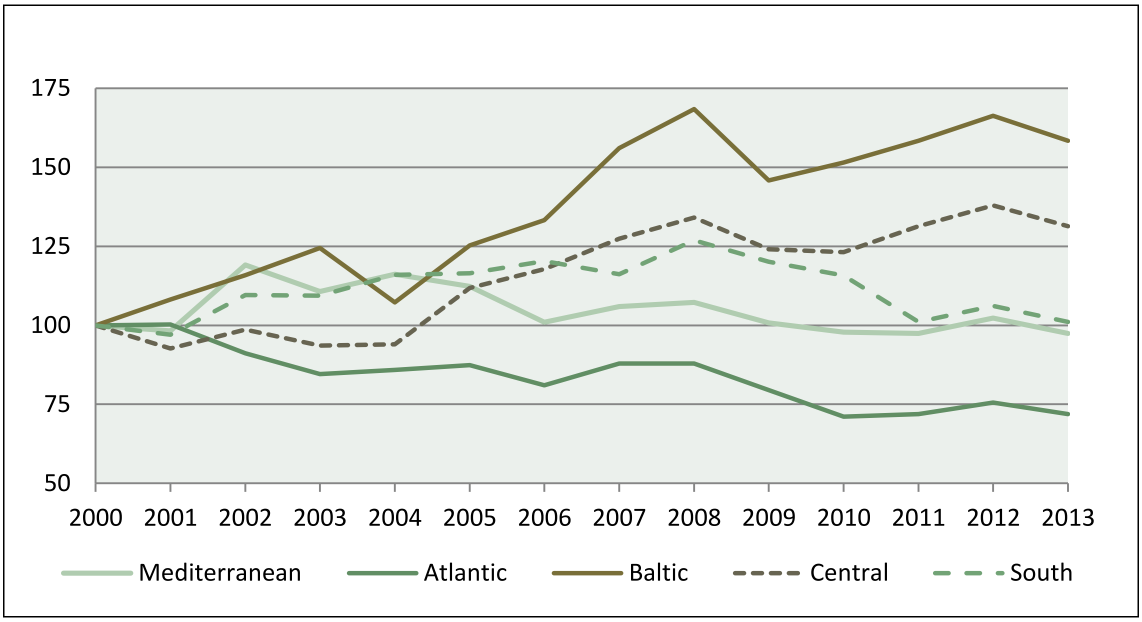
Source: Own calculations and figure based on FAO (2015b).

Annex B02: Use of fertilisers in sub-regions of the European Union, 2000-2013 (index, 2000 = 100)



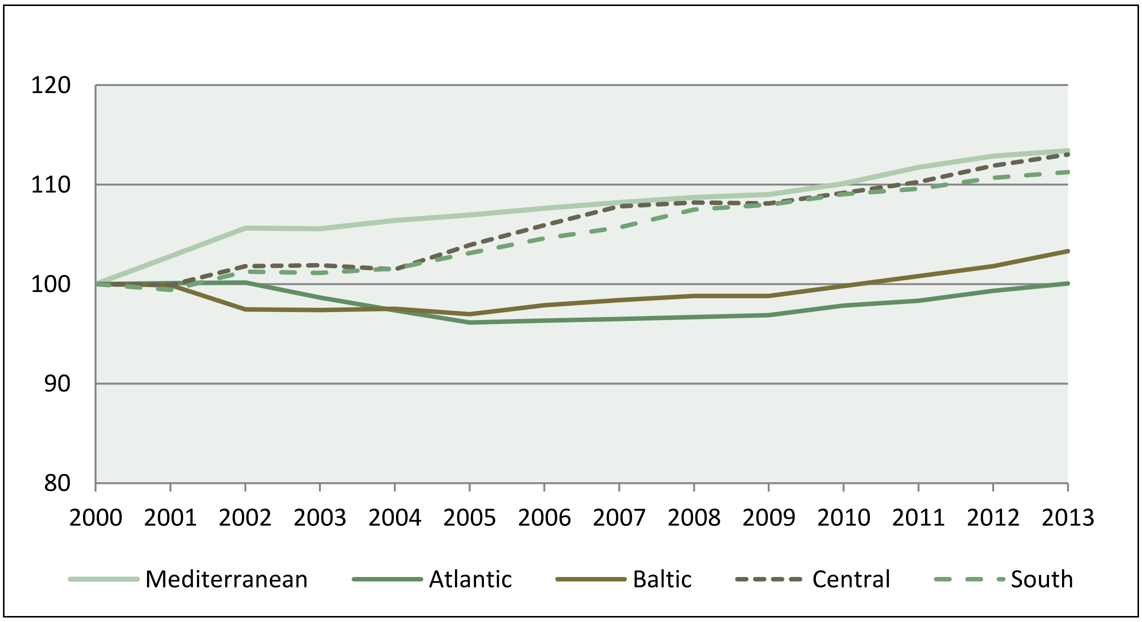
Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), Fertilizers Europe (2014) and KTBL (2014a).

Annex B03: Use of plant protection products in sub-regions of the European Union, 2000-2013 (index, 2000 = 100)



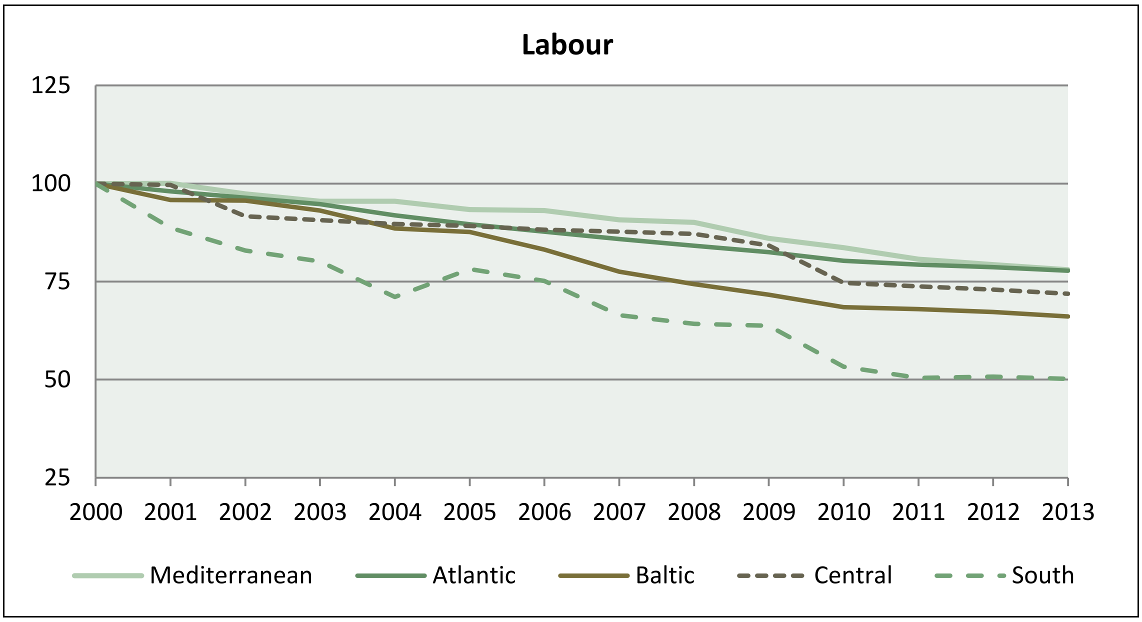
Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), and KTBL (2014a).

Annex B04: Use of agricultural machinery in sub-regions of the European Union, 2000-2013 (index, 2000 = 100)



Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), and KTBL (2014a).

Annex B05: Use of agricultural labour in sub-regions of the European Union, 2000-2013 (index, 2000 = 100)



Source: Own calculations and figure based on Eurostat (2015b) and FAO (2015b) as well as EC (2014), and KTBL (2014a).

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An ex-post evaluation and ex-ante assessment

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