SUSFANS Deliverable D4.4 Preliminary report on T4.4: drivers of crop production

Crop production in the context of food and nutrition security

SUSFANS DELIVERABLES

Andrea Zimmermann, Catharina Latka

Institute for Food and Resource Economics, University of Bonn

Abstract

Crop production is the most crucial primary agricultural production activity for both food and nutrition security. Around 70% of the calories per capita and day come from plant-based products. Besides its importance for direct human consumption, crop production is also crucial for producing feed for livestock and aquaculture. The report provides a qualitative assessment of drivers of crop production and preliminary work for a quantitative analysis of crop production in the EU.

Version	Release date	Changed	Status	Distribution
V1	30/09/2016	-		

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement

SUSFANS DELIVERABLE

Document information

Project name	SUSFANS
Project title :	Metrics, Models and Foresight for European SUStainable Food And Nutrition Security
Project no	633692
Start date:	April 2015
Report:	D4.4
Work package	WP4
WP title (acronym):	
WP leader:	UBO (Andrea Zimmermann), JRC (Adrian Leip)
Period, year:	1, 2016
Responsible Authors:	
Participant acronyms:	UBO
Dissemination level:	
Version	1
Release Date	
Planned delivery date:	September 30, 2016
Status	Final
Distribution	Internal

Dissemination level of this report

Confidential, only for members of the consortium (including the Commission Services)

ACKNOWLEDGMENT & DISCLAIMER

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633692. Neither the European Commission nor any person acting on behalf of the Commission is responsible for how the following information is used. The views expressed in this publication are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

Overview of WP4 driver deliverables

Generally, WP4 aims to develop a system understanding of the drivers of and prepare, collect and deliver the data for assessing FNS and its sustainability at the level of primary agricultural and fisheries production.

Within WP4, the deliverables D4.1 (drivers of livestock production in the EU), D4.2 (drivers of fisheries and aquaculture production in the EU), D4.4 (preliminary report on the drivers of crop production in the EU) and D4.5 (final report on the drivers of crop production in the EU) provide:

• An analysis of the drivers of livestock production in the EU;

• An analysis of the drivers of seafood production in the EU;

• An analysis of the drivers of crop production in the EU.

Table 1 gives an overview of the WP4 driver reports.

Table 1. Overview of WP4 driver deliverables

Production system	Methodology	Deliverable
Livestock	Qualitative analysis	D4.1
Seafood	Qualitative analysis	D4.2
Crops	Qualitative analysis	D4.4 (preliminary deliverable)
Crops	Quantitative analysis	D4.5 (final deliverable, due in March 2017)

Generally, primary agricultural production is not only affected by economic factors, but highly depends on biophysical factors as well. The economic aspects and, partly, their interplay with biophysical factors are part of the modelling work within the SUSFANS toolbox. The WP4 driver deliverables provide a basic understanding of the multi-disciplinary production system. Since economic factors are covered in the SUSFANS toolbox and the scenario work, emphasis is thereby put on biophysical and technology developments. A general introduction to the concept of drivers in primary production and drivers in the context of production economics is given in the appendix of each of the deliverables.

Table 2 shows the different foci of the individual drivers in the SUSFANS conceptual framework (CF) (Zurek et al., 2016) and each of the WP4 driver deliverables. Relevant for the WP4 driver deliverables are the indirect drivers that affect the whole food system and the direct drivers for producers. Indirect food system drivers considered in the CF are economic developments, population dynamics, technological change, agriculture and trade policies, environmental issues, and culture and lifestyle choices. Direct drivers for producers according to the CF are the regulatory environment, input and farm gate prices, contract opportunities, natural resource availability, available technology and producer and farm characteristics. The appendix provides a more detailed comparison of the drivers technological change and available technology.

Table 2. Different foci between WP4 driver deliverables and the CF

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4)
Indirect drivers				
Economic development	-Summarized by growth in GDP -Impact on consumption, consumer and producer prices, wages in food sector -Market power and imperfect competition	-Summarized by growth in GDP -development of livestock production	-Societal drivers affecting seafood prices -Macro- and microeconomics of EU seafood production	-Refers to CF (D1.1)
Population dynamics	-Population growth (in developing countries) -Demographic changes -Composition of diets	-Population growth (in developing countries) -Demographic changes -Composition of diets	-Demographics and expected effects on seafood demand	-Refers to CF (D1.1)
Technological change	-Innovation -Technology development -Competition for land from emerging biotechnology	-Progress in feeding technology -Progress in breeding	-Historical development and the interplay between farmed and fished seafood -Technical innovations in society enabling growth	-Public and private research (breeding, fertilizer and plant protection, machinery)
Agriculture and trade policies	-Impacts on prices and diets -Price	-Specific crop policies between EU and other	-Fishing policies between	-Specific crop policies between EU

	transmission between agricultural policies and consumer food prices -Price impacts through trade policies on commodity prices limited, highest effect on diets through general liberalization and economic growth -Impact of trade policies on price volatility -Effects on land use -Sanitary and phytosanitary regulations	countries -Food policies -Trade policies	EU and other countries -Food policies, trade barriers and regulations related to seafood -Beyond-EU regulatory environment of relevance to seafood production	and other countries -Food policies -Trade policies -Relevant sanitary and phytosanitary regulations
Environmental issues	-Climate change impacts on crop and livestock sectors -Soil carbon sequestration -Reduction of emissions from land use and carbon sequestration in biomass -Biomass production for energy uses -Energy prices	-Global environmental impact of livestock production. Competition for land between feed and food production	-Environmental pressures of seafood production -Effects on seafood production from changing environment	-Climate change
Culture and lifestyle choices	-Nutrition intake and changing dietary	-demand for livestock products over	-Consumer preferences related to	-Specific trends in crop

	behaviours -Undernourishment, malnourishment and human health	the years	seafood consumption	consumption
Direct drivers				
Regulatory environment	-Common Agricultural Policy (CAP) of the EU -Common Fisheries Policy (CFP) of the EU -Different directives (e.g. water framework directive, Marine Strategy Framework Directive) -Food safety and related standards	-EU legislations and policies affecting livestock production	-EU legislations and policies affecting seafood production	-EU cereals regime -EU oilseeds regime -Fruits and vegetable policies
Input and farm gate prices	-Interplay supply and demand -Relation input and output prices -Input costs -Producer prices	-Trend in livestock prices	-General economic data on EU seafood production	-Input prices refer to CF (D1.1) -Trends in crop prices
Contract opportunities	-Contract farming as part of vertical integration -Relevance of contract farming in different production systems	-Relevance of contract farming in different production systems	-Hinders for aquaculture growth -Outsourcing of activities	-Refers to CF (D1.1)
Natural resource availability	-Determines feasibility of primary production -Includes land,	-impact of current production levels on scare resources e.g.	-Production capacity and current	-Environmental setting on farm, refers to CF (D1.1)

	climate, soils, water, fish stocks	land use and future availability.	status of capture fisheries -The role for aquaculture related to general resource availability (e.g. seafood per capita, feed)	
Available technology	-Technology adoption & diffusion -Technology usage -Total factor productivity	-Feeding and breeding technologies are adapted in e.g. diet formulations	-Science and management behind current production -Difference in technology between individual enterprises, e.g. farmers' knowledge, skipper effect -Status of production systems and technical progress needed -Production efficiency incl. by-product utilization	-Management
Producer and	-Personal	- type of farms	-Seafood	-Refers to CF

farm characteristics	attitudes, values and goals, experiences, social influences -Path dependencies through existing farm characteristics and farm structure -Vessel characteristics and fleet structure -Effect of socio-economic characteristics on risk aversion and management decisions	- number of farms - animal numbers per farm	production characteristics in the EU (technology, knowledge, prices and costs)	(D1.1)

Table of Content

SUSFANS DELIVERABLE 2
Document information 2
Dissemination level of this report 2
ACKNOWLEDGMENT & DISCLAIMER 3
Overview of WP4 driver deliverables 4
Table of Content 10
1 Introduction 11
2 Crop production in the EU 11
3 SUSFANS conceptual framework 14
4 Indirect drivers of crop producers in the EU 15
4.1 Economic development 15
4.2 Population dynamics 16
4.3 Technological change 16
4.4 Agriculture and trade policies 19
4.5 Environmental issues 20
4.6 Culture and lifestyles 21
5 Direct drivers of crop producers in the EU 22
5.1 Regulatory environment per country 22
5.2 Input and farm gate prices 23
5.3 Contract opportunities 26
5.4 Natural resource availability 26
5.5 Available technology 27
5.6 Producer and farm characteristics 28
6 Hierarchy of drivers affecting crop production 29
7 Conclusions 31
Appendix 32
Drivers of primary production 32
Drivers in the context of production economics 33
Technological change vs. available technology 34
References 36

1 Introduction

Crop production is the most crucial primary agricultural production activity for both food and nutrition security. In 2011, around 70% of the calories per capita and per day came from plant-based products. Besides its importance for the direct human consumption, crop production is also crucial for producing feed for livestock and increasingly for aquaculture. The globally most consumed plant products are wheat, rice and maize (Khoury et al., 2014), the highest changes in relative abundance (in calories) refer to soybeans and other oilseeds (measured from 1961 to 2009, Khoury et al., 2014).

Most generally, crop production is primarily determined by the interplay of land use and crop yields. Both land use and crop yields are affected by various drivers. For the SUSFANS Conceptual Framework (CF) those were split into direct and indirect drivers. The aim of this deliverable is twofold: (1) it deepens the understanding of the different drivers from the CF with respect to crop production and (2) it lays the ground for the empirical analysis of crop yields as input for the modelling toolbox in WP9. Additionally, it informs WP1 on the specific understanding of the drivers in crop production and the WP5 case studies by considering fruits and vegetables as focus.

Generally, the paper focuses on the most important crops in Europe in terms of production amount, i.e. cereals, potatoes, sugar beet and important crops for nutrition security and the SUSFANS case study, vegetables and fruits.

The paper at hand is the first of two deliverables in task T4.4. This first deliverable is strongly aligned with the SUSFANS conceptual framework. Whereas the WP4 contribution to the conceptual framework comprises agricultural and fish production as a whole, the paper at hand deepens the driver section in the conceptual framework for crop production. The alignment with the conceptual framework guarantees overall consistency within the SUSFANS project and with the other WP4 deliverables on production drivers (D4.1 - Drivers of livestock production in the EU and D4.2 - Drivers of fisheries and aquaculture production in the EU). First the structure of crop production and crop farms in the EU are described, followed by a brief introduction to the SUSFANS conceptual framework and the description of indirect and direct drivers following the conceptual framework.

The second deliverable (D4.5) of task T4.4 will empirically assess the most important drivers and their impact on crop yields.

2 Crop production in the EU

In terms of total utilized agricultural area in the EU, cereal production accounted for about one third in 2013. Grassland (pasture and meadow, rough grazing and permanent grassland) accounted for more than another third of total utilized agricultural area (34.1%) (European Commission, 2015a).

From total EU cereal production (in tonnes), almost 45% are wheat followed by grain maize (23.4%) and barley (18.2%). Triticale and rye and maslin have production shares below 5% (Figure 1).

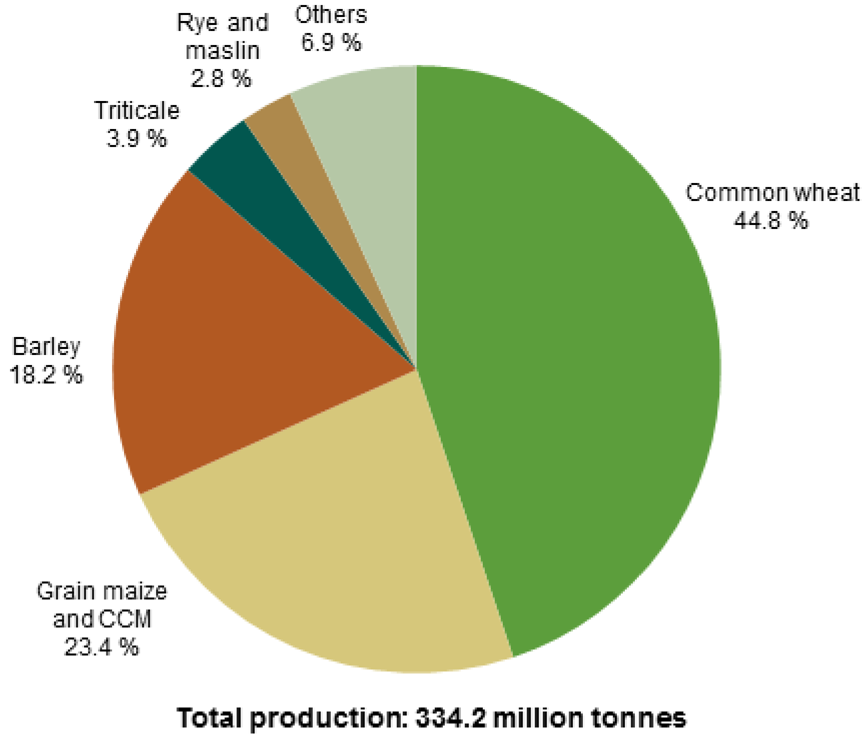

Figure 1. Production of cereals, EU-28, 2014 (% of total production of cereals)

Source: European Commission (2016a)

The main cereals producing EU Member States are given in Figure 2. The main wheat producers are France, Germany, United Kingdom and Poland. Rye and maslin are mainly produced in Germany and Poland. Despite their relatively smaller country size also Denmark and Austria are among the main rye and maslin producers. Barley is mainly produced by France, Germany, Spain and the United Kingdom, maize by France, Romania, Italy and Hungary. The main triticale producers in the EU are Poland, Germany, France and Hungary.

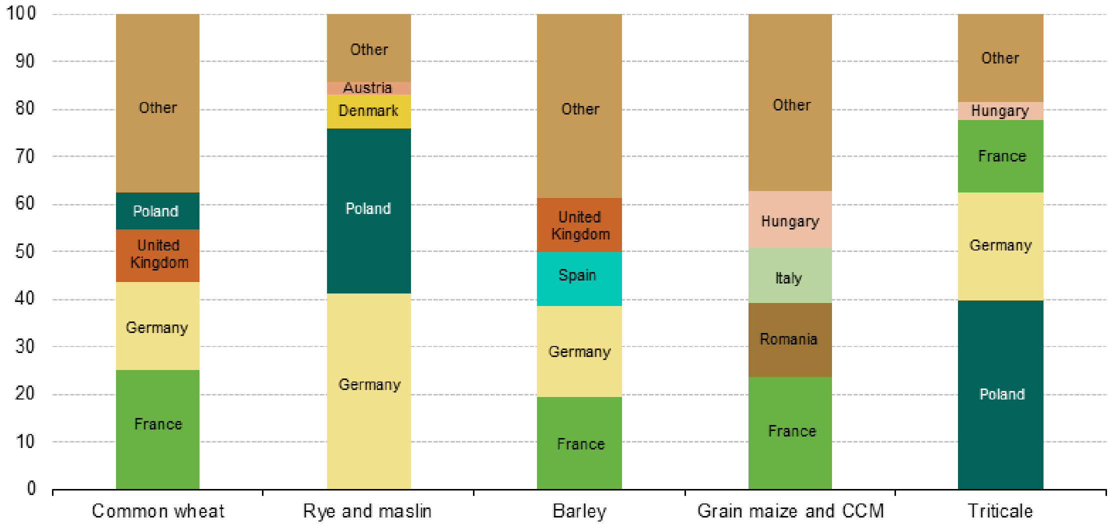

Figure 2. Production of cereals by main producing EU Member States, 2014 (% of EU-28 total)

Source: European Commission (2016a)

Among the main fruits and vegetables producers in the EU are tomatoes, carrots, onions, apples, peaches and citrus fruits. Table 3 gives a country-wise overview of the production quantities of these products in 2014. At EU-28 total, the fruits and vegetables with the highest production quantities are tomatoes, followed by apples and citrus fruits. The main producers of tomatoes are Italy, Spain, Portugal and Greece. The main carrot producers are Poland, United Kingdom, Germany, France and the Netherlands. Onions are mainly produced in the Netherlands and Spain. By far smaller onion production quantities are achieved by Poland, Germany and Italy. Main apple producing countries are Poland, Italy, France and Greece. Depending on climate, peaches and citrus fruits are only produced in part of the EU Member States. Main peaches producers are Spain, Italy and Greece. Most of the production of citrus fruits takes place in Spain, Italy and Greece as well.

Table 3. Production of fruit and vegetables, by country, 2014 (1000 tonnes)

	Tomatoes	Carrots	Onions	Apples	Peaches	Citrus fruits
EU-28	16 837	5 537	6 356	14 304	2 894	11 773
Belgium	249	328	102	318	0	0
Bulgaria	120	10	13	55	28	0
Czech Republic	9	26	38	128	1	0
Denmark	13	107	52	35	0	0
Germany	85	609	590	1 116	0	0
Estonia	1	13	0	1	0	0
Ireland	5	37	4	14	0	0
Greece	1 054	44	238	1 533	828	1 059
Spain	4 889	376	1 365	621	931	7 043
France	778	558	372	1 892	125	51
Croatia	20	7	28	97	3	70
Italy	5 624	526	419	2 454	860	3 140
Cyprus	18	2	8	8	2	105
Latvia	5	19	7	10	0	0
Lithuania	12	61	26	52	0	0
Luxembourg	0	1	0	3	0	0
Hungary	116	100	58	779	32	0
Malta	13	1	8	0	1	0
Netherlands	900	548	1 379	353	0	0
Austria	57	107	206	310	3	0
Poland	811	823	651	3 195	10	0
Portugal	1 400	105	57	274	41	304
Romania	479	139	250	503	23	0
Slovenia	7	4	8	71	4	0
Slovakia	22	7	24	49	2	0
Finland	40	74	26	5	0	0
Sweden	15	119	53	25	0	0
United Kingdom	99	786	374	404	0	0
Norway	14	55	22	13	0	0
Serbia	128	50	43	336	91	0
Turkey	11 850	558	1 938	2 480	532	2 454
Bosnia and Herzegovina	29	20	33	45	9	0

Source: European Commission (2016a)

3 SUSFANS conceptual framework

The SUSFANS conceptual framework (CF) is described by Zurek et al. (2016). The conceptual framework defines indirect and direct drivers of the EU food system (Figure 3). The indirect drivers considered are economic development, population dynamics, technological change, agriculture and trade policies, environmental issues and culture and lifestyles. These drivers are in detail characterised in Zurek et al. (2016) and are only briefly discussed in this deliverable with respect to crop production. Direct drivers in the CF refer to consumers, food chain actors and producers. The direct drivers for producers (regulatory environment, input and farm gate prices, contract opportunities, natural resource availability, available technology and producer and farm characteristics) are discussed in this deliverable with respect to crop production. Indirect and direct drivers as well as the direct drivers of different food system actors are closely interlinked with each other. The interlinkages are only sporadically addressed in this deliverable, but will be inherent in the modelling work of the SUSFANS project.

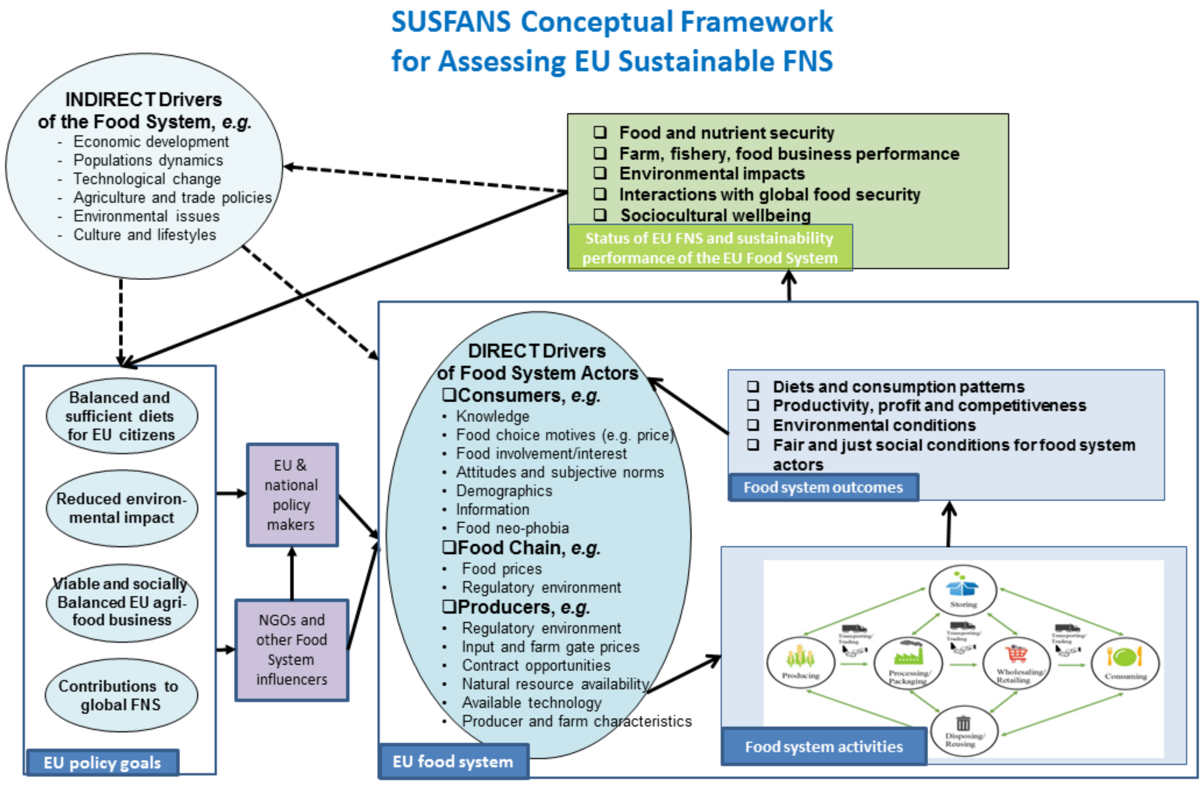

Figure 3. SUSFANS conceptual framework

Source: Zurek et al. (2016).

4 Indirect drivers of crop producers in the EU

The conceptual framework mentions several indirect drivers that affect the food system in the EU as a whole. These drivers are described in Zurek et al. (2016). They are briefly mentioned here and specified for crop production.

4.1 Economic development

Generally, higher economic growth is correlated with higher consumption of animal products (e.g. Kearney, 2010). Due to increased demand for animal and other processed products also crop production increases (e.g. Tilman et al., 2002). Together with global population growth and climate change (see below), this is currently seen as a main challenge to future crop production (e.g. Godfray et al., 2010; Nelson et al., 2014). However, Gil et al. (1995) find for Europe that in some countries total calorie consumption has declined already in the 1990s which indicates that further growth in per capita income could generate a smaller increase in total food consumption. Also, the proportion of calories from animal products has been stabilizing in the 1990s in Europe and its responsiveness to income growth has declined (Gil et al., 1995). The exact relationships between global economic development and the European food system will be assessed with the SUSFANS toolbox in the course of the project.

4.2 Population dynamics

Global population growth is generally seen as one of the main challenges for crop production. Since taking more land into production is not an alternative for meeting increasing global food demand, it is often argued for the 'sustainable intensification' of crop production in the meaning of yield increases without harming the environment (Godfray, 2015; Godfray and Garnett, 2014; Tilman et al., 2011). However, how such a sustainable intensification of crop production could be accomplished and what it means for European agriculture, is still very open with first specific research projects just having started, e.g. SUSTAg - Assessing options for the SUSTainable intensification of Agriculture for integrated production of food and non-food products at different scales (FACCE SURPLUS, http://faccesurplus.org/research-projects/sustag/).

Changes in the population composition globally and in Europe may also lead to diet and demand changes that in turn would have repercussion on food and crop production. The implications of these changes on crop production in the EU are unclear (Zurek et al., 2016).

4.3 Technological change

Technological change is one of the main drivers counteracting the risks to global food security through economic and population growth and climate change (Hazell and Wood, 2008; Benton et al., 2003). In crop production, technological change mainly refers to breeding progress, efficiency gains in fertilizer and plant protection use and machinery including digital farming. Below and in the second part of the paper we explicitly distinguish between technological change (1) increasing the biologically potential yield based on breeding and (2) management to decrease the gap between actually realised and potentially obtainable yields, i.e. the yield gap (Ewert et al., 2005; Lobell et al., 2009; Neumann et al., 2010; van Ittersum et al., 2013).

The prospects of an increasing world population go along with rising demand for food. This calls for further progress in crop yield and production. Yield increases can either be reached by closing the gap between actual and potential yield or by lifting potential yield (Fischer and Edmeades, 2010). Potential yield is mainly addressed by plant breeders who primarily strive for increasing possible crop yields (Tester and Langridge, 2010). Although plant breeding led to major achievements within the past decades, currently there is a controversy whether potential yield is stagnating and reaching its limits (Fischer and Edmeades, 2010; Slafer et al., 2013) or if, especially by making use of new technologies, still substantial potential for further yield increases is left (Reynolds et al., 2009).

Plant breeding summarizes methods for the creation, selection, and fixation of superior plant phenotypes in the development of improved cultivars for meeting the needs of farmers and consumers (Moose and Mumm, 2008). Breeding activities usually are indicated by the amount of new varieties that are released, but also by the increases in productivity measured over time (Van Tran and Duffy, 2003). Limitations in genetic variability, physiological or biological constraints as well as prevalent infrastructures and available resources influence the effect of breeding activities in different ecosystems (Van Tran and Duffy, 2003). Plant breeding has a very long history. It started with the domestication of visibly selected crop phenotypes in prehistoric times. In the 19^{th} and 20^{th} century scientific research by Charles Darwin and Gregor Mendel initiated further selection also based on the plants' genotypes (Moose and Mumm, 2008). The so-called "green revolution" in the 1960s is regarded as a milestone in plant breeding and international collaboration in agricultural research that led to the spread of high-yielding and fertilizer responsive varieties of wheat and rice used especially in developing countries (Jain, 2010). Since the 1980s plant biotechnology accelerates the progress in plant breeding (Moose and Mumm, 2008). Besides this enormous progress in plant breeding, the development of synthetic fertilizers made agricultural intensification possible at all. This led to higher yields due to simplified rotations mainly enabled by Haber-Bosch nitrogen (Tonitto et al., 2006).

A number of intertwined aims of plant breeding go along with reaching an increase of crop yields. Among these are the reduction in plant height and increasing the harvest index (De Vita et al., 2007), the improvement of nitrogen use efficiency (Cormier et al., 2013), yield stability within poor environmental conditions (Tester and Langridge, 2010), optimizing plant photosynthesis (Parry et al., 2007), increasing plant biomass (Reynolds et al., 2009), the improvement of nutritional qualities and other characteristics that are of commercial value (Moose and Mumm, 2008).

Plant breeding is regarded as a three-step process: At first populations with presumably useful genetic variation are created or collected. The second step is the identification of those plants with "superior phenotypes" and finally these serve as basis for new cultivars (Moose and Mumm, 2008). Three main breeding methods can be differentiated: Individuals for breeding can be selected based on their observable, natural variation. Another possibility is to control the mating by combining parents with desirable genes (Breseghello and Coelho, 2013). Mostly this is done by backcrossing, gene pyramiding or pedigree breeding (Moose and Mumm, 2008). Furthermore, molecular tools enable the breeder to systematically select certain genes or marker profiles. The application of the latter on the field is just in the early stages (Breseghello and Coelho, 2013). In research, however, molecular tools are widely available and routinely used already (Dwivedi et al., 2007). Molecular tools cover gene-based mapping, genome-wide linkage disequilibrium and association analysis, QTL (quantitative trait locus)-mapping and marker-assisted selection (MAS) (Dwivedi et al., 2007).

While the methods mentioned so far focus on the selection of specific genes for the breeding process from the pool of genes within the targeted species, biotechnology also enables the creation of further genetic diversity "beyond species boundaries" (Moose and Mumm, 2008). Transformation or gene modification allows to introduce genes from other species or even synthetically created genes in the plant genome which can lead to an "infinite pool of novel genetic variation" (Moose and Mumm, 2008). Although much research is going on in this field, political, societal, economic and bioethical issues restrict its application until now (Tester and Langridge, 2010). In addition, there is discussion about which organisms fall in the category of GMOs (Genetically Modified Organisms). This was, for example, the case for some new gene editing techniques where it was unclear whether these are regulated by the EU GMO regulation or not (European Seed Association, 2015; Lusser et al., 2011).

Recent progress in plant breeding reached the following achievements:

- Increased photosynthesis via greater radiation use efficiency and maximum photosynthetic rates at the leaf level (Fischer and Edmeades, 2010; Reynolds et al., 2009; Slafer et al., 2013)
- Improved drought tolerance in terms of improvements in yields under water-limiting conditions (Cattivelli et al., 2008)
- Improvements in nitrogen-use efficiency in European maize (Presterl et al., 2003)
- Increased carbon fixation efficiency and spike fertility in wheat (Reynolds et al., 2009)

Future developments and improvements are expected with respect to

- The optimization of photosynthesis by improving the working mechanism of the accountable enzyme "Rubisco" (Parry et al., 2007; Reynolds et al., 2009)
- The manipulation of the rate of crop development in the late reproductive phase and the prolongation of the phase of stem elongation to increase wheat biomass (Slafer et al., 2013)

Cereal breeding led to higher kernel numbers, a larger grain-sink size and the reduction in plant height to increase the harvest index for wheat (De Vita et al., 2007). Grain nitrogen yield and nitrogen use-efficiency could be improved for wheat (Cormier et al., 2013) and maize (Presterl et al., 2003). Carbon fixation could be improved (Reynolds et al., 2009) and research currently works on the enhancement of the photosynthesis process (Parry et al., 2007).

Fruit and vegetables are prone to pests and weeds. Some GMO-varieties are already in use, for instance concerning corn, that show resistance to some pathogens and that are tolerant to herbicides used to tackle the weeds (Silva Dias and Ortiz, 2014).

For other crops, aims in potato breeding, for example, are to increase its mineral and water use efficiency while the varieties should meet consumer demands (Haase and Haverkort, 2006). Breeding success with respect to sugar beet raised the yield of white sugar over the last decades. During this time breeding targets moved from a focus on yield to biomass quality (Loel et al., 2014). European soybean breeding aims at increasing the acreage to reduce the EU's import dependence. Therefore the broadening of its genetic diversity is suggested to overcome the prevalent climatic limitations (Hahn and Würschum, 2014).

4.4 Agriculture and trade policies

The indirect and direct effects of agricultural and trade policies on the EU food system are discussed in D1.1 (Zurek et al., 2016). Besides those, EU's regulation on Genetically Modified Organisms (GMOs) affects trade with crops and also crop production. Cultivation of GMO products is largely prohibited in the EU. The only areas where GM crops are grown in any significant numbers are Spain and Portugal that produce Bt maize (GMO Compass, 2013).

Sanitary for human and animal health and phytosanitary for plant health regulations affect crop production as well. They came into force in 1995 with the establishment of the WTO. Food safety and animal and plant health regulations are applied to the extent necessary to protect human, animal and plant health and life. Based on scientific justification, countries can set own standards that are stricter than the international ones as long as their use is not unjustified for the purpose of trade restriction. The aims of these regulations are to protect plant life from pests, diseases, disease causing organisms; protect human life from plant-carried diseases and prevent damage to a country from pests (WTO, 1998). The agreement on Sanitary and Phytosanitary (SPS) measures clarifies the basis for trade so that exporters and importers gain greater certainty about trade barriers (WTO, 2010a). Henson and Loader (1999) find that since setting different standards, if justifiable, is allowed according to the agreement, trade of some goods has impeded:

- An example is the case of aflatoxins, some poisonous chemicals, prevalent especially in stored agricultural crops (Otsuki et al., 2001). EU aflatoxin standards which are stricter than SPS regulations, affect many exports from developing countries to the EU (Jha, 2005).

- Further EU standards have an impact on US exports. EU regulations with respect to GM-varieties affect corn and soy exports from the US, while maximum residue limits hinder US exports of fruits and vegetables. Also the US import approval process for new varieties of fruits and vegetables influences EU fruits and vegetables exports to the US (Arita et al., 2015).
- The so-called EC-Biotech case is an example for a dispute on SPS measures that reached the WTO dispute settlement panel (WTO, 2010b). The US, Canada and Argentina claimed that the European Community (EC) has used a moratorium that suspended exports of biotech products into the community and that this moratorium violated the SPS agreement. The EC argued that the way how genetically modified products were treated on a case-by-case basis could not be regarded as SPS measure. Although the Panel agreed that this was no SPS measure, they found the moratorium to be inconsistent with WTO rules. National bans of GMO products which were found to be SPS measures though were criticized by the Panel not to be sufficiently scientifically approved (Negi, 2007). In addition, it is argued that this Panel report has widened the area of measures that fall under the SPS agreement, like domestic regulations in the GMO case (Peel, 2006).

SPS measures are also a topic within the discussion about the Transatlantic Trade and Investment Partnership (TTIP) agreement since these measures differ substantially between the EU and the US, e.g. with respect to pesticide residues standards (Xiong and Beghin, 2016).

4.5 Environmental issues

Apart from its impacts on the environment, crop production is heavily influenced by environmental issues themselves. One of the most discussed global environmental impacts on crop production is climate change (Gregory et al., 2005; Hermans et al., 2010; Hertel, 2011; Iglesias et al., 2011; Kriegler et al., 2012; Schmidhuber and Tubiello, 2007; Wheeler and Braun, 2013).

Whereas the overall adverse effects of climate change on global agriculture are largely agreed on (IPCC, 2014), climate change effects on Europe can be very different. Most European studies agree that there is a tendency for mainly adverse effects on crop production in Southern European countries and often positive effects on crop production in the North (Audsley et al., 2006; Hermans et al., 2010; Wolf et al., 2015). However, these effects have been explored for cereals, oilseeds and potatoes and considerably less quantitative analysis of climate change impacts on fruit and vegetable production is available. Moretti et al. (2010) assess climate change impacts on postharvest quality of fruit and vegetables, which might also impact the nutritional value of these crops. Large-scale economic analyses of the fruit and vegetables sector under climate change are, to our knowledge, currently not available. Region specific studies refer, for example, to olive (Ponti et al., 2014; Quiroga and Iglesias, 2009) and citrus and grapevine production (Quiroga and Iglesias, 2009) in the Mediterranean.

The effect of climatic factors on crop yields will be considered in the quantitative analysis of yield gaps in D4.5 and in the SUSFANS toolbox.

4.6 Culture and lifestyles

Culture and lifestyles particularly affect the diets, i.e. consumption of agricultural products. Their effect on crop production is therefore very indirect. Evidence from the literature regarding plant based proteins and diets shows that more than 1 million tons of vegetable proteins are estimated to be consumed every year and that at global scale the markets for vegetable proteins are growing (Logatcheva and Galen, 2015). Diet shifts towards less meat and more plant-based diets are observed (Springmann et al., 2016). De Boer et al. (2006) show that in all EU countries, cereals (followed by vegetables and potatoes) are the largest supplier of plant protein. For France, lifestyle changes led to an increased use of plant proteins. The main sources of the increased plant protein consumption are wheat and soy (Estève-Saillard, 2016). For Germany, increases in consumption of cereals and vegetables are measured, whereas the consumption of potatoes, fruits and meat decreases (Noleppa and Cartsburg, 2015). On average, the German lifestyle is described to be among the highest in terms of resource and energy consumption in the world. Changes in lifestyles are often hampered by psychological barriers since consumption reductions might be regarded as losses and require habitual changes. However, some sustainable lifestyle-changes already have become fashionable e.g. eating vegetarian (Lehmann and Rajan, 2015).

Regarding health and the reduction of meat consumption there is an increased awareness of consumers about the nutritional impact of an unhealthy lifestyle (Viscecchia et al., 2016), whereas the current debate around eating less meat is also based on concerns about animal welfare, reactive nitrogen, and greenhouse gas emissions (Westhoek et al., 2014). It is also found that both country class and food related lifestyle significantly account for variation in meat and organic food consumption (Thøgersen, 2017). However, since European diets are already very high in animal products, a further increase in demand for animal products is rather unlikely (Röös et al., 2016).

Research on European lifestyle changes shows that diet-related diseases are an important topic on the agenda in an ageing European society. Among these diseases are obesity, coronary heart disease and diabetes that result from diets characterised to be high in fat, sugar and cholesterol (Rabbinge and Linnemann, 2009). For Germany it is found that the number of vegetarians is increasing especially within the younger generations. This development leads to a reduced demand for meat products and should be favourable for the demand of cereals, vegetables and fruits (Oltersdorf and Ecke, 2003). However, over the period between 2006 and 2012, national dietary guidelines were not met. Less plant-based and more meat products were consumed than according to the guidelines (Gose et al., 2016).

According to de Boer et al. (2006) further research is needed in a multidisciplinary analysis to develop policy options for a transition from animal to plant proteins. Some proposals have been made referring to consumer education, food guidelines, the development of plant-based meat-alternatives and measures of fiscal policies (subsidies, taxes) (Sabaté and Soret, 2014).

5 Direct drivers of crop producers in the EU

As opposed to the indirect drivers, direct drivers affect crop production very directly on farm.

5.1 Regulatory environment per country

The regulatory environment for agriculture in the EU is general determined by the Common Agricultural Policy (CAP). Besides EU regulations that are applied across all Member States similarly, many decisions reach the Member States in form of a directive. The water framework directive and its integral part, the nitrates directive, is one of these and has an impact on the agricultural sector (e.g. Bazzani et al., 2004). Please refer to Zurek et al. (2016) for more detail on the CAP and other environmental legislation affecting the agricultural sector as a whole. Below the policies directly affecting crop production in the EU are briefly described.

Plenty of evidence exists for the impact of policies and regulations on primary agricultural production (e.g. Britz et al., 2012; Britz and Delzeit, 2013; Gocht et al., 2013; Zimmermann and Britz, 2013; Schneeberger, Darnhofer, and Eder, 2002; Ericsson et al., 2009). Most relevant for cereal and fruit and vegetable production are the corresponding market organizations. Since 2008 the different regimes for arable crops have been integrated into the Single Common Market Organisation (CMO). Since then EU policy is limited to the two main areas intervention and trade measures (European Commission, 2016b).

Regarding cereals, the EU is one of the world's biggest producers and an important trader in global cereals markets. Changes to the Common Agricultural Policy have gradually removed product-specific subsidies for cereals, oilseeds, protein crops and rice and EU support for arable crops, which used to be provided through a complex system of market measures, has been simplified. The direct payment system allows farmers to switch to different crops or types of production in response to market developments. Buying-in cereals and rice to public storage, the so-called intervention, was introduced as safety-net for farmers in terms of protecting them from low market prices. It is used only in cases of real necessity.

With respect to trade, about 15% of the EU's wheat production is exported annually, while large quantities of oilseeds, animal feedstuffs and rice are imported. The entry of cereals and rice into the EU is controlled by an import regime. “Imports are subject to the issuing of a standardised import licence and, in general, payment of a tariff. For some cereals tariffs are variable, for others tariffs are fixed. In addition - in accordance with the EU's commitments under the World Trade Organisation (WTO) - a number of fixed tariff import quotas are in place at a lower or zero duty. Exports of cereals and rice to countries outside the EU are mostly subject to the issuing of an export licence. These exports have not been subsidised since 2006 “ (European Commission, 2016b).

The fruit and vegetable sector of the EU is supported through a market-management scheme with four broad goals: (1) a more competitive and market-oriented sector, (2) fewer crisis-related fluctuations in producers' income, (3) greater consumption of fruit and vegetables in the EU, (4) increased use of eco-friendly cultivation and production techniques. With respect to (1) competitiveness and market-orientation, producers are encouraged to join producer organisations, which receive support for implementing operational programmes based on national strategies. In some EU regions and for a transitional time period, producer groups can apply for financial aid to help them attain recognition as producer organisations. Support for preventing (2) income fluctuation from crises is offered under operational programmes for product withdrawal, green harvesting or non-harvesting, promotion and communication tools, training, harvest insurance and help to secure bank loans and cover administrative costs of setting up farmer-owned stabilisation funds. (3) Greater consumption of fruits and vegetables by children is promoted by a school fruit scheme and support is given to the free distribution of fruits and vegetables to schools, hospitals and charities. (4) Eco-friendly cultivation and production of fruits and vegetables is promoted by reserving 10% of spending in the operational programmes for environmental actions going beyond mandatory environmental standards (European Commission, 2016c).

5.2 Input and farm gate prices

“In economic theory, the price for any specific good is determined by the interplay between supply and demand. As market conditions change (supply and/or demand shocks), price adjustments take place. This way, prices transfer information about markets. The most important prices at primary production level are input and farm gate or producer prices. The relationship between input and producer prices is one of the most important drivers for decision-making on the farms.

Input quantities weighted by their prices enter producer balances as costs. Inputs are generally categorized into fixed, quasi-fixed and variable inputs. Depending on the time horizon considered, fixed and quasi-fixed inputs are not clearly defined. Usually, they include labour, land, building and machinery, i.e.

everything that has to be paid irrespective of the current production. Important variable inputs are, for example, energy, water, fertilizers and plant protection (e.g. Moore et al., 1994; Just et al., 1983).

Figure 4 gives an overview of the average shares of intermediate inputs in the EU28 in 2014. Intermediate inputs cover purchases made by farmers for raw and auxiliary materials that are used as inputs for crop and animal production and expenditure on veterinary services, repairs, maintenance and other services. The highest share of intermediate inputs is used for feeding stuffs in animal production (36.9%). It is followed by energy and lubricants for crop and animal production (12.0%). Fertilisers and soil improvers account for 7.6%. Seeds and planting stock account for 5.1% and plant protection products for 4.9%" (Zurek et al., 2016).

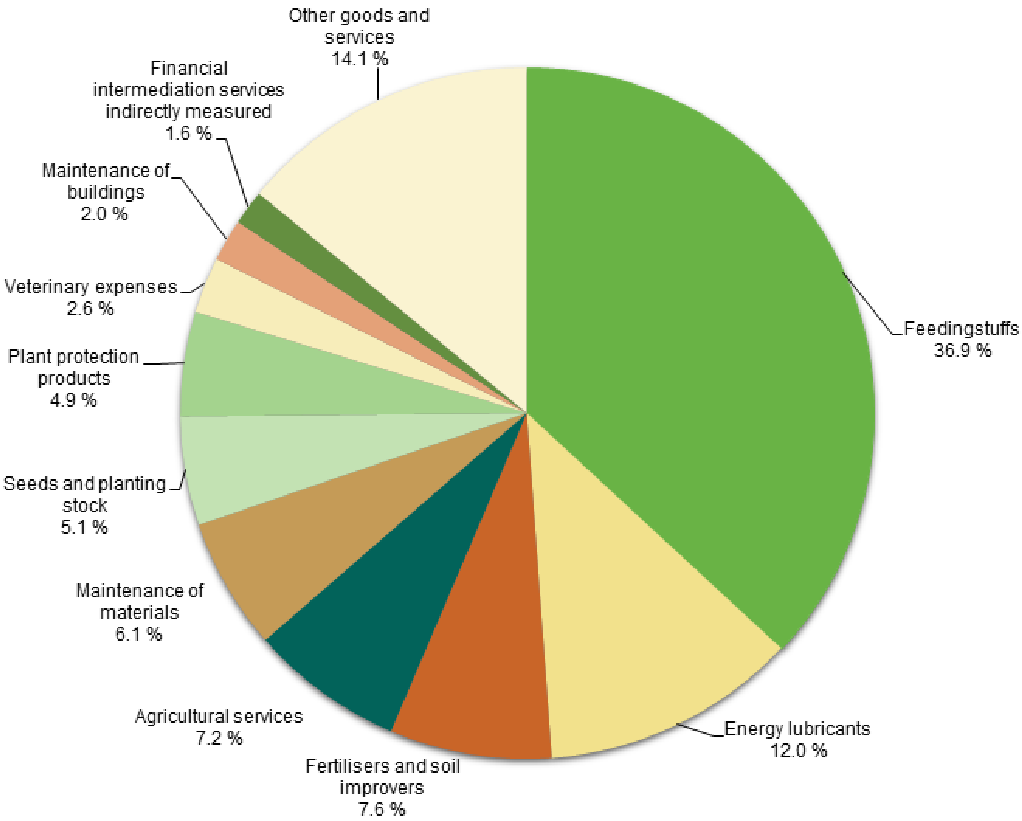

Figure 4. Intermediate inputs consumed by the agricultural industry at basic prices, EU-28, 2014

Source: European Commission (2015b).

Figure 5 shows deflated price indices for cereals, vegetables and horticultural products, potatoes and fruits for 2005 to 2014. Among the selected crops shown, the greatest variations in EU-28 prices and the overall highest price increases between 2005 and 2014 were recorded for cereals and vegetables.

For crop output at the EU-28 level, the price indexes were lower in 2014 than in 2010 (by – 0.4 %). This was the case in half of the EU Member States. Belgium (– 24.5 %), Malta (– 14.7 %) and Portugal (– 14.5 %) were the EU Member States with the sharpest decreases of deflated output prices for crops. By contrast, output prices for crops rose at a relatively fast pace in the Czech Republic, (+ 20.0 %) and Cyprus (+ 15.3 %) during the period 2010–14 (European Commission, 2015b).

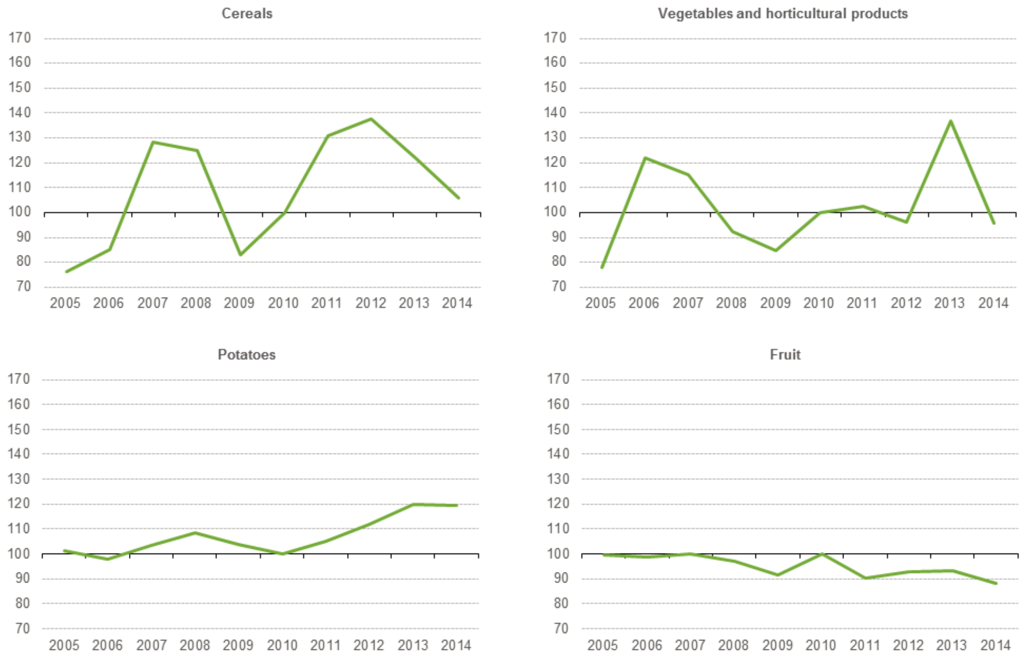

Figure 5. Deflated price indices for selected crop outputs, EU-28, 2005–14 (2010=100)

Source: European Commission (2015b).

Plenty of explanation and analysis exists for cereal price developments globally and in the EU (Braun, 2007; Dawe et al., 2015; Headey and Fan, 2008). Since cereal markets are highly globally integrated, global developments usually also affect European prices (Jacks et al., 2011; Zanias, 1999).

Producers prices have usually been volatile for fresh fruits and vegetables and seem declining in trend in the last few years, while retail prices are either constant or increasing, indicating either increasing rents being captured by downstream actors or increasing levels of value added. In the context of increasing concerns of possible malfunctions of the European food supply chain (price hikes of 2007-2008 and potential price stickiness in the food supply chain), consideration for the weak bargaining power of the fruits and vegetables exists (Petriccione et al., 2011). Much of the decline in fruit and vegetable prices in early 2014 reflects the mild winter of 2013-14 in conjunction with the unwinding of earlier upward impacts resulting from adverse weather conditions (https://www.ecb.europa.eu/pub/pdf/other/eb201506_focus07.en.pdf). A special factor currently affecting food price inflation (both in terms of unprocessed and processed food products) is the Russian ban on imports from the European Union. The Russian ban became effective in mid-2014 and may have prevented a stronger recovery in food prices. Indeed, anecdotal evidence at the time pointed to a negative impact on prices of unprocessed food such as apples and processed food such as dairy products (https://www.ecb.europa.eu/pub/pdf/ecbu/eb201506.en.pdf). Outside the EU, fresh fruit and vegetables are mainly exported to Russia, Belarus, Ukraine, Switzerland and Norway such that Russia is an important export destination for these products. The length of this ban is currently unknown (CBI Ministry of Foreign Affairs, 2015).

5.3 Contract opportunities

““Contract farming can be defined as agricultural production carried out according to an agreement between a buyer and farmers, which establishes conditions for the production and marketing of a farm product or products. Typically, the farmer agrees to provide agreed quantities of a specific agricultural product. These should meet the quality standards of the purchaser and be supplied at the time determined by the purchaser. In turn, the buyer commits to purchase the product and, in some cases, to support production through, for example, the supply of farm inputs, land preparation and the provision of technical advice” (FAO, n.d.). Contracts can be negotiated between input suppliers (e.g. seed and feeding stuff companies) and farmers as well as between farmers and upstream supply chain companies (e.g. slaughterhouses, wholesalers, supermarkets)” (Zurek et al., 2016).

Though there is a vast literature on contract farming in developing countries, almost no information on contract farming in Europe is available (Zurek et al., 2016). Contract opportunities in European crop production are mainly used in sugar, fruit and vegetable production and in the grain sector (Lipinska, 2013). According to Balmann et al. (2006) contract farming will become more important for crop producers in the future.

5.4 Natural resource availability

Natural resource availability is interpreted as the environmental setting on farm. Natural resource availability is the most important driver of agriculture. It determines agriculture in terms of which farming activities can pursued at all (e.g. olive production in Finland not possible) and which results, i.e. yields can be achieved (e.g. lower crop yields on poorer soils).

Natural resource availability includes mainly land, climate, soils and water (van Ittersum and Rabbinge, 1997). Since most of the respective text in D1.1 refers to the environmental conditions and their effect on crop production in the EU, they are not further described here (Zurek et al., 2016).

Most of these factors will be taken into account in the quantitative assessment of yield gaps in Europe in D4.5.

5.5 Available technology

The conceptual framework (D1.1) mainly refers to technology adoption and diffusion, technology usage and total factor productivity under this point. In line with our definition of having the breeding process in order to extend yield frontiers (i.e. potential yields) as indirect driver under technological innovation and efforts to decrease the yield gap as direct driver on farm, we refer to management here. Management highly depends on the available technology on farm (e.g. machinery) and the technical knowledge of the farmer (e.g. on fertilizer and plant protection application.

The yield gap is broadly defined as the gap between potentially attainable yields and actually achieved yields on farm. Figure 6 gives an overview of the definition of different yield levels. The yield potential is generally defined by biophysical factors only, i.e. CO_2, radiation, temperature and cultivar features. Sometimes water-limitation is included in the definition of the yield potential. According to van Ittersum et al. 2013), about 80% of the potential yield are usually exploitable depending on optimal management. The exploitable yield gap is the difference between the exploitable yield (80% of potential yield) and the average yield on farm.

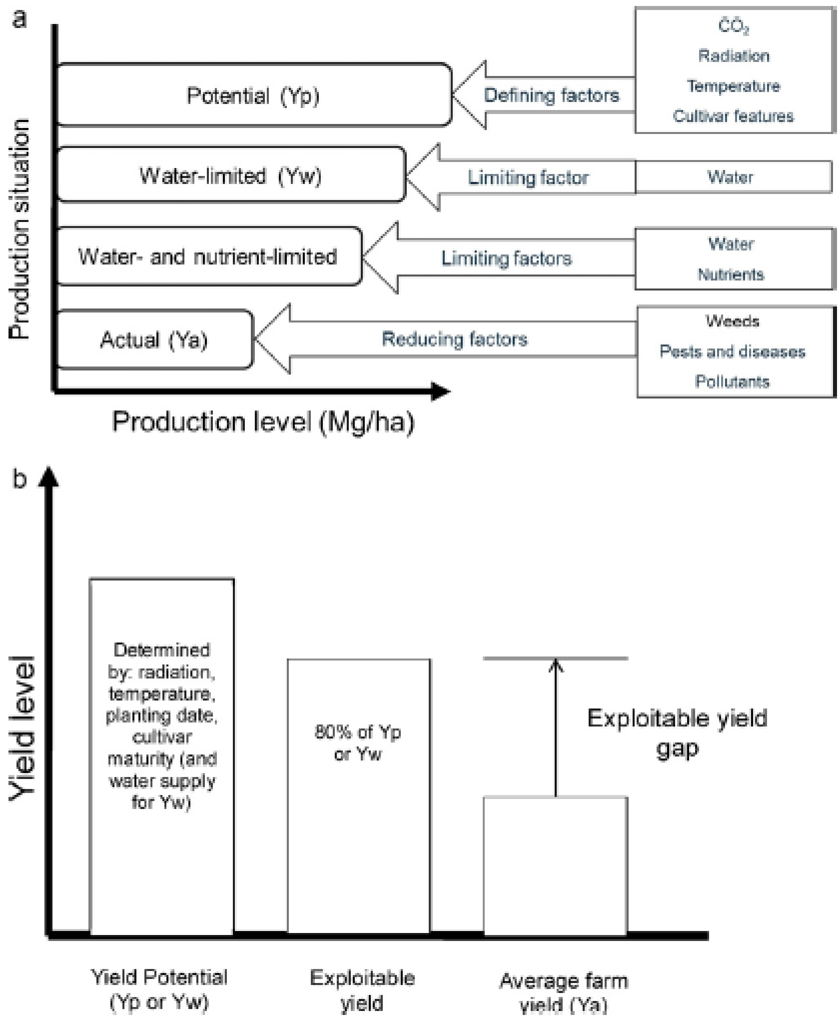

Figure 6. Yield gap definition

Source: van Ittersum et al. (2013).

By nature, yield gap assessments need to be multi-disciplinary based on biophysical and economic expertise. The literature provides a number of global and European yield gap analyses, e.g. Baldos and Hertel, 2012; Lobell et al., 2009; Neumann et al., 2010; Reidsma et al., 2009c; van Ittersum et al., 2013.

In the high-intensive crop production in the EU, often up to 80% yield gap exploitation are achieved. Current yield gap levels and an empirical assessment of their determining factors will be presented in the empirical part on yield gaps (introduction below and full assessment in the final version of this deliverable, D4.5).

5.6 Producer and farm characteristics

"Besides direct production factors, personal attitudes, values and goals, experiences as well as social influences drive producers' decisions (Öhlmér et al., 1998). Agricultural production is also heavily influenced by path dependencies through existing farm characteristics and farm structure (e.g. Balmann et al., 1996; Zimmermann and Heckelei, 2012)“ (Zurek et al., 2016).

Producer and farm characteristics play a major role in all decision making on farm. However, since they are not unique to the crop production system, they are not explicitly treated here, but described in D1.1 (Zurek et al., 2016).

Producer and farm characteristics have a significant impact on farm management and management practices that are directly related to crop production. Depending on data availability, they will be explicitly considered as drivers in the empirical work on yield gaps in Europe in D4.5.

6 Hierarchy of drivers affecting crop production

Based on the purely qualitative analysis of the drivers, a hierarchy of their impacts on crop production is almost impossible to identify. Quantitative assessments considering all of these drivers are currently not available. However, some of these drivers are frequently taken into account in integrated assessments[1] of the agricultural sector. The drivers usually considered are technology, population developments, global GDP growth, climate change and, partly, agricultural and trade policies. Among those it is often found that climate change can have a severe effect on the sector, which, however, can even be outperformed by technology and economic changes (Nelson et al., 2014; Schneider et al., 2011; von Lampe et al., 2014; Wolf et al., 2015). In particular, technical progress and its potential impact on crop production is very difficult to assess and usually only addressed in a very stylized manner in economic agricultural sector models (Ewert et al., 2005; Wolf et al., 2015). However, due to its severe impact on the sector, research particularly dedicated to technical progress and its effects is ongoing. Currently, also progress is being made in explicitly considering agricultural and policy changes and other adaptations to climate change in integrated assessments, for example in the AgMIP (http://www.agmip.org/), MACSUR (http://macsur.eu/) and SUSTAg (http://faccesurplus.org/research-projects/sustag/) projects.

Prices and, partly, management are usually endogenous in large-scale integrated assessments of the agricultural sector which emphasizes their importance in the modelling work and the sector itself. However, they react to other biophysical and market changes and are therefore usually considered as outcome indicators transmitting information about the sector.

[1] The term Integrated Assessment Modelling is often applied to modelling exercises integrating models from different disciplines, e.g. climate, crop and economic models for the analysis of climate change impacts on the agricultural sector.

Natural resource availability is the most crucial and basic factor for crop production. It is usually indirectly considered by calibrating integrated assessment models to specific region characteristics.

Culture and lifestyle changes are sometimes considered in terms of demand scenarios. They can impact the sector, but their impacts are usually smaller than those of other global drivers (climate change, population and income growth, technical progress). Contract opportunities and vertical integration are usually not considered in integrated assessments and likely less important regarding their effects on production per se. Producer and farm characteristics can severely affect production on individual farms. However, they are difficult to cover in large-scale assessment and might cancel out on average.

Management has recently received a lot of attention in the context of climate change adaptation and modelling work is in progress (e.g. in the MACSUR (http://macsur.eu/) project).

The above mentioned drivers are usually assessed with respect to their impacts on cereal, oilseed, potato and sometimes sugar beet production. Their effects on fruit and vegetable production are often not considered.

7 Conclusions

This first qualitative part of the analysis done in task T4.4 described the direct and indirect drivers of crop production in the EU focusing on cereal and fruit and vegetable production. This part intended to develop the understanding of the sector for supporting the SUSFANS conceptual framework in WP1, further empirical analysis in WP4 and primary production background for the fruits and vegetables case study in WP5. The second part of the T4.4 analysis will be based on empirical analyses of the crop production drivers. The empirical analyses will be added in the final version of this deliverable (D4.5) in March 2017.

Appendix

Drivers of primary production

„Hazell and Wood (2008) define a driver as 'any natural- or human-induced factor that directly or indirectly brings about change in an agricultural production system'. They distinguish global-scale drivers, country-scale drivers and local-scale drivers. According to their nomenclature, global-scale drivers affect all agriculture around the world and include trade expansion, value chain integration, climate change, agricultural support in the Organisation for Economic Cooperation and Development (OECD) and the Word Trade Organisation (WTO), globalization of science and knowledge, technology and products relevant to agricultural development. As such, they are almost identical with our indirect drivers of the agro-food system. Country-scale drivers affect agriculture within a country (e.g. infrastructure, market access) and local-scale drivers are specific to each local geographical area and different types of agricultural production systems. However, the drivers they subsume under country- and local-scale drivers largely differ from our category of direct drivers. In our framework, direct drivers are defined as drivers that directly affect the decision-making on site.

The ultimate decision-making of agricultural production takes place on the farms. The farmers/fishers or producers make their decisions based on a variety of drivers. Examples of decision-making processes in fisheries and their influence on the efficiency of the fishery and its products are given in Ruttan and Tyedmers (2007) and Ziegler et al. (2015). Drivers that affect the producers directly are reviewed in the following.

Öhlmér et al. (1998) identify eight elements of decision-making at the farm level: (1) values and goals, (2) problem detection, (3) problem definition, (4) observation, (5) analysis, (6) development of intention, (7) implementation, and (8) responsibility bearing. Values and goals are internal direct drivers and briefly reviewed below. External direct drivers mainly affect the problem detection. Once a problem due to a change in external drivers is detected, more information is gathered in the elements problem definition and observation, which finally lead to a decision process and a potential change in production activities (Öhlmér et al., 1998).

Within the EU food system, several drivers that influence actions and decision-making processes of primary agricultural and fishery producers can be distinguished. Although a strict assignment of these factors to different categories is barely possible due to their interdependencies, the drivers that are mentioned in the literature are broadly classified into a number of categories" (Zurek et al., 2016).

Drivers in the context of production economics

Primary agricultural and aquaculture production means transforming inputs into outputs (please note that this does not necessarily apply to capture fishery). In its simplest form, a farm produces a single output for which it uses N inputs (e.g. labour, machinery, feed, fertilizer, etc.). This relationship can be summarized in a production function

$$q = f(\mathrm{x})$$

where q is a function f of $\mathrm{x} = (x_1, x_2, \dots, x_N)$ inputs. Assuming these inputs x are under the control of the decision maker, other inputs like climate might be outside the control of the decision maker and could be added as inputs z leading to production function

$$q = f(\mathrm{x,z}).$$

There is plenty of literature on properties of production functions and their various transformations (e.g. Coelli et al., 2005). Clearly, decision making will be affected by both controllable and uncontrollable inputs. In the framework of the drivers considered here, all biophysical drivers are inputs that are outside the control of the farmer. Controllable inputs usually have prices attached to them (e.g. machinery, feed, fertilizer). Depending on these input prices, farmers may decide based on a cost function approach where costs are minimized:

$$c(w, q) = \min_{x} \mathrm{w'x}$$

where $\mathrm{w} = (w_1, w_2, \dots, w_N)$ is a vector of input prices. In addition to input prices, farms might also consider output prices in their decision making. Assuming profit maximizing behaviour, this can be represented by a profit function:

$$\pi(\mathrm{p,w}) = \max_{\mathrm{q,x}} \mathrm{p'q} - \mathrm{w'x}$$

where profit π varies the M with output prices $\mathrm{p} = (p_1, p_2, \dots, p_M)$ (Coelli et al., 2005). This highlights the importance of both input and output prices in the decision-making process.

Inputs as well as output prices are, in turn, affected by various other drivers. “In economic theory, the price for any specific good is determined by the interplay between supply and demand. As market conditions change (supply and/or demand shocks), price adjustments take place. This way, prices transfer information about markets” (Zurek et al., 2016). Mainly, prices are affected by the indirect drivers considered here: broader economic development, population dynamics, technological change, agriculture and trade policies, environmental issues and culture and lifestyles.

Besides the price information, other factors affect decision-making on farm directly. Thus, the regulatory environment has to be taken into account, contract opportunities might provide options for cost-reduction through collaboration with others and exploiting scale effects, as mentioned above, natural resource availability has a direct impact as well as the available technology and producer and farm characteristics.

Technological change vs. available technology

One of the main differences of the WP4 deliverables among each other and compared to the SUSFANS Conceptual Framework (CF) is related to the indirect driver 'technological change' and the direct driver 'available technology'. Since the distinction between those two is not necessarily clear, how they are treated in the CF and in the WP4 driver deliverables is shown in Table 4. The interpretation and usage of these terms in the WP4 driver deliverables highly depends on the production system and the different foci required for their analysis. Generally, one might argue that even the indirect driver 'technological change' very directly affects primary producers.

Table 4. Technological change vs. available technology

Document	Indirect driver 'technological change'	Direct driver 'available technology'	Comment
CF (D1.1)	- Innovation - Technology development	- Technology adoption & diffusion - Technology usage	The distinction here is that an innovation is not necessarily used on farm. This depends on technology adoption and diffusion. Usually, there is a considerable time gap between the actual innovation and the use on farm.
Livestock (D4.1)	- Progress in feeding technology - Progress in breeding	-Feeding and breeding technologies are adapted in e.g. diet formulations	Feeding and breeding strategies aiming to increase productivity will eventually become available on farm. The time gap in which the farmers adopt the breeding and feeding strategies will depend on things as profitability, feasibility and on the corporation the farmer is joining.
Seafood	- Historical	- Science and	The distinction here is

(D4.2)	development and the interplay between farmed and fished seafood - Technical innovations in society enabling growth	management behind current production - Difference in technology between individual enterprises, e.g. farmers' knowledge, skipper effect - Status of production systems and technical progress needed - Production efficiency incl. by-product utilization	that the indirect drivers are those related to the history behind the status and drivers for current production systems, including other technological development in society enabling growth, whereas the direct drivers are those related to the available and needed technology of current production systems
Crop (D4.4)	- Public and private research (breeding, fertilizer and plant protection, machinery)	- Management	This translates into the concept of technical progress in terms of (1) increasing crop potential through public and private research and (2) decreasing the yield gap (i.e. the gap between potential and actually achieved yields) on farm

References

Arita, S., Mitchell, L., Beckman, J., 2015. Estimating the Effects of Selected Sanitary and Phytosanitary Measures and Technical Barriers to Trade on U.S.-EU Agricultural Trade.

Audsley, E., Pearn, K.R., Simota, C., Cojocaru, G., Koutsidou, E., Rounsevell, M.D.A., Trnka, M., Alexandrov, V., 2006. What can scenario modelling tell us about future European scale agricultural land use, and what not? Environ. Sci. Policy 9, 148–162. doi:10.1016/j.envsci.2005.11.008

Baldos, U.L.C., Hertel, T.W., 2012. Economics of global yield gaps: A spatial analysis, in: 2012 Annual Meeting, August 12-14, 2012, Seattle, Washington.

Balmann, A., Dautzenberg, K., Happe, K., Kellermann, K., 2006. On the dynamics of structural change in agriculture: Internal frictions, policy threats and vertical integration. Outlook Agric. 35, 115–121. doi:10.5367/000000006777641543

Balmann, A., Odening, M., Weikard, H.-P., Brandes, W., 1996. Path-dependence without increasing returns to scale and network externalities. J. Econ. Behav. Organ. 29, 159–172. doi:10.1016/0167-2681(95)00055-0

Bazzani, G.M., Di Pasquale, S., Gallerani, V., Viaggi, D., 2004. Irrigated agriculture in Italy and water regulation under the European Union water framework directive. Water Resour. Res. 40, W07S04. doi:10.1029/2003WR002201

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182–188. doi:10.1016/S0169-5347(03)00011-9

Braun, J. von, 2007. The World Food Sitution: New Driving Forces and Required Actions. Intl Food Policy Res Inst.

Breseghello, F., Coelho, A.S.G., 2013. Traditional and Modern Plant Breeding Methods with Examples in Rice (Oryza sativa</i> L.). J. Agric. Food Chem. 61, 8277–8286. doi:10.1021/jf305531j

Brisson, N., Gate, P., Gouache, D., Charmet, G., Oury, F.-X., Huard, F., 2010. Why are wheat yields stagnating in Europe? A comprehensive data analysis for France. Field Crops Res. 119, 201–212. doi:10.1016/j.fcr.2010.07.012

Britz, W., Delzeit, R., 2013. The impact of German biogas production on European and global agricultural markets, land use and the environment. Energy Policy 62, 1268–1275. doi:10.1016/j.enpol.2013.06.123

Britz, W., Gocht, A., Pérez Domínguez, I., Jansson, T., Grosche, S.-C., Zhao, N., 2012. EU-Wide (Regional and Farm Level) Effects of Premium Decoupling and Harmonisation Following the Health Check Reform. Ger. J. Agric. Econ. 61, 44–56.

Calderini, D.F., Slafer, G.A., 1998. Changes in yield and yield stability in wheat during the 20th century. Field Crops Res. 57, 335–347. doi:10.1016/S0378-4290(98)00080-X

Cattivelli, L., Rizza, F., Badeck, F.-W., Mazzucotelli, E., Mastrangelo, A.M., Francia, E., Marè, C., Tondelli, A., Stanca, A.M., 2008. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crops Res. 105, 1–14. doi:10.1016/j.fcr.2007.07.004

CBI Ministry of Foreign Affairs, 2015. CBI Trade Statistics: Fresh Fruit and Vegetables in Europe.

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., Battese, G.E., 2005. An Introduction to Efficiency and Productivity Analysis, 2nd edition. ed. Springer, New York.

Cormier, F., Faure, S., Dubreuil, P., Heumez, E., Beauchêne, K., Lafarge, S., Praud, S., Le Gouis, J., 2013. A multi-environmental study of recent breeding progress on nitrogen use efficiency in wheat (Triticum aestivum L.). Theor. Appl. Genet. 126, 3035–3048. doi:10.1007/s00122-013-2191-9

Dawe, D., Morales-Opazo, C., Balie, J., Pierre, G., 2015. How much have domestic food prices increased in the new era of higher food prices? Glob. Food Secur., Special Section on "Selected papers from the 3rd Africa Rice Congress " 5, 1–10. doi:10.1016/j.gfs.2015.01.001

de Boer, J., Helms, M., Aiking, H., 2006. Protein consumption and sustainability: Diet diversity in EU-15. Ecol. Econ. 59, 267–274. doi:10.1016/j.ecolecon.2005.10.011

De Vita, P., Nicosia, O.L.D., Nigro, F., Platani, C., Riefolo, C., Di Fonzo, N., Cattivelli, L., 2007. Breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars released in Italy during the 20th century. Eur. J. Agron. 26, 39–53. doi:10.1016/j.eja.2006.08.009

Dwivedi, S.L., Crouch, J.H., Mackill, D.J., Xu, Y., Blair, M.W., Ragot, M., Upadhyaya, H.D., Ortiz, R., 2007. The Molecularization of Public Sector Crop Breeding: Progress, Problems, and Prospects, in: Advances in Agronomy. Elsevier, pp. 163–318.

Ericsson, K., Rosenqvist, H. akan, Nilsson, L.J., 2009. Energy crop production costs in the EU. Biomass Bioenergy 33, 1577–1586.

Estève-Saillard, M., 2016. Tendance de marché en France sur la présence des protéines végétales dans les produits alimentaires. OCL 23, D403. doi:10.1051/ocl/2016015

European Commission, 2016a. Agricultural production - crops - Statistics Explained [WWW Document]. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_production_-_crops (accessed 8.16.16).

European Commission, 2016b. Cereals, oilseeds and protein crops, rice - Agriculture and rural development [WWW Document]. URL http://ec.europa.eu/agriculture/cereals/index_en.htm (accessed 8.22.16).

European Commission, 2016c. Fruit and vegetable regime - Agriculture and rural development [WWW Document]. URL http://ec.europa.eu/agriculture/fruit-and-vegetables/index_en.htm (accessed 8.22.16).

European Commission, 2015a. Farm structure statistics - Statistics Explained [WWW Document]. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Farm_structure_statistics (accessed 6.14.16).
European Commission, 2015b. Agricultural accounts and prices - Statistics Explained [WWW Document]. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_accounts_and_prices (accessed 6.13.16).
European Commission, 2015c. FADN Homepage [WWW Document]. URL http://ec.europa.eu/agriculture/ricaprod/ (accessed 9.13.15).
European Commission, 2015d. Farm Accountancy Data Network (FADN) - Agriculture and rural development [WWW Document]. URL http://ec.europa.eu/agriculture/fadn/index_en.htm (accessed 9.13.15).
European Commission, 2015e. Glossary:Nomenclature of territorial units for statistics (NUTS) - Statistics Explained [WWW Document]. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Nomenclature_of_territorial_units_for_statistics_(NUTS) (accessed 9.13.15).
European Commission, 2014. Agriculture - FADN : F. A. D. N. - OTHER MAPS AND "SHAPEFILES" [WWW Document]. URL http://ec.europa.eu/agriculture/rica//othermaps_en.cfm (accessed 10.5.15).
European Seed Association, 2015. Regulatory approaches to modern plant breeding -the case of mutagenesis and new gene editing technologies.
Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M.J., Leemans, R., 2005. Future scenarios of European agricultural land use: I. Estimating changes in crop productivity. Agric. Ecosyst. Environ. 107, 101–116. doi:10.1016/j.agee.2004.12.003
FAO, n.d. Contract Farming: FAQ [WWW Document]. URL http://www.fao.org/ag/ags/contract-farming/faq/en/ (accessed 6.14.16).
Finger, R., 2010. Evidence of slowing yield growth – The example of Swiss cereal yields. Food Policy 35, 175–182. doi:10.1016/j.foodpol.2009.11.004
Fischer, R.A. (Tony), Edmeades, G.O., 2010. Breeding and Cereal Yield Progress. Crop Sci. 50, S-85. doi:10.2135/cropsci2009.10.0564
Gil, J.M., Gracia, A., Pérez, L.P.Y., 1995. Food consumption and economic development in the European Union. Eur. Rev. Agric. Econ. 22, 385–399. doi:10.1093/erae/22.3.385
GMO Compass, 2013. GM Maize Cultivation in Europe 2013 [WWW Document]. URL http://www.gmo-compass.org/eng/agri_biotechnology/gmo_planting/392.gm_maize_cultivation_europe_2013.html (accessed 9.23.16).
Gocht, A., Britz, W., Ciaian, P., Paloma, S.G. y, 2013. Farm Type Effects of an EU-wide Direct Payment Harmonisation. J. Agric. Econ. 64, 1–32. doi:10.1111/1477-9552.12005
Godfray, H.C.J., 2015. The debate over sustainable intensification. Food Secur. 7, 199–208. doi:10.1007/s12571-015-0424-2
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food

Security: The Challenge of Feeding 9 Billion People. Science 327, 812–818. doi:10.1126/science.1185383

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philos. Trans. R. Soc. Lond. B Biol. Sci. 369, 20120273. doi:10.1098/rstb.2012.0273

Gose, M., Krems, C., Heuer, T., Hoffmann, I., 2016. Trends in food consumption and nutrient intake in Germany between 2006 and 2012: results of the German National Nutrition Monitoring (NEMONIT). Br. J. Nutr. 115, 1498–1507. doi:10.1017/S0007114516000544

Götz, C., Valin, H., Havlík, P., Obersteiner, M., 2016. A long-term projection of land productivity based on Shared Socioeconomic reference Pathways. Unpublished draft.

Grassini, P., Eskridge, K.M., Cassman, K.G., 2013. Distinguishing between yield advances and yield plateaus in historical crop production trends. Nat. Commun. 4. doi:10.1038/ncomms3918

Gregory, P.J., Ingram, J.S.I., Brklacich, M., 2005. Climate change and food security. Philos. Trans. R. Soc. B Biol. Sci. 360, 2139–2148. doi:10.1098/rstb.2005.1745

Haase, N.U., Haverkort, A.J., 2006. Potato Developments in a Changing Europe. Wageningen Academic Pub.

Hafner, S., 2003. Trends in maize, rice, and wheat yields for 188 nations over the past 40 years: a prevalence of linear growth. Agric. Ecosyst. Environ. 97, 275–283. doi:10.1016/S0167-8809(03)00019-7

Hahn, V., Würschum, T., 2014. Molecular genetic characterization of Central European soybean breeding germplasm. Plant Breed. 133, 748–755. doi:10.1111/pbr.12212

Hazell, P., Wood, S., 2008. Drivers of change in global agriculture. Philos. Trans. R. Soc. B Biol. Sci. 363, 495–515. doi:10.1098/rstb.2007.2166

Headey, D., Fan, S., 2008. Anatomy of a crisis: the causes and consequences of surging food prices. Agric. Econ. 39, 375–391. doi:10.1111/j.1574-0862.2008.00345.x

Henson, S., Loader, R., 1999. Impact of sanitary and phytosanitary standards on developing countries and the role of the SPS Agreement. Agribusiness 15, 355–369. doi:10.1002/(SICI)1520-6297(199922)15:3<355::AID-AGR5>3.0.CO;2-I

Hermans, C.M.L., Geijzendorffer, I.R., Ewert, F., Metzger, M.J., Vereijken, P.H., Woltjer, G.B., Verhagen, A., 2010. Exploring the future of European crop production in a liberalised market, with specific consideration of climate change and the regional competitiveness. Ecol. Model. 221, 2177–2187. doi:10.1016/j.ecolmodel.2010.03.021

Hertel, T.W., 2011. The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making? Am. J. Agric. Econ. 93, 259–275. doi:10.1093/ajae/aaq189

Iglesias, A., Quiroga, S., Diz, A., 2011. Looking into the future of agriculture in a changing climate. Eur. Rev. Agric. Econ. 38, 427–447. doi:10.1093/erae/jbr037

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.
Jacks, D.S., O'Rourke, K.H., Williamson, J.G., 2011. Commodity Price Volatility and World Market Integration since 1700. Rev. Econ. Stat. 93, 800–813. doi:10.1162/REST_a_00091
Jain, H.K., 2010. Green Revolution: History, Impact and Future. The Green Revolution: Histor.
Jha, V., 2005. Environmental Regulation and Food Safety: Studies of Protection and Protectionism. IDRC.
Just, R.E., Zilberman, D., Hochman, E., 1983. Estimation of Multicrop Production Functions. Am. J. Agric. Econ. 65, 770–780. doi:10.2307/1240465
Kearney, J., 2010. Food consumption trends and drivers. Philos. Trans. R. Soc. Lond. B Biol. Sci. 365, 2793–2807. doi:10.1098/rstb.2010.0149
Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H., Struik, P.C., 2014. Increasing homogeneity in global food supplies and the implications for food security. Proc. Natl. Acad. Sci. 111, 4001–4006. doi:10.1073/pnas.1313490111
Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., Wilbanks, T., 2012. The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways. Glob. Environ. Change 22, 807–822. doi:10.1016/j.gloenvcha.2012.05.005
Lehmann, H., Rajan, S.C., 2015. Sustainable Lifestyles. Pathways and Choices for India and Germany.
Lin, M., Huybers, P., 2012. Reckoning wheat yield trends. Environ. Res. Lett. 7, 24016. doi:10.1088/1748-9326/7/2/024016
Lipinska, I., 2013. Contemporary significance of the cultivation contract. J. Agribus. Rural Dev.
Lobell, D.B., Cassman, K.G., Field, C.B., 2009. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. Annu. Rev. Environ. Resour. 34, 179–204. doi:10.1146/annurev.environ.041008.093740
Loel, J., Kenter, C., Märländer, B., Hoffmann, C.M., 2014. Assessment of breeding progress in sugar beet by testing old and new varieties under greenhouse and field conditions. Eur. J. Agron. 52, 146–156. doi:10.1016/j.eja.2013.09.016
Logatcheva, E.D., Galen, M.A. van, 2015. Primary food processing: cornerstone of plant-based food production and the bio-economy in Europe. LEI Wageningen UR, The Hague.
Lusser, M., Parisi, C., Plan, D., Rodríguez-Cerezo, E., 2011. New plant breeding techniques State-of-the-art and prospects for commercial development.pdf.
Moore, M.R., Gollehon, N.R., Carey, M.B., 1994. Multicrop production decisions in western irrigated agriculture: the role of water price. Am. J. Agric. Econ. 76, 859–874.
Moose, S.P., Mumm, R.H., 2008. Molecular Plant Breeding as the Foundation for 21st Century Crop Improvement. Plant Physiol. 147, 969–977. doi:10.1104/pp.108.118232

Moretti, C.L., Mattos, L.M., Calbo, A.G., Sargent, S.A., 2010. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. Food Res. Int., Climate Change and Food Science 43, 1824–1832. doi:10.1016/j.foodres.2009.10.013

Negi, A., 2007. World Trade Organization and the EC Biotech Case: Procedural and Substantive Issues. Int. Stud. 44, 1–22. doi:10.1177/002088170604400101

Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., Lampe, M.V., Lotze-Campen, H., d'Croz, D.M., Meijl, H. van, Mensbrugghe, D. van der, 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. Proc. Natl. Acad. Sci. 111, 3274–3279. doi:10.1073/pnas.1222465110

Neumann, K., Verburg, P.H., Stehfest, E., Müller, C., 2010. The yield gap of global grain production: A spatial analysis. Agric. Syst. 103, 316–326. doi:10.1016/j.agsy.2010.02.004

Noleppa, S., Cartsburg, M., 2015. Nahrungsmittelverbrauch und Fußabdrücke des Konsums in Deutschland: Eine Neubewertung unserer Ressourcennutzung.

Öhlmér, B., Olson, K., Brehmer, B., 1998. Understanding farmers' decision making processes and improving managerial assistance. Agric. Econ. 18, 273–290. doi:10.1016/S0169-5150(97)00052-2

Oltersdorf, U., Ecke, J., 2003. Entwicklungstendenzen bei Nahrungsmittelnachfrage und ihre Folgen.

Otsuki, T., Wilson, J.S., Sewadeh, M., 2001. Saving two in a billion: quantifying the trade effect of European food safety standards on African exports. Food Policy 26, 495–514. doi:10.1016/S0306-9192(01)00018-5

Parry, M.A.J., Madgwick, P.J., Carvalho, J.F.C., Andralojc, P.J., 2007. PAPER PRESENTED AT INTERNATIONAL WORKSHOP ON INCREASING WHEAT YIELD POTENTIAL, CIMMYT, OBREGON, MEXICO, 20–24 MARCH 2006 Prospects for increasing photosynthesis by overcoming the limitations of Rubisco. J. Agric. Sci. 145, 31. doi:10.1017/S0021859606006666

Peel, J., 2006. A GMO by Any Other Name . . . Might Be an SPS Risk!: Implications of Expanding the Scope of the WTO Sanitary and Phytosanitary Measures Agreement. Eur. J. Int. Law 17, 1009–1031. doi:10.1093/ejil/chl033

Petriccione, G., dell'Aquila, C., Perito, M.A., Solazzo, R., Cioffi, A., Garcia-Alvarez-Coque, J.-M., 2011. THE EU FRUIT AND VEGETABLES SECTOR: OVERVIEW AND POST 2013 CAP PERSPECTIVE. Study of the European Parliament.

Ponti, L., Gutierrez, A.P., Ruti, P.M., Dell'Aquila, A., 2014. Fine-scale ecological and economic assessment of climate change on olive in the Mediterranean Basin reveals winners and losers. Proc. Natl. Acad. Sci. 111, 5598–5603. doi:10.1073/pnas.1314437111

Powell, J.P., Rutten, M., 2013. Convergence of European wheat yields. Renew. Sustain. Energy Rev. 28, 53–70. doi:10.1016/j.rser.2013.07.048

Presterl, T., Seitz, G., Landbeck, M., Thiemt, E.M., Schmidt, W., Geiger, H.H., 2003. Improving nitrogen-use efficiency in european maize. Crop Sci. 43, 1259–1265.
Quiroga, S., Iglesias, A., 2009. A comparison of the climate risks of cereal, citrus, grapevine and olive production in Spain. Agric. Syst. 101, 91–100. doi:10.1016/j.agsy.2009.03.006
Rabbinge, R., Linnemann, A., 2009. Forward Look on European Food Systems in a Changing World.
Ray, D.K., Mueller, N.D., West, P.C., Foley, J.A., 2013. Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS ONE 8, e66428. doi:10.1371/journal.pone.0066428
Reidsma, P., Ewert, F., Boogaard, H., Diepen, K. van, 2009a. Regional crop modelling in Europe: The impact of climatic conditions and farm characteristics on maize yields. Agric. Syst. 100, 51–60. doi:10.1016/j.agsy.2008.12.009
Reidsma, P., Ewert, F., Lansink, A.O., Leemans, R., 2009b. Vulnerability and adaptation of European farmers: a multi-level analysis of yield and income responses to climate variability. Reg. Environ. Change 9, 25–40. doi:10.1007/s10113-008-0059-3
Reidsma, P., Lansink, A.O., Ewert, F., 2009c. Economic impacts of climatic variability and subsidies on European agriculture and observed adaptation strategies. Mitig. Adapt. Strateg. Glob. Change 14, 35–59. doi:10.1007/s11027-008-9149-2
Reynolds, M., Foulkes, M.J., Slafer, G.A., Berry, P., Parry, M.A.J., Snape, J.W., Angus, W.J., 2009. Raising yield potential in wheat. J. Exp. Bot. 60, 1899–1918. doi:10.1093/jxb/erp016
Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., Garnett, T., 2016. Protein futures for Western Europe: potential land use and climate impacts in 2050. Reg. Environ. Change. doi:10.1007/s10113-016-1013-4
Sabaté, J., Soret, S., 2014. Sustainability of plant-based diets: back to the future. Am. J. Clin. Nutr. ajcn.071522. doi:10.3945/ajcn.113.071522
Schmidhuber, J., Tubiello, F.N., 2007. Global food security under climate change. Proc. Natl. Acad. Sci. 104, 19703–19708. doi:10.1073/pnas.0701976104
Schneeberger, W., Darnhofer, I., Eder, M., 2002. Barriers to the adoption of organic farming by cash-crop producers in Austria. Am. J. Altern. Agric. 17, 24–31.
Schneider, U.A., Havlík, P., Schmid, E., Valin, H., Mosnier, A., Obersteiner, M., Böttcher, H., Skalský, R., Balkovič, J., Sauer, T., Fritz, S., 2011. Impacts of population growth, economic development, and technical change on global food production and consumption. Agric. Syst. 104, 204–215. doi:10.1016/j.agsy.2010.11.003
Silva Dias, J., Ortiz, R., 2014. Advances in Transgenic Vegetable and Fruit Breeding. Agric. Sci. 5, 1448–1467. doi:10.4236/as.2014.514156
Slafer, G., Abeledo, L., Miralles, D., Gonzalez, F., 2013. Dept. Produccion Vegetal, Fac. Agronomia, Univ. de Buenos Aires, 1417 Buenos Aires, Argentina, in: Wheat in a Global Environment: Proceedings of the 6th

International Wheat Conference, 5–9 June 2000, Budapest, Hungary. Springer Science & Business Media, p. 487.
Springmann, M., Godfray, H.C.J., Rayner, M., Scarborough, P., 2016. Analysis and valuation of the health and climate change cobenefits of dietary change. Proc. Natl. Acad. Sci. 113, 4146–4151. doi:10.1073/pnas.1523119113
Tester, M., Langridge, P., 2010. Breeding Technologies to Increase Crop Production in a Changing World. Science 327, 818–822. doi:10.1126/science.1183700
Thøgersen, J., 2017. Sustainable food consumption in the nexus between national context and private lifestyle: A multi-level study. Food Qual. Prefer. 55, 16–25. doi:10.1016/j.foodqual.2016.08.006
Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. 108, 20260–20264. doi:10.1073/pnas.1116437108
Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677. doi:10.1038/nature01014
Tonitto, C., David, M.B., Drinkwater, L.E., 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agric. Ecosyst. Environ. 112, 58–72. doi:10.1016/j.agee.2005.07.003
van Ittersum, M.K., Cassman, K.G., Grassini, P., Wolf, J., Tittonell, P., Hochman, Z., 2013. Yield gap analysis with local to global relevance—A review. Field Crops Res., Crop Yield Gap Analysis – Rationale, Methods and Applications 143, 4–17. doi:10.1016/j.fcr.2012.09.009
van Ittersum, M.K., Rabbinge, R., 1997. Concepts in production ecology for analysis and quantification of agricultural input-output combinations. Field Crops Res. 52, 197–208. doi:10.1016/S0378-4290(97)00037-3
Van Tran, D., Duffy, R., 2003. Proceedings of the 20th Session of the International Rice Commission (Bangkok, Thailand, 23–26 July 2002).
Viscecchia, R., De Devitiis, B., Baselice, A., Stasi, A., Nardone, G., 2016. Supplements consumption, health oriented behaviour and beyond. doi:10.13128/REA-18645
von Lampe, M., Willenbockel, D., Ahammad, H., Blanc, E., Cai, Y., Calvin, K., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., Mason d'Croz, D., Nelson, G.C., Sands, R.D., Schmitz, C., Tabeau, A., Valin, H., van der Mensbrugghe, D., van Meijl, H., 2014. Why do global long-term scenarios for agriculture differ? An overview of the AgMIP Global Economic Model Intercomparison. Agric. Econ. 45, 3–20. doi:10.1111/agec.12086
Westhoek, H., Lesschen, J.P., Rood, T., Wagner, S., De Marco, A., Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M.A., Oenema, O., 2014. Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Glob. Environ. Change 26, 196–205. doi:10.1016/j.gloenvcha.2014.02.004
Wheeler, T., Braun, J. von, 2013. Climate Change Impacts on Global Food Security. Science 341, 508–513. doi:10.1126/science.1239402

Wolf, J., Kanellopoulos, A., Kros, J., Webber, H., Zhao, G., Britz, W., Reinds, G.J., Ewert, F., de Vries, W., 2015. Combined analysis of climate, technological and price changes on future arable farming systems in Europe. Agric. Syst. 140, 56–73. doi:10.1016/j.agsy.2015.08.010

WTO, 2010a. The WTO Agreements Series Sanitary and Phytosanitary Measures.

WTO, 2010b. European Communities — Measures Affecting the Approval and Marketing of Biotech Products [WWW Document]. URL https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds291_e.htm (accessed 9.12.16).

WTO, 1998. Understanding the WTO Agreement on Sanitary and Phytosanitary Measures [WWW Document]. URL https://www.wto.org/english/tratop_e/sps_e/spsund_e.htm (accessed 9.7.16).

Xiong, B., Beghin, J., 2016. TTIP and agricultural trade: The case of tariff elimination and pesticide policy cooperation. Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University.

Zanias, G.P., 1999. Seasonality and spatial integration in agricultural (product) markets. Agric. Econ. 20, 253–262. doi:10.1016/S0169-5150(99)00006-7

Zimmermann, A., Britz, W., 2013. European farms' participation in agri-environmental measures.

Zimmermann, A., Heckelei, T., 2012. Structural Change of European Dairy Farms – A Cross-Regional Analysis. J. Agric. Econ. 63, 576–603. doi:10.1111/j.1477-9552.2012.00355.x

Zurek, M., Ingram, J., Zimmermann, A., Garrone, M., Rutten, M., Inge Tetens, Adrian Leip, Veer, P. van't, Muriel Verain, Emily Bouwman, Stephan Marette, Chiaoya Chang, Catharina Latka, Sara Hornborg, Friederike Ziegler, Joost Vervoort, Thom Achterbosch, Ida Terluin, Petr Havlik, Andre Deppermann, 2016. A Framework for Assessing and Devising Policy for Sustainable Food and Nutrition Security in EU: The SUSFANS conceptual framework. SUSFANS deliverable D1.1, H2020 / SFS-19-2014: Sustainable food and nutrition security through evidence based EU agro-food policy, GA no. 633692.