The drivers of crop production at regional level in the EU: an econometric analysis

Deliverable No. D4.5

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SUSFANS DELIVERABLES

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. The report provides a qualitative assessment of drivers of crop production and a quantitative analysis of crop yields in the EU. Crop yield trends are largely positive throughout the EU. Average efficiencies in yield exploitation are between 70 and 80% depending on the crop. Climate has mixed effects on crop yields and farm size, fertilizer and plant protection all clearly positively affect crop yields.

Version	Release date	Changed	Status	Distribution
V1	30/03/2017	--	Final	--

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633692

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:	D4.5 The drivers of crop production at regional level in the EU: an econometric analysis
Work package	WP4
WP title (acronym):	Drivers and data: primary agricultural and fisheries production
WP leader:	UBO, Andrea Zimmermann; JRC, Adrian Leip
Period, year:	2, 2017
Responsible Authors:	Andrea Zimmermann, Catharina Latka
Participant acronyms:	UBO
Dissemination level:	Public
Version	V1
Release Date	30/03/2017
Planned delivery date:	30/03/2017
Status	Final
Distribution	Public

Dissemination level of this report

Public

ACKNOWLEDGMENT & DISCLAIMER

This project has received funding from the European Union's Horizon 2020 research and innovation program 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.

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DELIVERABLE SHORT SUMMARY FOR USE IN MEDIA

The report describes and analyses crop production in the EU. It focuses on cereal production with case studies for soybean production in South Europe and fruits and vegetables production in the SUSFANS case study region Italy. The report identifies main drivers of crop production and analyses the development of crop yield growth and the impacts of climate and management on crop yields at regional level in the EU.

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 also for aquaculture. Understanding what drives crop production and the development of crop yields helps projecting future developments that are crucial for food and nutrition security and allows identifying risks and (policy) measures for improvement. Through the regionally specific analysis, also regional hot spots and regions with potential for further intensification can be identified.

The indirect and direct drivers of crop production are identified based on a literature review. Yield trends and yield gaps, the gap between biologically attainable and actually achieved yields, are empirically analysed. Yield trend estimation is based on a statistical-econometric fixed-effects model. The determinants of frontier yields and the yield gap are estimated using a Stochastic Frontier Analysis (a simplified illustration of the concept is provided in Figure 1). Both empirical analyses are applied to single farm data from the European Farm Accountancy Data Network (FADN).

Crop yield trends are positive throughout the EU. Assuming linear trends for all crops and regions, annual soft wheat yield growth was 41 kg/ha. For barley yield growth was 26 kg/ha and for maize 184 kg/ha.

However, depending on the time horizon considered, cereal yield growth tends to decelerate in the Western Member States (EU15), whereas they appear to accelerate in the Eastern Member States (EU10) perhaps reflecting a catching-up from generally lower yield levels in the East. A simplified illustration of the development of cereal yield growth is given in Table 1.

These findings should be treated with caution as the analysis also very clearly shows the sensitivity of the results depending on the time period considered. Trends in potato, sugar beet and soybean production are positive in the EU. With increasing yields, the variability of yields tends to increase as well.

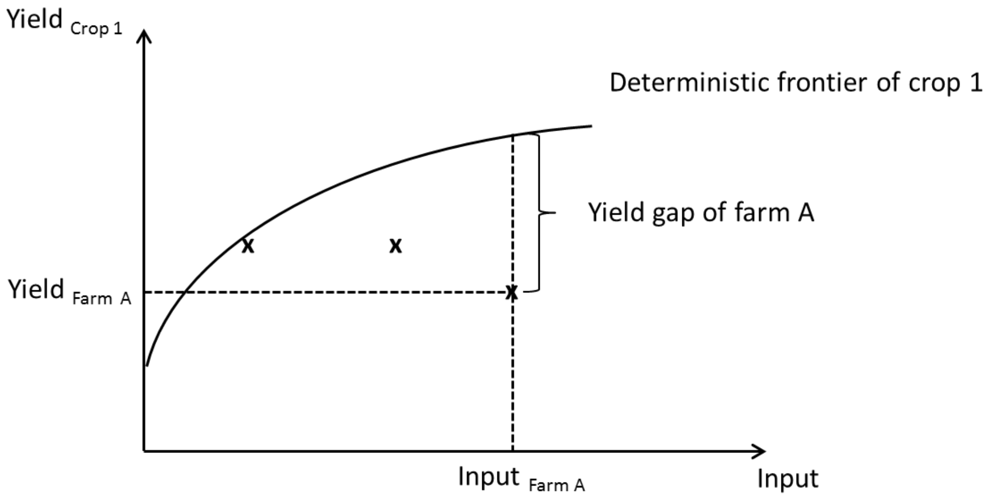
Table 1. Simplified illustration of cereal yield trend developments in the EU, 1989-2011

Crop	EU15	EU10	Romania/Bulgaria
Soft wheat			
Barley			
Maize			

Source: Own illustration.

The EU average yield exploitation is around 70% for potatoes and up to 80% for soft wheat with yield gaps often being higher in southern parts of the EU and lower in the central and north. Regional frontier yields are driven by breeding (represented by a trend variable) and local climate. The technology trend is clearly positive in the EU average, whereas climate can have different effects depending on the crop and region considered. All considered management variables (economic farm size, fertilizer and plant protection expenditure) clearly positively affect yield gap exploitation. A fruits and vegetables case study for Italy generally confirms the EU-wide results for the other crops in terms of yield determinants. On average achieved yields are 61% for orange, 65% for lemon and 69% for tomato from the frontier yields in Italy.

Figure 1. Simplified yield gap illustration



Source: Based on Coelli et al. (2005) and Neumann et al. (2010)

The commonly shared hypothesis is that intensification is the preferred option over expansion of area under crops. Though intensification is land-sparing, it could lead to other environmental (or even health) risks through overfertilization and adverse effects of plant protection such that crop land use can also be too intense. In some areas even an extensification could be the most logical path towards sustainable resource use. As environmental and other externalities cannot be shown with our approach alone, the results of this study will be further used to improve the spatial analysis of environmental indicators in D4.6 and to improve supply side reactions in the agricultural sector model CAPRI in WP9. The improved input-output coefficients in CAPRI will help in identifying risks and trade-offs between ex- and intensification for food production and environment.

TEASER FOR SOCIAL MEDIA

In 50 words, why should it be read:
Crop production is the most crucial agricultural production activity for food and nutrition security. Around 70% of calories come from plant-based products. Yield growth is largely positive in the EU with signs for deceleration in the West. Around 75% of the attainable crop yield is achieved by an average farm.

In 140 letters, why I should be interested:
#Cropproduction crucial for food and nutrition. Signs for decelerating #cropyield growth in EU. 75% of possible yield achieved by EU farms.

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. The report provides a qualitative assessment of drivers of crop production and a quantitative analysis of crop yields in the EU. Crop yield trends are largely positive throughout the EU. Average efficiencies in yield exploitation are between 70 and 80% depending on the crop. Climate has mixed effects on crop yields and farm size, fertilizer and plant protection all clearly positively affect crop yields.

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 2 gives an overview of the WP4 driver reports (D4.1, D4.2 and D4.4/D4.5). Deliverable D4.5 is a follow-up on D4.4 that adds on the quantitative part. The first part on the qualitative analysis remained unchanged. Therefore D4.4 and D4.5 are treated as the same in Table 2.

Table 2. Overview of WP4 driver deliverables

Production system	Methodology	Deliverable
Livestock	Qualitative analysis	D4.1
Seafood	Qualitative analysis	D4.2
Crops	Qualitative/quantitative analysis	D4.4 (preliminary deliverable)
Crops	Quantitative analysis	D4.5 (final deliverable)

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 3 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 3. Different foci between WP4 driver deliverables and the CF

Driver	**CF (D1.1)**	**Livestock (D4.1)**	**Seafood (D4.2)**	**Crop (D4.4/D4.5)**
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	-Progress in feeding	-Historical developme	-Public and private

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4/D4.5)
	development -Competition for land from emerging biotechnology	technology -Progress in breeding	nt and the interplay between farmed and fished seafood -Technical innovations in society enabling growth	research (breeding, fertilizer and plant protection, machinery)
Agriculture and trade policies	-Impacts on prices and diets -Price 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	-Specific crop policies between EU and other countries -Food policies -Trade policies	-Fishing policies between EU and other countries -Food policies, trade barriers and regulations related to seafood -Beyond-EU regulatory environment of relevance to seafood production	-Specific crop policies between EU and other countries -Food policies -Trade policies -Relevant sanitary and phytosanitary regulations

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4/D4.5)
	-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 behaviours -Undernourishment, malnourishment and human health	-demand for livestock products over the years	-Consumer preferences related to seafood consumption	-Specific trends in crop consumption
Direct drivers				
Regulatory environment	-Common Agricultural Policy (CAP) of the EU -Common	-EU legislations and policies affecting livestock production	-EU legislations and policies affecting	-EU cereals regime -EU oilseeds regime -Fruits and

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4/D4.5)
	Fisheries Policy (CFP) of the EU -Different directives (e.g. water framework directive, Marine Strategy Framework Directive) -Food safety and related standards		seafood production	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 aquacultur e growth -Outsourcin g of activities	-Refers to CF (D1.1)
Natural resource availability	-Determines feasibility of primary production -Includes land, climate, soils,	-impact of current production levels on scare resources e.g. land use and	-Production capacity and current status of	-Environment al setting on farm, refers to CF (D1.1)

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4/D4.5)
	water, fish stocks	future availability.	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	- Management

Driver	CF (D1.1)	Livestock (D4.1)	Seafood (D4.2)	Crop (D4.4/D4.5)
			needed - Production efficiency incl. by-product utilization	
Producer and farm characteristics	-Personal 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	- type of farms - number of farms - animal numbers per farm	-Seafood production characteristics in the EU (technology, knowledge, prices and costs)	-Refers to CF (D1.1)

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 provides empirical analyses 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 and the empirical analysis 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 consists of two main parts. The first part of the paper is strongly aligned with the SUSFANS CF. Whereas the WP4 contribution to the CF comprises agricultural and fish production as a whole, the paper at hand deepens the driver section in the CF for crop production. The alignment with the CF 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). In this first part, first the structure of crop production and crop farms in the EU are described, followed by a brief introduction to the SUSFANS CF and the description of indirect and direct drivers following the conceptual framework.

The second part of the paper is based on empirical work. Since land use as driver of crop production is extensively addressed in the agricultural sector models of WP9, but less research has been done on improving yield responses in the models (e.g. Adenäuer et al., 2016), the empirical analyses focus on crop yields. Yield growth can be decomposed into productivity growth due to technical progress (e.g. breeding, machinery) and to decreasing the yield gap, i.e. the gap between biological potential and actually realised yields, by management. The deliverable first refers to a yield trend analysis in section 7 and a yield gap analysis particularly addressing biophysical factors driving potential yields and management variables driving yield gap exploitation in section 8. The final section 9 concludes.

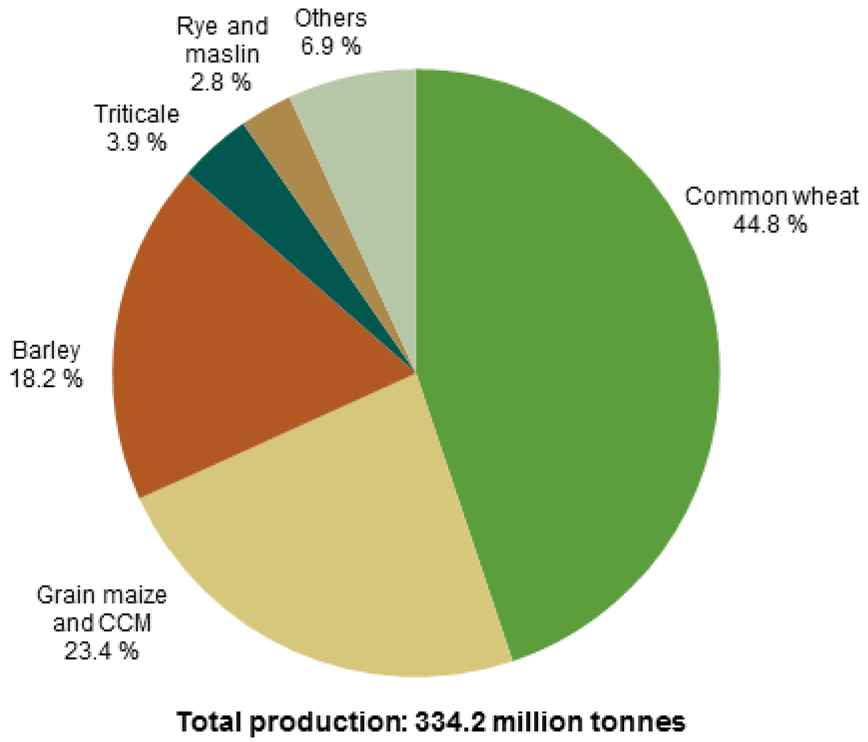
The research in this deliverable is unique in terms of providing a comprehensive overview of crop production and its drivers in the first part and in using EU-wide farm-level panel data for analysing yield trends and gaps for a wide range of crops in the empirical part.

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).

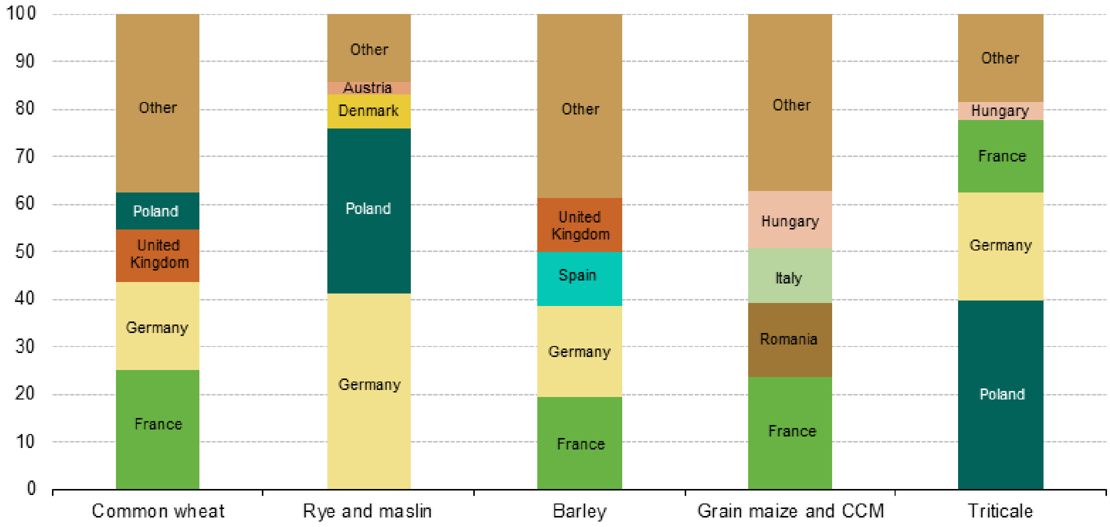
Figure 2. Production of cereals, EU-28, 2014 (% of total production of cereals)



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 3. 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)

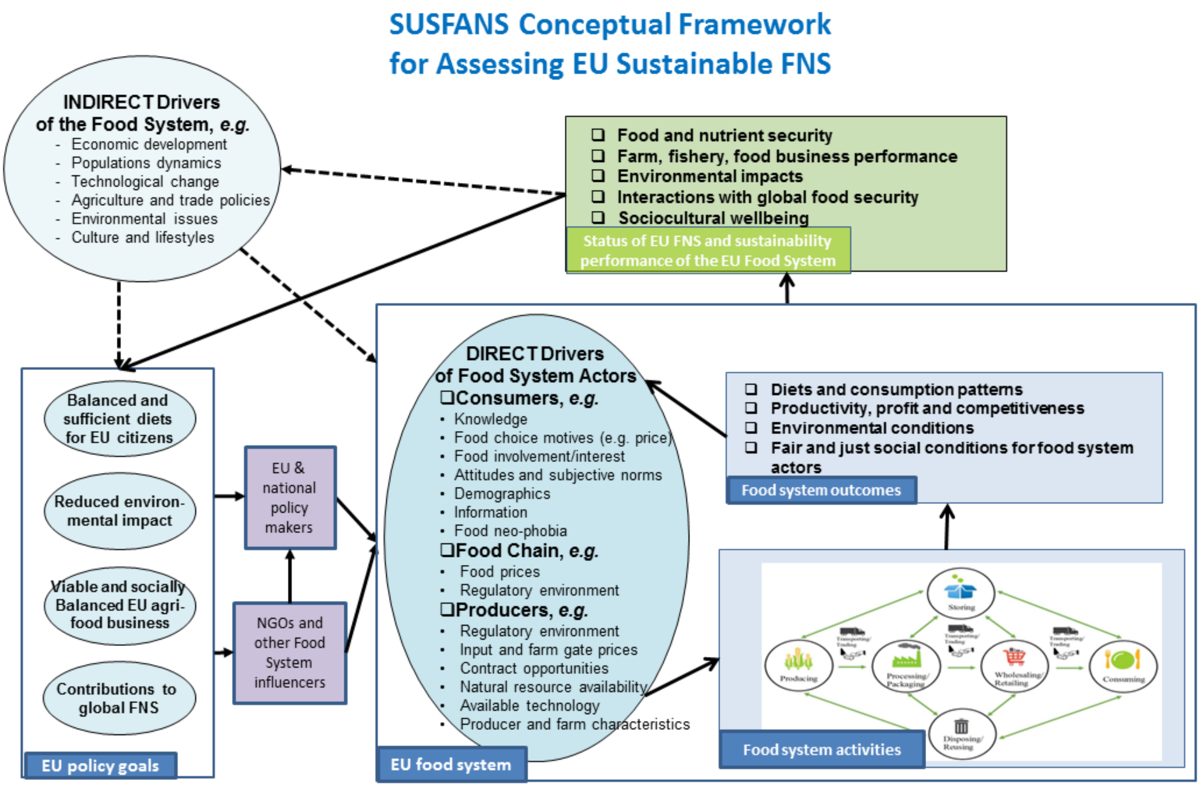
	Tomatoes	Carrots	Onions	Apples	Peaches	Citrus fruits
EU-28	16 837	5 537	6 356	14 304	2 894	11 773
Belgium	249	328	102	318	0	0
Bulgaria	120	10	13	55	28	0
Czech Republic	9	26	38	128	1	0
Denmark	13	107	52	35	0	0
Germany	85	609	590	1 116	0	0
Estonia	1	13	0	1	0	0
Ireland	5	37	4	14	0	0
Greece	1 054	44	238	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 4. 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 19th and 20th 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 is considered in the quantitative analysis of yield gaps below 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).

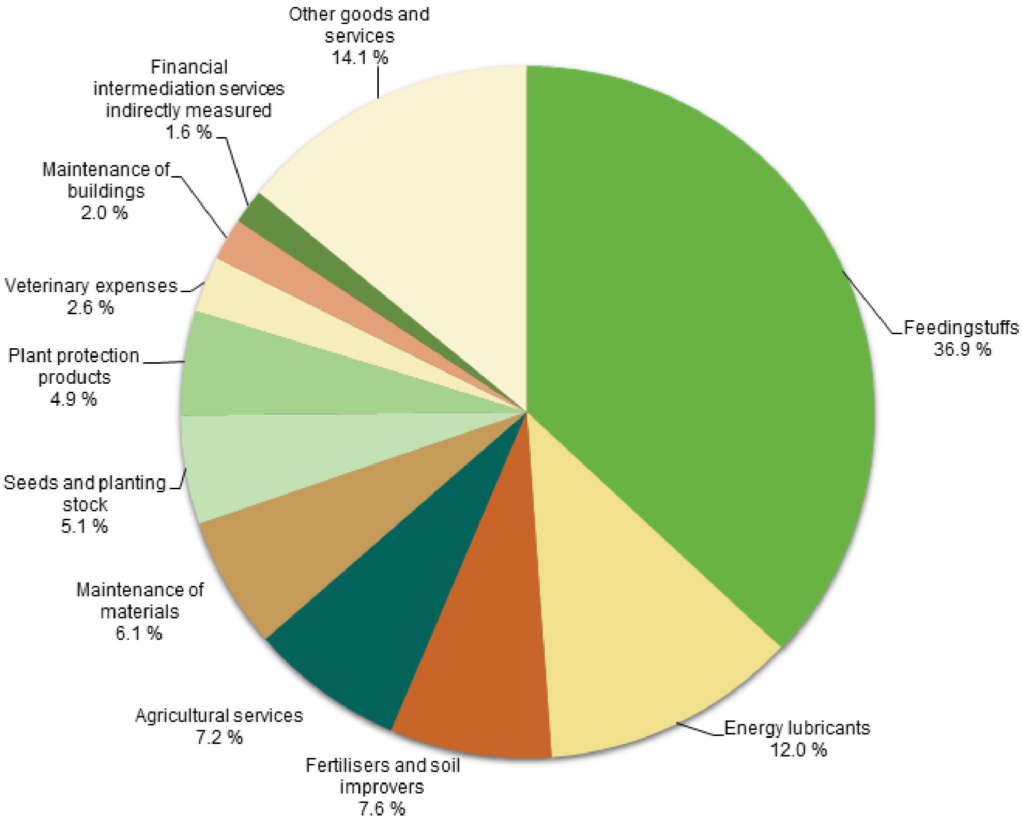
5.2 Input and farm gate prices

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

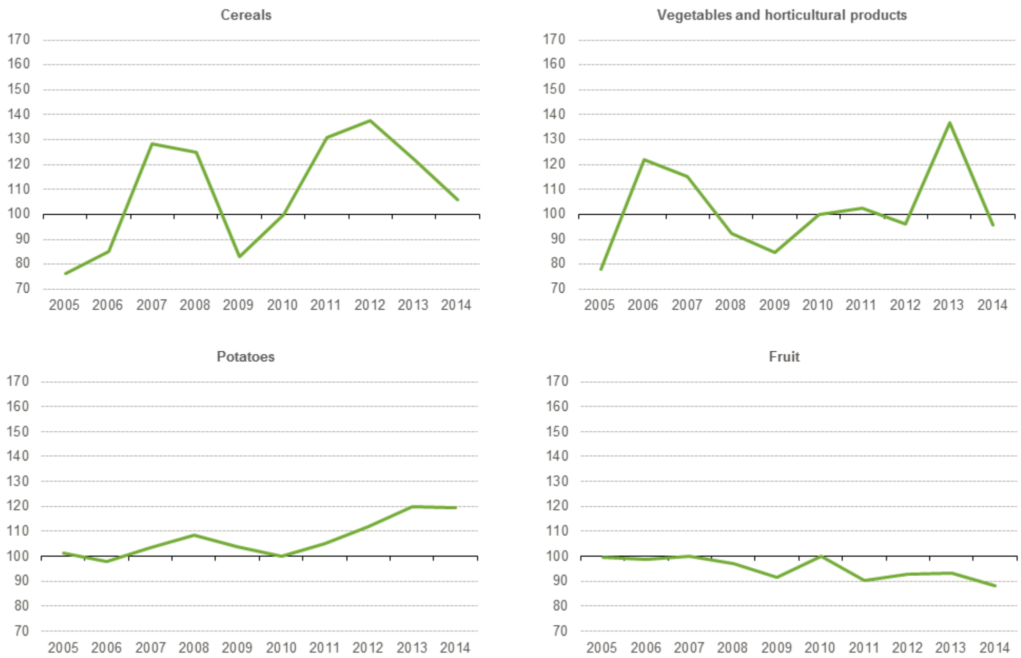


Source: European Commission (2015b).

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, 2015a).

Figure 6. Deflated price indices for selected crop outputs, EU-28, 2005–14 (2010=100)



Source: (European Commission, 2015a).

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).

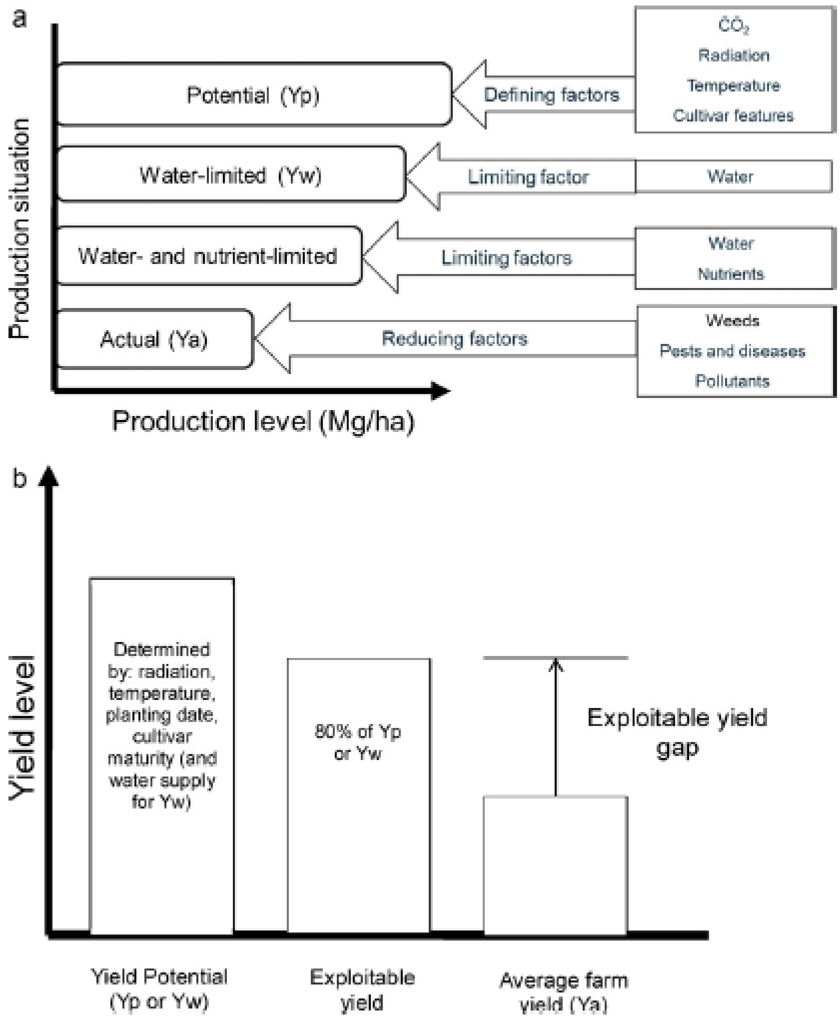
Natural resource availability includes mainly land, climate, soils and water (van Ittersum and Rabbinge, 1997). Since most of the respective text in D1.1 refers to the environmental conditions and their effect on crop production in the EU, they are not further described here (Zurek et al., 2016).

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 7. 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 are presented in the empirical part on yield gaps in this deliverable.

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.

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.

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

[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.

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 EMPIRICAL ANALYSIS OF CROP YIELD TRENDS IN THE EU

Europe is a significant contributor to global food production. It is the largest producer of wheat in the world (contribution to global wheat production around 20%), the largest producer of barley (around 40% contribution to global production) and the fourth largest producer of maize (around 7% contribution to global production). For future global food security, crop production is supposed to need to double until 2050. Since land expansion is not an option due to various environmental concerns, it is often called for a "sustainable intensification" of crop production (Godfray and Garnett, 2014). First questions for an understanding and assessment of EU's future crop production potential are: (1) how crop yields have developed so far and (2) where production could still be intensified in the EU. These questions will be addressed by yield trend analyses of a number of crops at regional level in the EU. Besides these basic questions, crop yield trend estimates are an important driver of economic agricultural sector models.

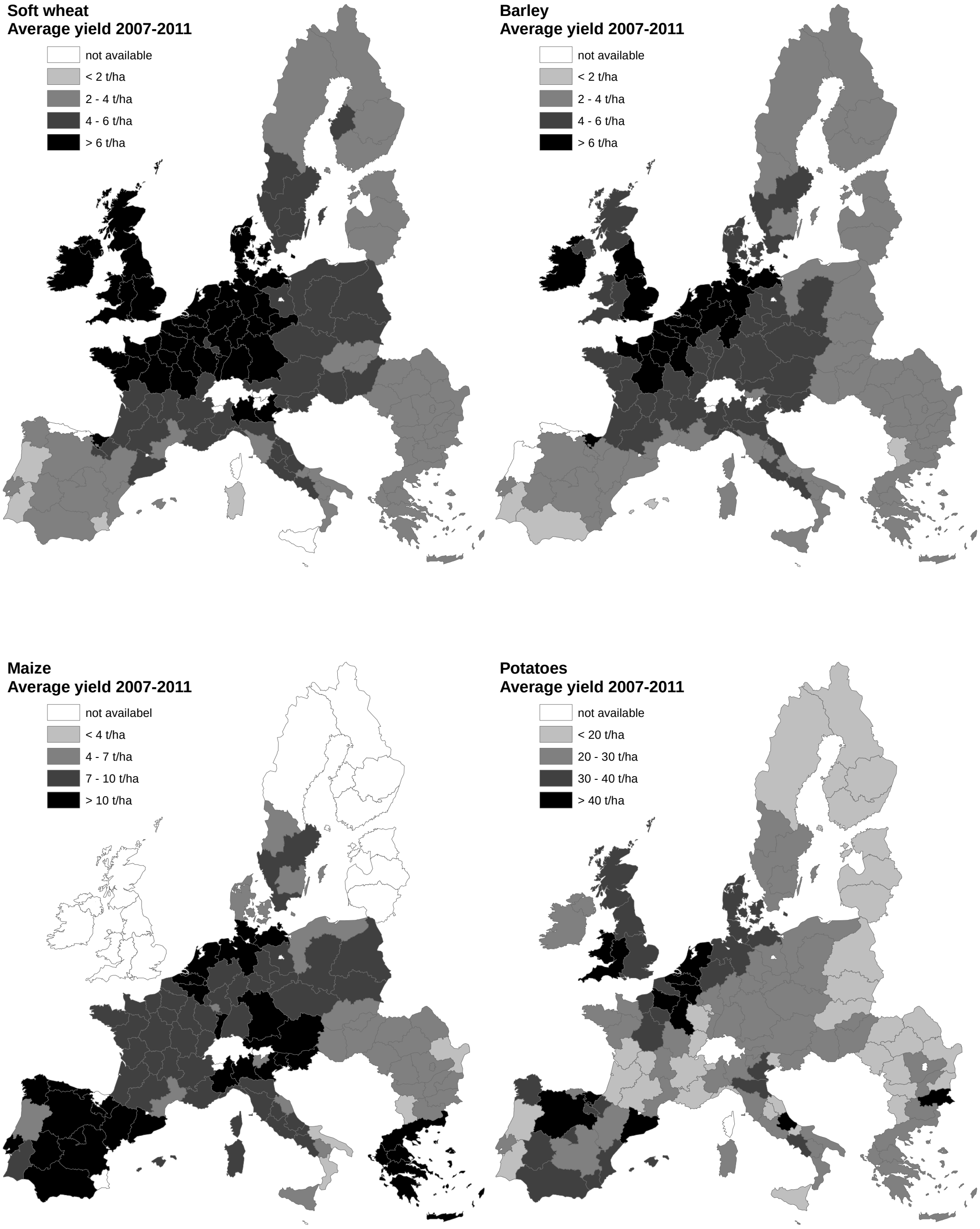
7.1 Data

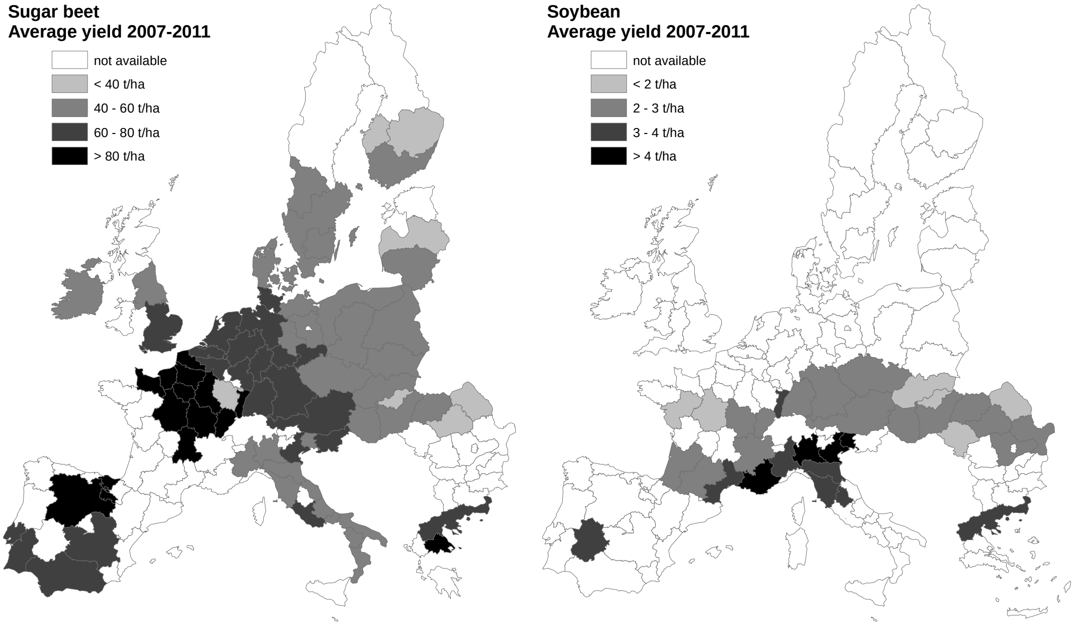
The empirical analysis uses farm data from the Farm Accountancy Data Network (FADN) (European Commission, 2015b). FADN provides European-wide data of about 80,000 sample farms. The sample farms are selected in order to best represent the total population of about 5,000,000 farms in the EU (please refer to the official FADN webpage for further information on the sampling criteria, (European Commission, 2015b). Data are collected annually based on a rotating panel, i.e. farms enter and exit the sample arbitrarily. They are allowed to stay in the sample for up to seven years. FADN is the only source of harmonized microeconomic data of agricultural holdings in the EU (European Commission, 2015c). Though single farm data are available, for data protections reasons, the exact location of the farms is not given. Instead farms are allocated to so-called FADN regions, which are similar to, but not in all cases identical with NUTS1 and/or NUTS2 administrative regions of the European Union's Nomenclature of Territorial Units for Statistics (NUTS, (European Commission, 2015d). We apply EU27 FADN data of the time period 1989-2011. For the analysis solely crop yields are used, which are calculated by dividing each farm's production quantity of a specific crop by the area planted of this crop. The analysis comprises six crops: soft wheat, barley, maize, potatoes, sugar beet, and soybeans. The crops are selected based on their importance for the global (soft wheat, barley, maize), European (sugar beet), and local market (potatoes). Soybean production is considered for its increasing importance for the European market and local production areas.

7.2 Regional distribution of crop yields in the EU

Crop yield levels differ between different regions in the EU. To get a grasp of the regional differences in yield levels, Figure 8 shows the regional distribution of five-year yield averages for soft wheat, barley, maize, potatoes and soybeans from 2007 to 2011. The figure reveals high yield levels for soft wheat and barley in the North West of the EU (UK, France, Germany), whereas yield levels for these crops are lower in a half circle around these regions (North East, North of Italy, South France), and again lower in North Scandinavia, South East and South). For maize, very high yield levels are achieved in Spain, Greece and parts of the North West (Netherlands, Germany). Medium high maize yield levels dominate in France, Italy, and the East, whereas yield levels in Hungary, Bulgaria and Romania are relatively low. Potato yield levels are high in the North West and parts of Spain, medium high in Germany and Eastern European countries, they are relatively low in the very North (North of Sweden and Finland) and the very East (Baltic states, East Poland, Romania). Sugar beet yield levels are very high in North and Central France and part of Spain, high in Germany, Austria, Slovenia and South East England, and medium high in the South of Spain, parts of England and Ireland, South Scandinavia and Finland and Eastern European countries apart from the South where sugar beet is not grown. Soybean production in the EU is located in a stripe from Central and South France and North Italy over South Germany, Austria and Czech Republic to the South East of Europe, namely Slovakia, Hungary, Bulgaria and parts of Greece. High soybean yield levels are achieved in South France and North Italy, Greece and a region in Spain, whereas yield levels in the more Northern soybean growing parts are a bit lower.

Figure 8. Five-year averages of regional yields, 2007-2011



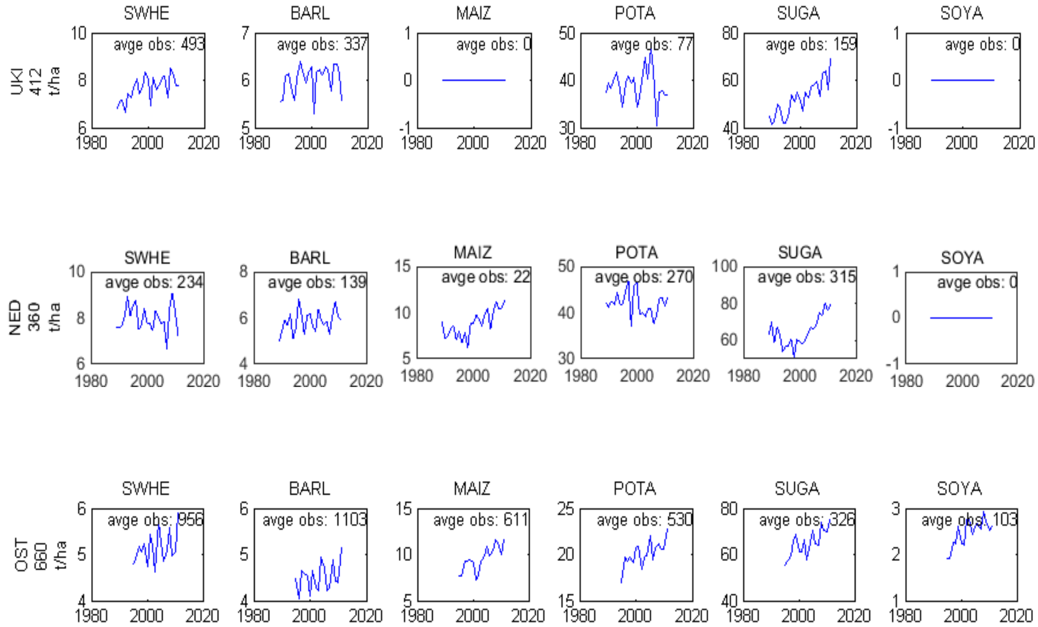


Data source: EU-FADN – DG AGRI.

7.3 Exemplary yield developments over time

Figure 9 shows the development of average crop yields over time exemplarily for a few regions. The figure shows that average yields can vary considerably over time even within the same region.

Figure 9. Exemplary yield developments for selected regions



Data source: EU-FADN – DG AGRI.

7.4 Methods

There exist plenty of yield trend analyses. Table 4 provides an overview of these. Methodologically, we follow Reidsma et al. (2009b) and Finger (2010) in analysing both yield trends and trends in yield variability. Following Hafner (2003) and Finger (2010), we estimate both linear and quadratic trend models. The variability analysis is again based on Reidsma et al. (2009b) and Finger (2010).

Table 4. Yield trend analyses literature

Study	Aim	Countries	Resolution	Data	Time series	Data source	Crops
Hafner (2003)	Trends	Global	Country	Time series	1961-2001	FAO	Wheat, maize, rice
Ewert et al. (2005)	Trends	EU15	Country	Time series	1961-2002	FAO	Wheat, potatoes, sugar beet, maize
Reidsma et al. (2009b)	Trends + variability	EU15	Region, farm type	Time series	1990-2003	FADN	Wheat, barley, maize, sugar beet, potato
Finger (2010)	Trends + variability	Switzerland	Country	Time series	1961-2006	FAO	Wheat, triticale, rye, oats, maize, barley
Brisson et al. (2010)	Trends	France	Geographical sectors (district)	Time series	1956-2009	FAO, field trials	Wheat
Lin and Huybers (2012)	Trends	Global	Country, partly region	Time series	1961-2010	FAO	Wheat

Study	Aim	Countries	Resolution	Data	Time series	Data source	Crops
Powell and Rutten (2013)	Trends	Europe	Country	Time series	1961-2010	FAO	Wheat
Ray et al. (2013)	Trends	Global	Political units (district)	Time series	1989-2008	Various	Wheat, maize, rice, soybean
Grassini et al. (2013)	Trends	Selected countries and regions	Selected countries and regions	Time series	1965-2010	FAO	Wheat, maize, rice

7.4.1 Yield trend estimation

Trends are calculated at regional level. For each region, a linear and a quadratic trend model including farm fixed effects is estimated. The linear trend model is estimated as:

$$y_{it} = \alpha_i + \beta \cdot t_{it} + u_{it} \tag{1}$$

where y_{it} is the yield of farm i at time t, α_i are the farm fixed effects, β is the annual yield change in a region and t_{it} is the trend variable with $t_{it} = 1$ in 1989. u_{it} are the error terms. The quadratic trend model is estimated as:

$$y_{it} = \alpha_i + \beta_1 \cdot t_{it} + \beta_2 \cdot t_{it}^2 + u_{it} \tag{2}$$

where t_{it}^2 is the squared time index and β_2 the respective coefficient. If β_2 is positive (negative) yield growth is accelerating (decelerating). For both models White's heteroskedasticity corrected standard errors are calculated. Following Hafner (2003) and Finger (2010) the quadratic model is selected if β_2 in equation (2) differs from zero at 5% significance level (please note that this automatically implies that the goodness of fit of the quadratic model is better than the one of the linear model). Both models are rejected if their coefficients are not significant at least at 10 percent level.

7.4.2 Yield variability estimation

Following Calderini and Slafer (1998), Reidsma et al. (2009b) and Finger (2010), we assess trends in absolute and relative yield variability based on the regression residuals. Yield variability is defined as the absolute residual ($|u_{it}|$) of the trend estimation (equation 1 or equation2 depending on the selected trend model). The residuals are regressed against a trend variable in order to determine their variability over time:

$$|u_{it}| = \delta_i + \gamma \cdot t_{it} \tag{3}$$

where δ_i are the farm fixed effects, t_{it} is the trend variable with $t_{it} = 1$ in 1989 and γ is the respective coefficient indicating an increasing absolute yield variability over time if positive and a decreasing one if negative.

In order to account for increasing/decreasing yield levels over time, trends in relative yield variability are analysed by defining relative yield variability as the quotient of the absolute residuals divided by the predicted yields:

$$|u_{it}| / \tilde{y}_{it} = \delta_i + \gamma \cdot t_{it} \tag{4}$$

where $|u_{it}|$, δ_i and t_{it} are as above, $\tilde{y}_{it}$ is the predicted yield from equation 1 or 2 depending on the selected trend model and γ is the coefficient indicating increasing relative yield variability if positive and vice versa.

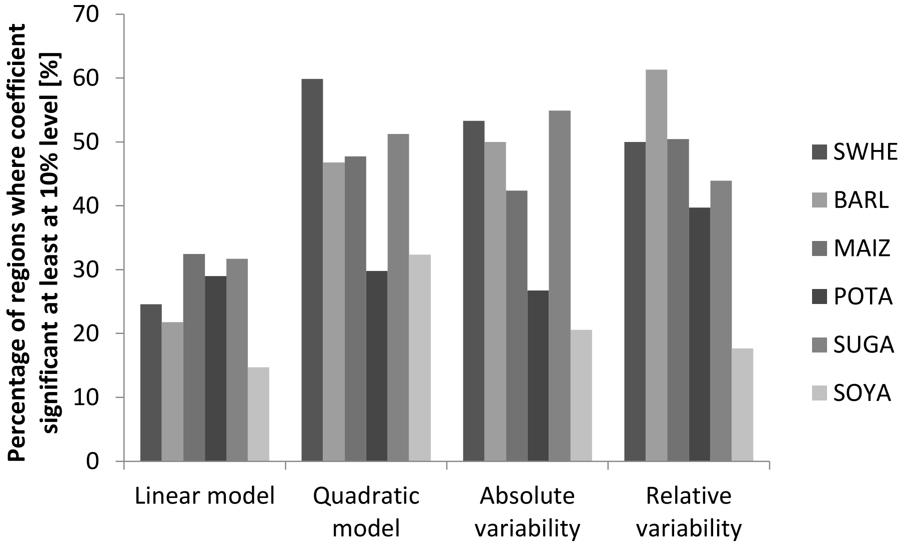
7.5 Results

The results section is split into two subsections. The first subsection (section 7.5.1) presents general results on model performance, model selection and significance levels, the second subsection (section 7.5.2) shows the crop specific results differentiated by region.

7.5.1 General results

The average R^2 of the linear models selected across regions and crops is 0.61, the one for the quadratic models is 0.60. 72.5 percent of the estimates are significant considering both linear and quadratic models together. Figure 10 shows the percentage of regions where the trend coefficient is significant at least at 10 percent level for the different models and divided by crops. The figure reveals that for all crops the quadratic model is more often chosen than the linear model. Only in the case of potato yields, the quadratic model is just slightly more often selected.

Figure 10. Percentage of regions where coefficient significant at least at 10% level



Data source: EU-FADN – DG AGRI.

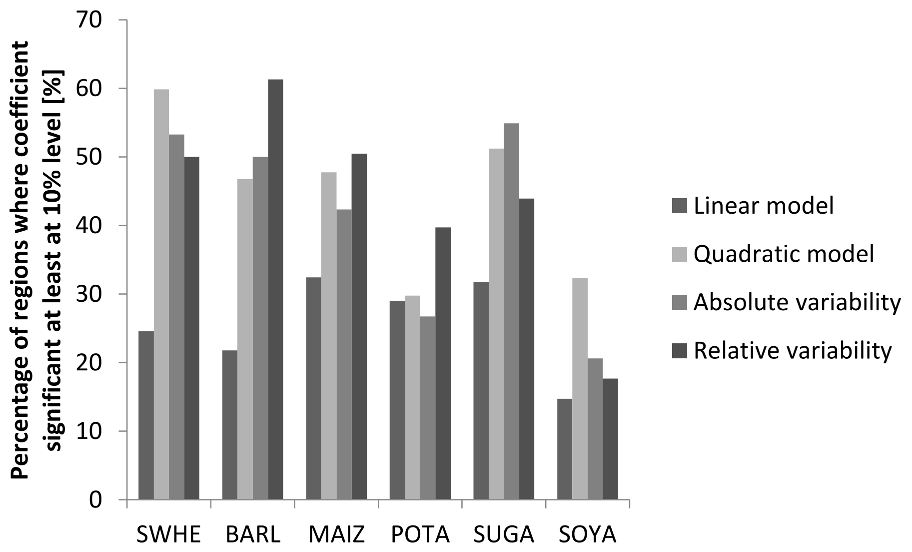
For better visibility, Figure 11 illustrates the same relationships, i.e. the percentage of regions where the trend coefficient is significant at least at 10% level from the perspective of the crops. Generally, most models are significant for the cereals and sugar beet, whereas they are less so for potatoes and soybeans. An overview of the number of regions for which one of the models is significant, the percentage of regions in which the linear and the quadratic model are significant, respectively, and the average R^2s per model type is also given in Table 5.

Table 5. Overview of significant model types and average R2s across regions per crop

Crop	# of significant regions	Linear model		Quadratic model	
		%age of regions whith linear trend	Average R^2	%age of regions with quadratic trend	Average R^2
			Cereals		
Soft wheat	103	32	0.62	68	0.62
Barley	85	32	0.60	68	0.57
Maize	89	40	0.60	60	0.61
			Root crops		
Potatoes	77	49	0.62	51	0.60
Sugar beet	68	38	0.52	62	0.56
			Oilseeds		
Soybean	16	31	0.72	69	0.63

Source: Own estimations based on FADN 1989-2011.

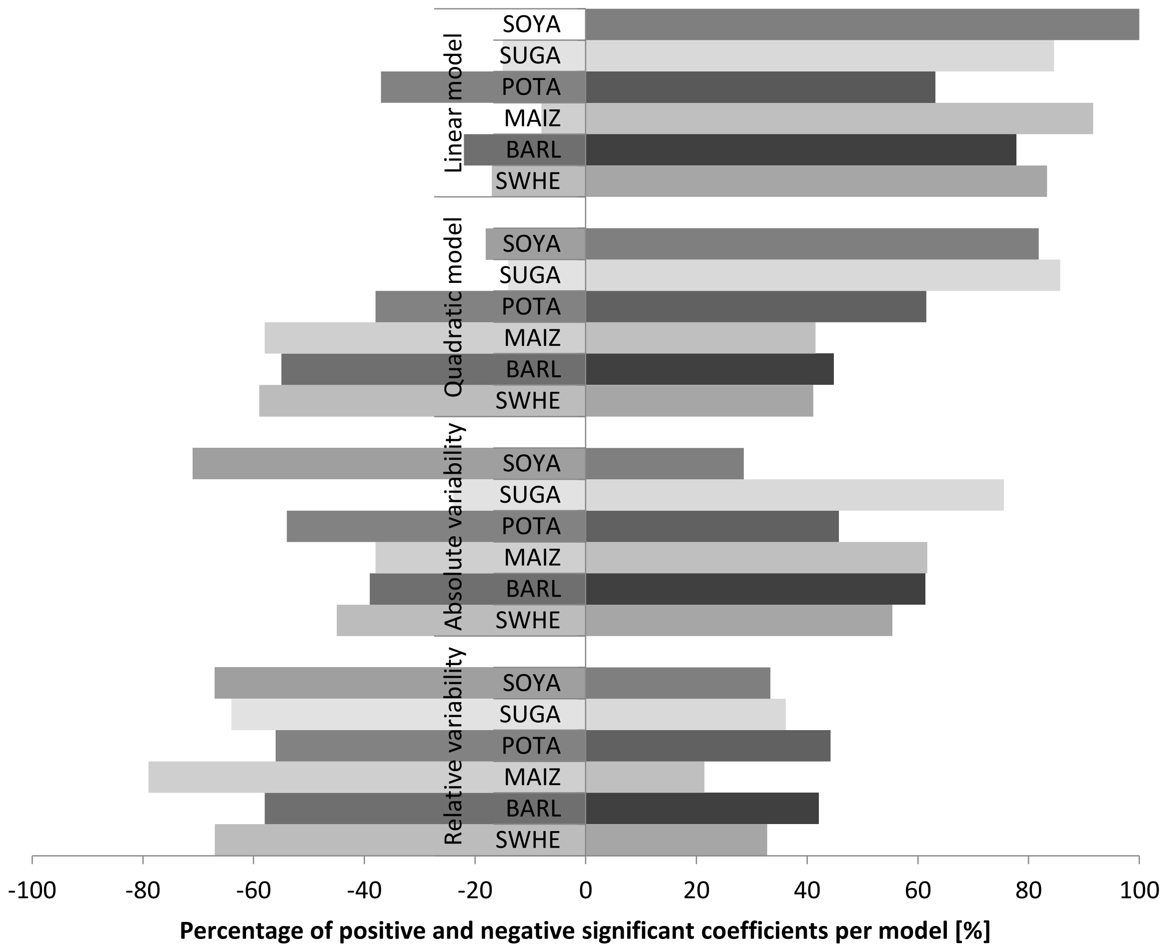
Figure 11. Percentage of regions where coefficient significant at least at 10% level



Data source: EU-FADN – DG AGRI.

Figure 12 displays the percentage of positive and negative significant coefficients per model. In case the linear model was selected, the majority of trend coefficients of all crops is positive, for soybean even all linear coefficients are positive. This indicates linearly increasing yields in those cases. The pattern is different in case where the quadratic model is superior. For soft wheat, barley and maize, the majority of the coefficients of the squared trend is negative indicating decreasing yield growth rates (please note that in all cases where the squared trend coefficient is negative, the coefficient for the simple trend is positive in the quadratic models estimated). For potatoes, sugar beet and soybeans it is the other way around, most coefficients referring to the squared trend are positive indicating accelerating yield growth towards the end of the time series. The absolute variability over time tends to increase for soft wheat, barley, maize and sugar beet and tends to decrease for potatoe and soybean yields. The relative variability, i.e. the variability normalized by the yield levels decreases in the majority of cases for all crops considered.

Figure 12. Effects across regions



Data source: EU-FADN – DG AGRI.

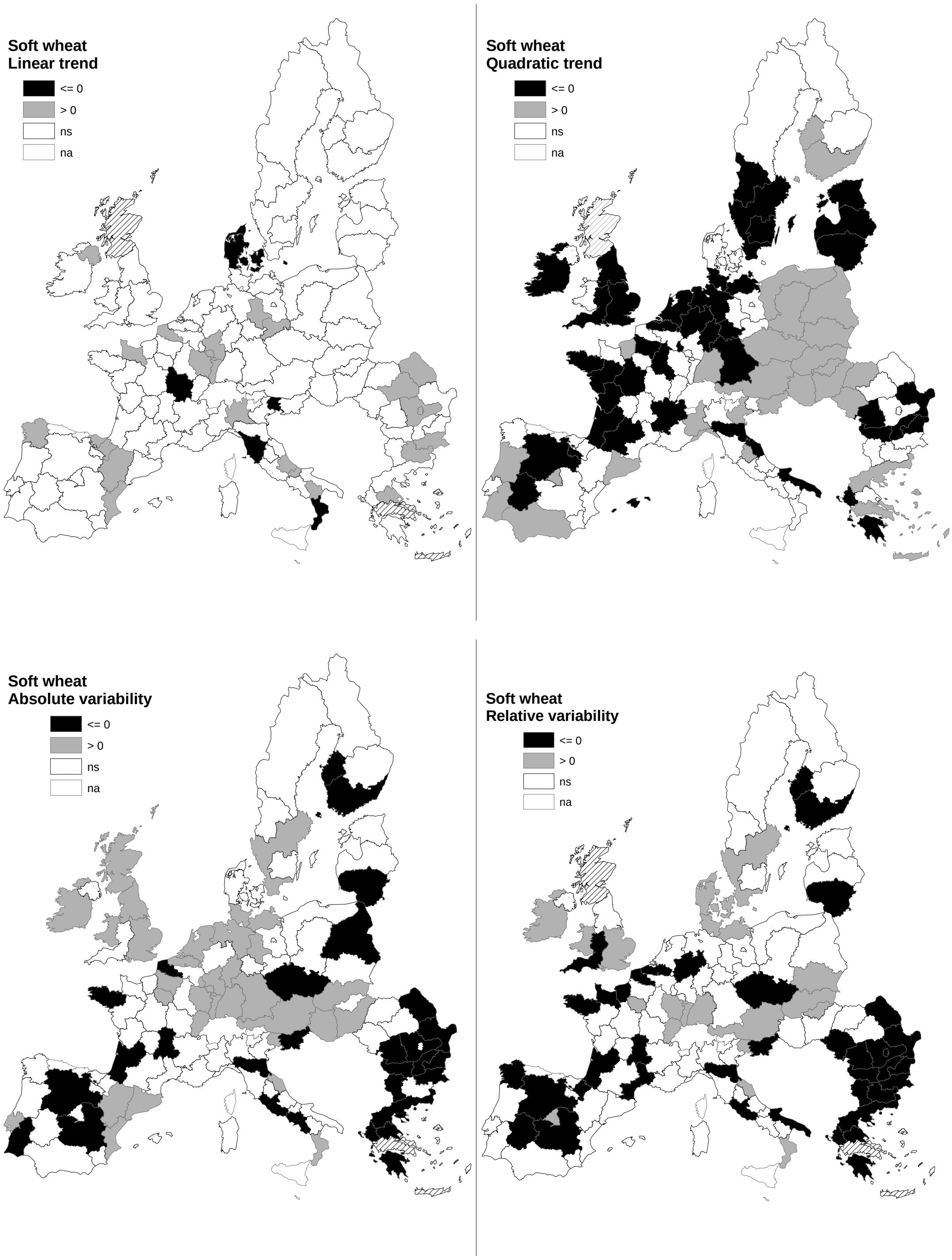
7.5.2 Regional patterns

Within this section, we show for each of the six crops the regional distribution of the direction of the trend and variability models (i.e. positive or negative trends). The maps are chosen to reveal geographical patterns of yield developments. We show only the general direction (positive or negative) in order to focus on main patterns. Please note that for the quadratic model only the direction of the coefficient of the squared trend is shown, which determines accelerating yield growth if positive and decelerating or even decreasing yield growth if negative. The maps are based on shape files of the FADN regions from the European Commission (2014).

7.5.2.1 Soft wheat

From 103 regions for which one of the models was significant, for 30 regions (32 percent) the linear and for 73 regions (68 percent) the quadratic model was chosen. For both linear and quadratic models the average R^2 is 0.62. In the large majority of regions the quadratic model is superior to the linear model in the case of soft wheat (Figure 13). The linear trend model was only selected in some scattered regions, where mostly a positive linear trend is observed. There is a clear pattern for the direction of yield trends in the quadratic models. In Western Europe yield growth is decelerating and in Eastern Europe it is accelerating. Exceptions from this rule are regions in South Spain where yield growth is accelerating and Baltic countries where yield growth is decelerating. Both absolute and relative variability in soft wheat yields tend to decrease in Spain and Southeast Europe, whereas there is a slight tendency for them to increase in the Western and Central parts of Europe.

Figure 13. Regional distribution of trend and variability directions of soft wheat yields

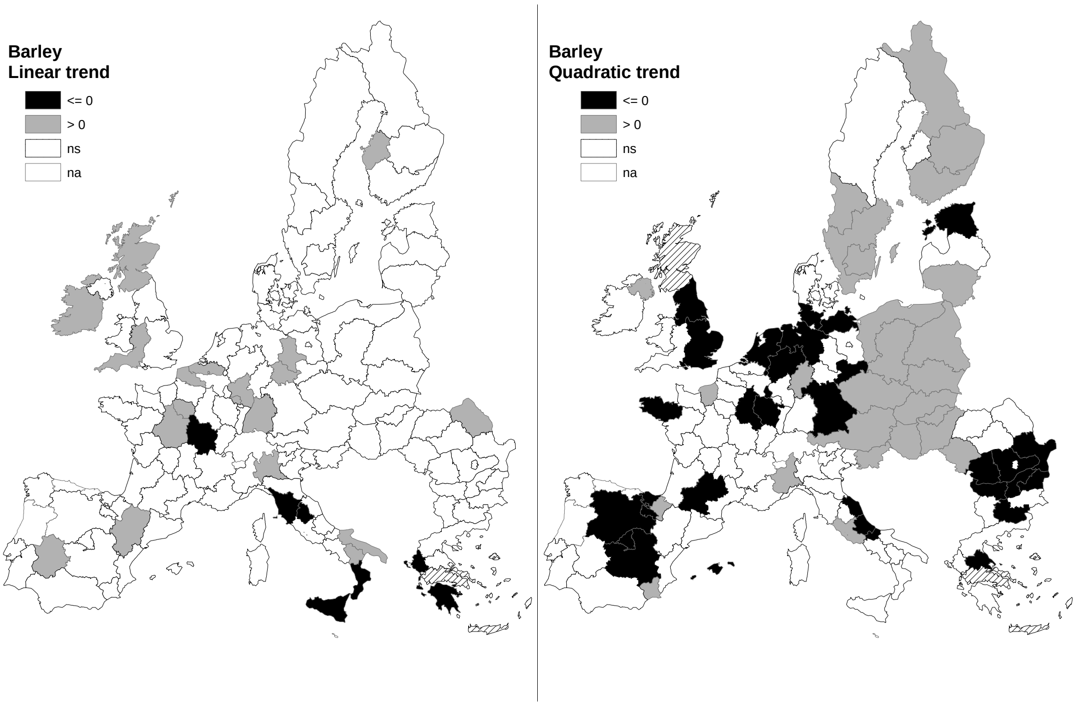


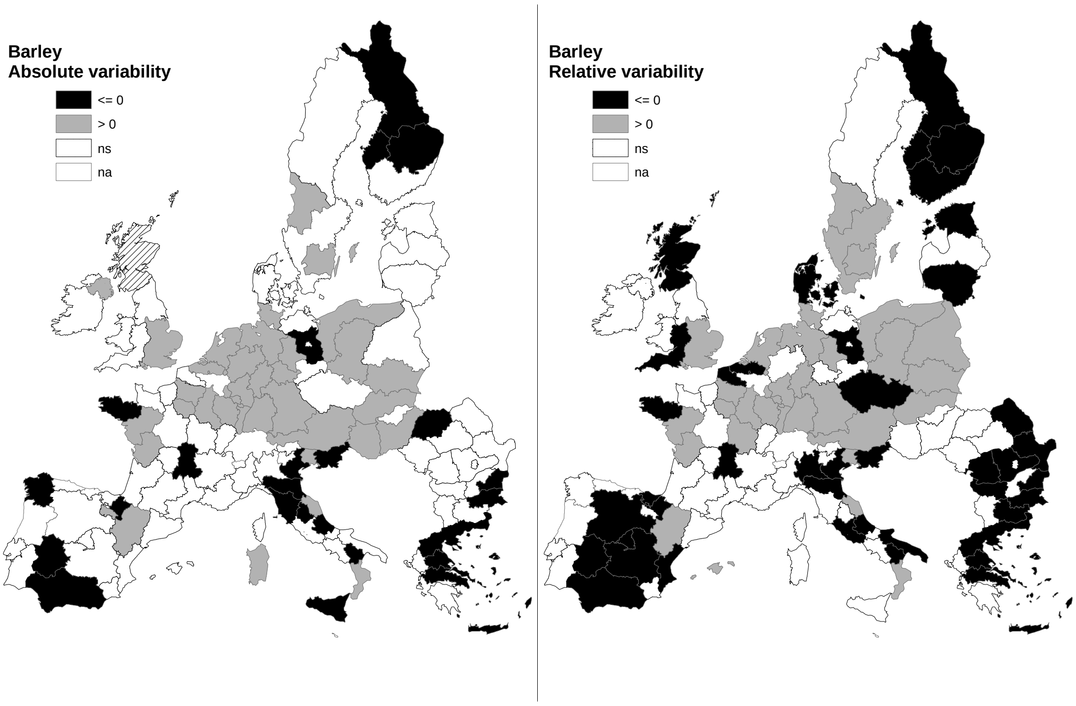
Data source: EU-FADN – DG AGRI.

7.5.2.2 Barley

In 26 percent of 85 regions the linear trend model was selected, for 68 percent the quadratic model proved superior. The average R^2's are 0.60 and 0.57, respectively. For barley yield trends, a similar pattern as for soft wheat yields can be observed (Figure 14). Again, the quadratic model is superior in the majority of regions and where the linear model is selected, barley yield trends tend to be positive. In the quadratic model decelerating yield growth is prevalent in Western Europe where significant and accelerating yield growth patterns dominate East Europe apart from the South. For absolute and relative yield variability the patterns are even clearer than for soft wheat. Both increase over time in central parts of Europe and decrease in a circle of marginal areas around these central parts (Finland, Southeast, South, very West of the EU).

Figure 14. Regional distribution of trend and variability directions of barley yields



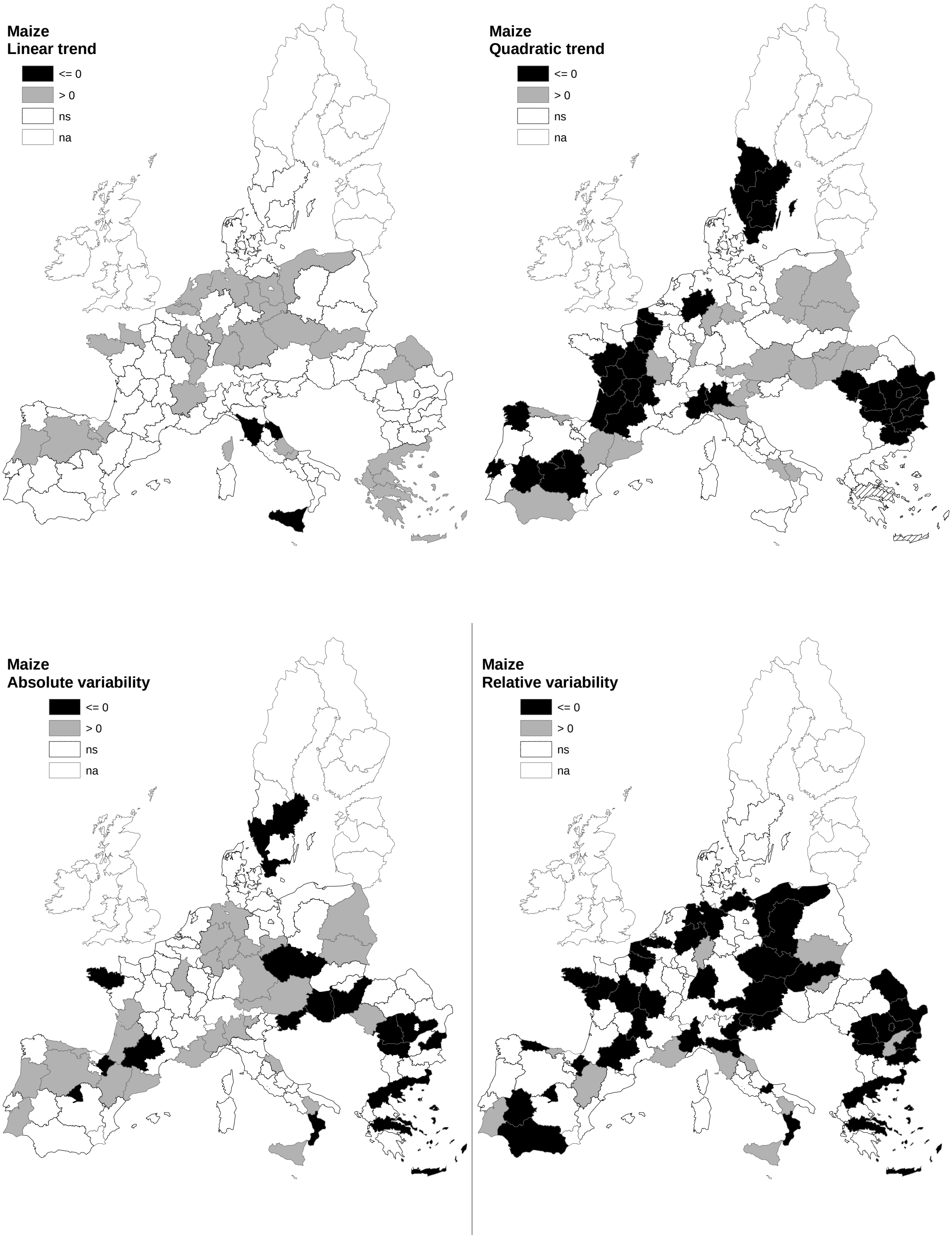


Data source: EU-FADN – DG AGRI.

7.5.2.3 Maize

For maize, one of the two trend models is significant in 89 regions. Of those, in 40 percent the linear, in 60 percent the quadratic model is selected. The average R^2 is 0.60 for the linear models and 0.61 for the quadratic models. The large majority of linear trends is positive throughout the EU (Figure 15). Only in Italy three regions reveal a negative linear trend in maize yields. The picture is mixed for the quadratic trend models. Decelerating yield growth if found for West Europe, particularly the West France and South Sweden. For Eastern Europe, usually accelerating yield growth is found apart from Bulgaria and Romania where yield growth is also decelerating or yields are even decreasing.

Figure 15. Regional distribution of trend and variability directions of maize yields

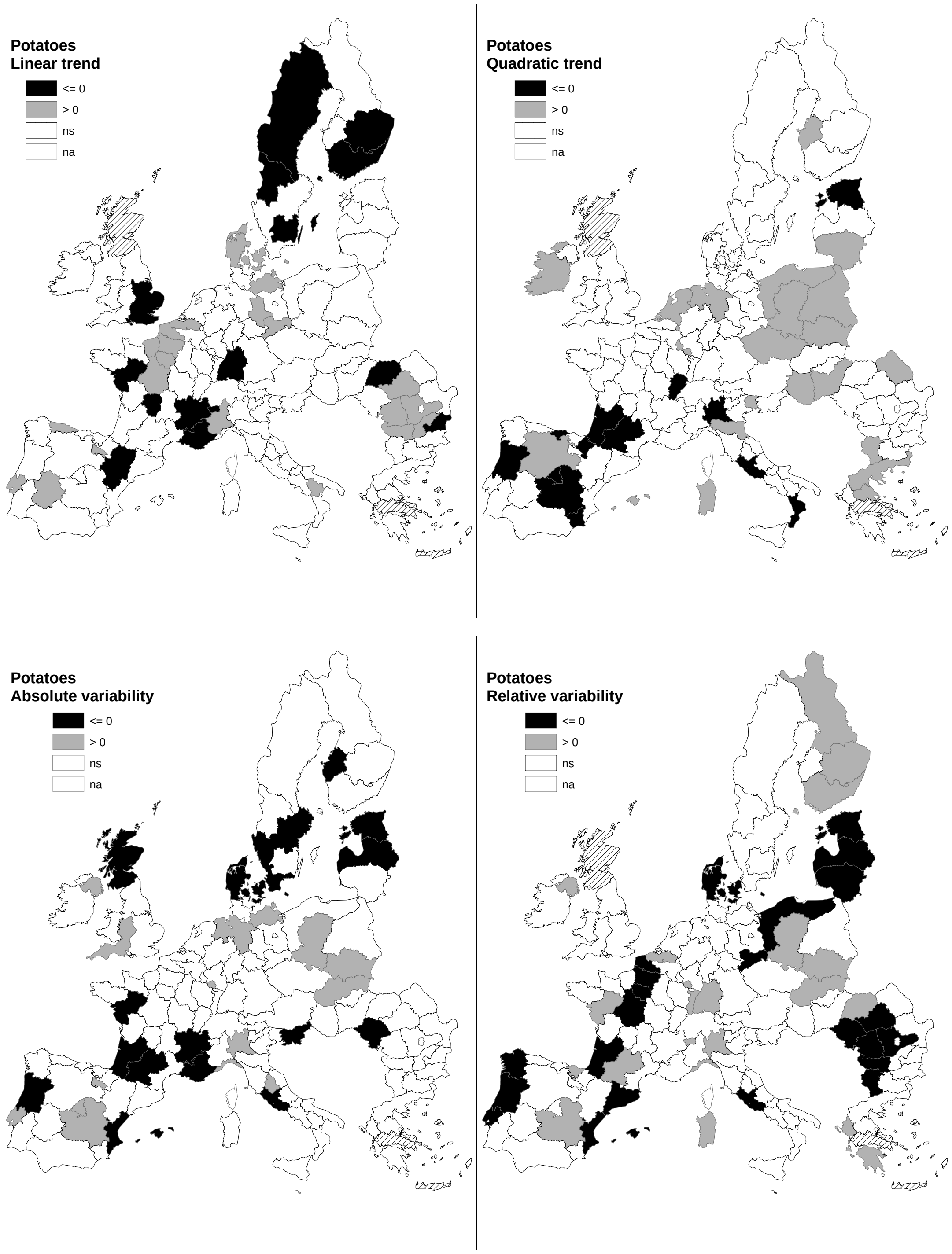


Data source: EU-FADN – DG AGRI.

7.5.2.4 Potatoes

For potatoes, out of 77 significant cases, 49 percent were estimated as linear and 51 percent as quadratic model. In case of the linear models, the average R2 is 0.62, for the quadratic models it is 0.60. A clear regional pattern cannot be identified (Figure 16).

Figure 16. Regional distribution of trend and variability directions of potato yields

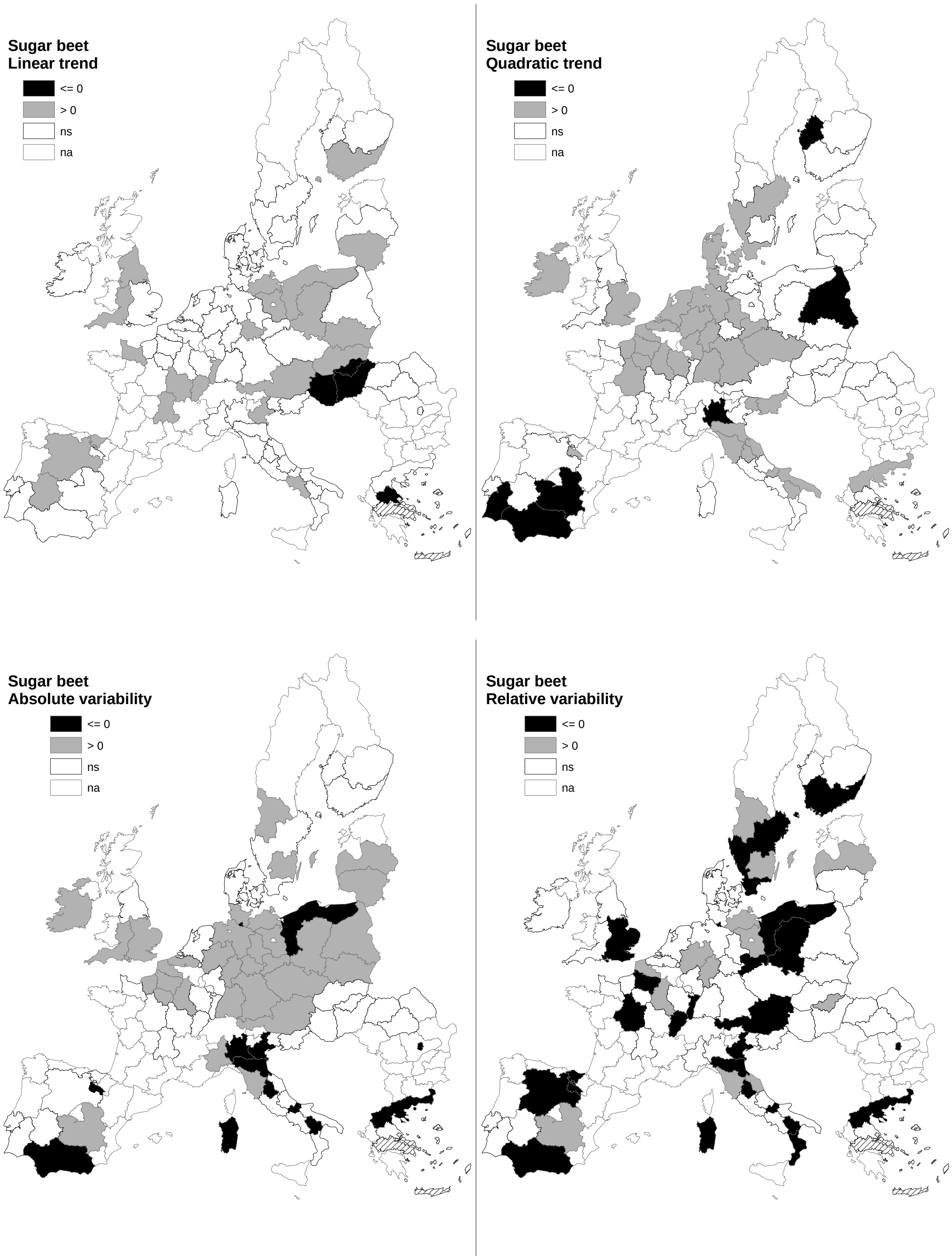


Data source: EU-FADN – DG AGRI.

7.5.2.5 Sugar beet

For sugar beet, 68 regions with significant estimates are found. In 38 percent of these, the linear model was chosen, in 62 percent the quadratic. The average R^2 of the linear models is 0.52, the average R^2 of the quadratic models is 0.56. Yield developments tend to be positive throughout the EU (Figure 17).

Figure 17. Regional distribution of trend and variability directions of sugar beet yields

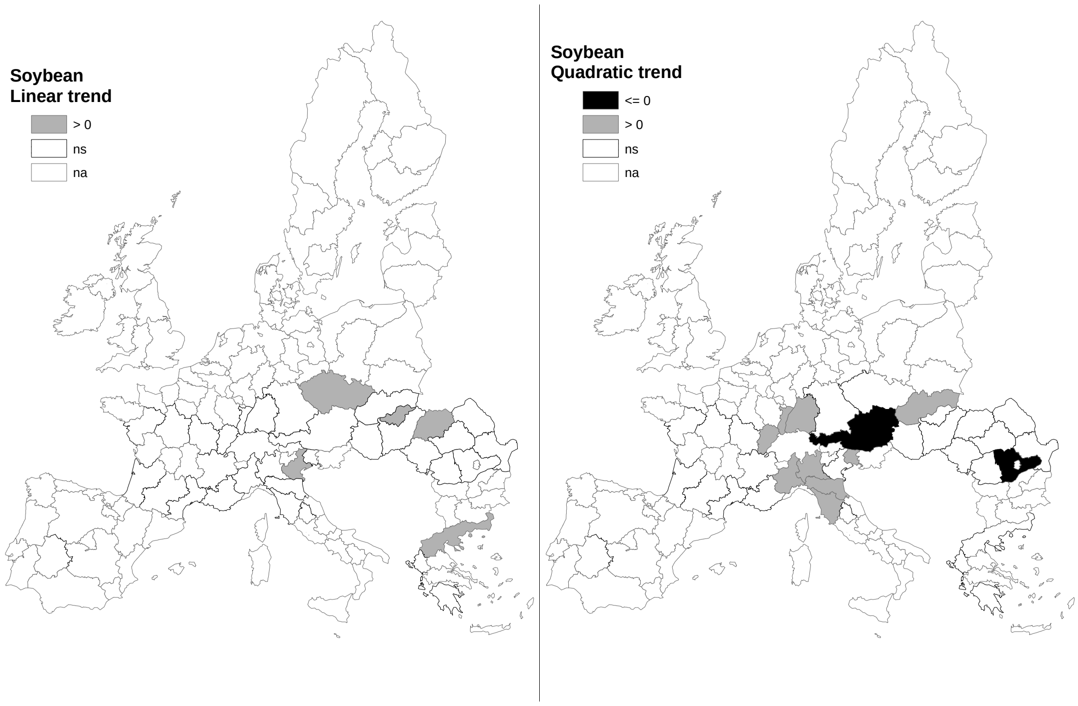


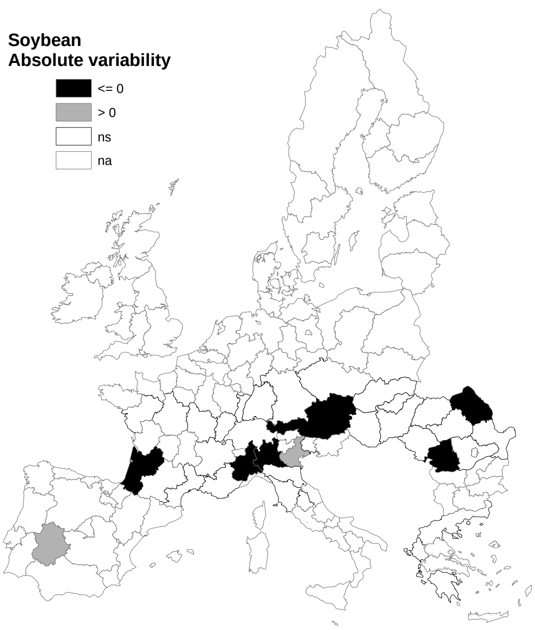
Data source: EU-FADN – DG AGRI.

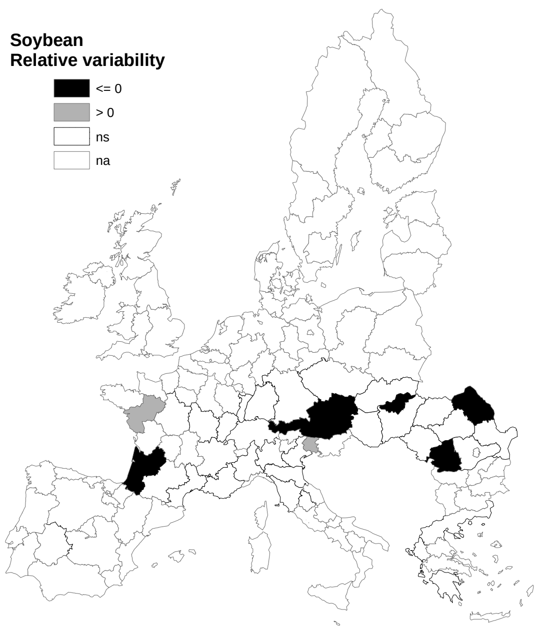
7.5.2.6 Soybean

Though soybean production is found in a larger amount of regions in southern Europe, significant coefficients are only found for 16 regions. In five of them the linear model was superior, in the other eleven the quadratic model. The average R^2 of the linear models is 0.72, the one of the quadratic models is 0.63. Yield trends are generally positive, except for Austria, and yield variability is decreasing (Figure 18).

Figure 18. Regional distribution of trend and variability directions of soybean yields







Data source: EU-FADN – DG AGRI.

7.5.3 Yield trend summary

Assuming linear trends for all crops and regions, Table 6 provides an overview of the EU27 average estimates. Following these averages, annual soft wheat yield growth was 41 kg/ha. For barley yield growth was 26 kg/ha and for maize 184 kg/ha. Finger (2010) found the average linear yield growth for wheat in Switzerland to be 75 kg/ha, for barley 82 kg/ha and for maize 124 kg/ha. Tremendous yield growth is estimated for sugar beet, whereas potato yields tend to decline. Soybean yields tend to increase slightly.

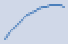
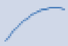
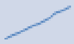
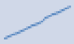
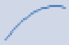
Table 6. Linear trend estimates per crop, EU27 average

Crop	Trend estimate
SWHE	0.041
BARL	0.026
MAIZ	0.184
POTA	-0.109
SUGA	0.588
SOYA	0.023

Data source: EU-FADN – DG AGRI.

Summarizing the regional results from both linear and quadratic trends, cereal yield growth tends to decelerate in the EU15 and Romania and Bulgaria, whereas it accelerated in the EU10 (Table 7).

Table 7. Cereal yield trend developments in the EU

Crop	EU15	EU10	RO/BG
SWHE			 / 
BARL			
MAIZ	 / 		

Source: Own illustration.

As shown exemplarily for soft wheat and maize yields in the Annex, these patterns are less clear if applying a rolling regression over several time periods.

8 TOWARD AN ECONOMETRIC FRAMEWORK FOR EXPLAINING YIELD GAPS

Agreeing that increased future global food demand will have to be met by production intensification rather than land use expansion (Hertel, 2011), scientists have moved to empirically analyse the causes for differences between potentially attainable yields and actually realised yields – the yield gap (Neumann et al., 2010). We aim at disentangling the effects of biophysical and management impacts on crop yields by analysing yield gaps at regional level in the EU. Apart from generally improving our understanding of yield gaps and their drivers in the EU, our analysis will contribute to the integration of economic and biophysical models at a later stage of our research (WP9).

8.1 Literature

For empirically determining a production function based on potential yields and their land heterogeneity, statistical-econometric pre-work is required. More particularly, one would have to explicitly distinguish between biophysical drivers (b) and managerial/economic drivers (m) of actually observed yields already in the econometric setup to obtain the respective parameters for the simulation model. Requiring a good deal of multidisciplinary cooperation between meteorologists, crop scientists and economists, work on this differentiation has just started. To our knowledge only two statistical-econometric studies attempt to disentangle the biophysical and economic effects determining potential and actual yields, respectively: Neumann et al. (2010) and Baldos and Hertel (2012). A tabular overview of the studies mentioned here is given in Table 8. Both build upon the large strand of economic productivity and efficiency analyses (e.g. Coelli et al. 2005). In the agricultural economics literature, the efficiency analyses are usually based on production function approaches. The overall or activity (e.g. crop) specific production functions are thereby either represented in terms of a programming (Data Envelopment Analysis – DEA) or of a statistical-econometric approach (Stochastic Frontier Analysis – SFA). Explained are efficiency measures or output, respectively, in economic terms. A bridging study between traditional farm efficiency analyses and so-called yield gap analyses is provided by Reidsma et al. (2009c) who still focus on explaining economic output per crop. However, apart from managerial, economic and political factors, they are the first who also include biophysical determinants – namely, temperature and precipitation - in their analysis. Neumann et al. (2010) and Baldos and Hertel (2012) extend the approach by specifically targeting at explaining crop yields and yield gaps in physical terms and at global level. Both take three crops of global relevance into account: wheat, maize, and rice. Neumann et al. (2010) use a temperature measure, precipitation, Photosynthetically Active Radiation (PAR) and soil fertility constraints as independent variables explaining regional yield frontiers, which are interpreted as regional potential yields. The regional deviation from potential yields is explained by managerial and locational factors such as irrigation and slope and macroeconomic factors such as agricultural population, market access and market influence. Baldos and Hertel (2012) determine regional frontier yields by temperature, precipitation, soil constraints and slope. Deviations from frontier yields are explained by population, fertilizer use, irrigation, market accessibility, market influence and institutional strength.

Table 8. Econometric yield gap studies

Study	Focus/aim	Crops	Regional extent/resolution	Time series	Method	Dependent	Determinants frontier	Determinants inefficiency
Reidsma et al. (2009)	Climate change adaptation	Cereals, maize, arable crops, other agricultural activities	EU15; national level	1990-2003	SFA, translog distance function (multiple outputs)	Output (€)	Fertilizer, crop protection, economic size, irrigated area, land allocation, temperature, precipitation, subsidies, trend	
Neumann et al. (2010)	Yield gap analysis	Wheat, maize, rice	Global; 26 regions	2000	SFA, Cobb-Douglas production function	Actual yield	Temperature, precipitation, PAR, soil fertility constraints	Irrigation proxy, slope, proxy for agricultural population density, market accessability
Baldos and Hertel (2012)	Yield gap analysis	Wheat, maize, rice	Global; 8 regions	2000	DEA + spatial Durbin-Tobit model	Yield gap = efficiency scores for rainfed and irrigated areas	Precipitation, temperature, terrain constraint, soil constraint, slope	Popultation, fertilizer use, irrigation, market access, proxy for market influence, proxy for institutional strength, spatial weights

8.2 Econometric framework

Section 8.2 is integrated with the SUSFANS working paper by (Adenäuer et al., 2016), which connects the yield gap analysis with the modelling work in WP9. In the following, we describe the yield gap analysis as applied in WP4.

An econometric Stochastic Frontier Analysis (SFA) following Neumann et al. (2010) allows estimating the parameters of the biophysical drivers (b) and the managerial/economic drivers (m) simultaneously. In the stylised form

$$y_j = \exp\left(\beta_0 + \beta_1 \ln b_j\right) \times \exp\left(v_j\right) \times \exp\left(i_j\right) \quad (5)$$

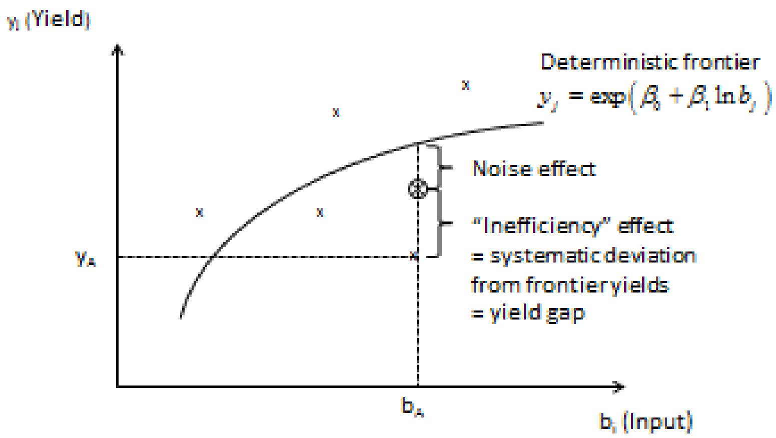
the output *y* of crop *j*, in this case the actual crop yield, would be explained by a deterministic component which represents the potential yield y^{pot} and is based on biophysical drivers b and their coefficients β_1 (β_0 is the coefficient of the constant), a noise effect *v*, and a term representing management i in equation. The management term i can further be parameterized as

$$i_j = \delta m_j \quad (6)$$

which is based on managerial and other non-biophysical drivers *m* and their coefficients δ. Though a classical Cobb-Douglas production function is shown here for illustrational purposes, other functional forms might actually be more applicable depending on further theoretical and methodological considerations. Figure 18 depicts the stochastic production frontier. It shows the production frontier which is y^{pot} and depends on the biophysical drivers. Both positive and negative deviations from the frontier production can be due to noise effects, whereas systematic negative deviations are due to non-biophysical factors such as management. Following the literature, those are usually termed "inefficiency"[2]. However, in this context, they should not be termed "inefficiency" anymore, but may rather be well-founded, for example, due to economic considerations. In this setting, it would be interpreted as the systematic deviation from frontier yields, i.e. the yield gap.

[2] Please note that the "inefficiency" terminology is due to historic reasons. In fact, most researchers in this field would doubt that it represents inefficiency, but would rather be determined by other economically reasonable considerations.

Figure 19. Stochastic production frontier



Source: Based on Neumann et al. (2010).

8.3 Data and Method

Singe farm data from the FADN are used and combined with climate data from Janssen et al. (2009). Due to limited climate data availability only the years 1995 to 2006 could be considered. Estimations are done region-wise and for five crops within each FADN region. The crops considered are soft wheat (SWHE), barley (BARL), maize (MAIZ), potato (POTA) and as EU-wide (where available) case study soybean (SOYA). Additionally, for linking up with the SUSFANS fruits and vegetable case study, fruits and vegetables were considered in the SUSFANS case study country Italy. Due to limited data availability in FADN, just tomatoes, oranges and lemons could be considered.

The explanatory variables considered for determining the frontier yields are a trend (YEAR), precipitation (PREC), radiation (RAD) and temperature (TEMP). For each of them the sums over the crop specific growing periods were considered (details on the calculation of the climate variable sums are provided in the Annex).

The equation below shows the finally applied regression. The actual yields (y) are regressed against the climate and management variables for each crop (j) per year (t) and region (r). The management variables considered are economic farm size (ESU), fertilizer expenditure per ha (FERT) and plant protection expenditure per ha (PROTEC). Please note that due to limited data availability, just the fertilizer and plant protection expenditure per total Utilized Agricultural Area (UAA) per farm could be used.

$$\begin{aligned} ln\left(y_{jtr}\right) &= \beta_0 + \beta_1 ln\left(YEAR_{jtr}\right) + \beta_2 ln\left(PREC_{jtr}\right) + \beta_3 ln\left(RAD_{jtr}\right) \\ &+ \beta_4 ln\left(TEMP_{jtr}\right) + v_{jtr} - i_{jtr} \end{aligned} \tag{7}$$

with

$$i_{jtr} = \delta_1\left(ESU_{jtr}\right) + \delta_2\left(FERT_{jtr}\right) + \delta_3\left(PROTEC_{jtr}\right) \tag{8}$$

According to Coelli et al. (2005), efficiency is measured as the ratio of the observed output over the corresponding frontier output.

$$E_{jr} = \frac{y_{jr}}{\exp\left(b'_{jr}\beta + v_{jr}\right)} = \frac{\exp\left(b'_{jr}\beta + v_{jr} - i_{jr}\right)}{\exp\left(b'_{jr}\beta + v_{jr}\right)} = \exp\left(-i_{jr}\right) \tag{9}$$

The analysis is done using the SFA package by Coelli and Henningsen (2013).

8.4 Results

8.4.1 Efficiency

Table 9 shows the mean efficiencies per region, again averaged across the EU regions considered. Please note that due to data limitations estimations did not run for all regions, and, in most cases, East European countries could therefore not be considered. This could be improved with longer climate time series. Which regions could be considered per crop is shown in the efficiency figure below (Figure 20). EU-wide mean efficiencies are relatively high in general with the lowest average efficiency for potatoes (0.69) and the highest for soft wheat (0.80).

Table 9. Mean efficiencies, averages across the EU

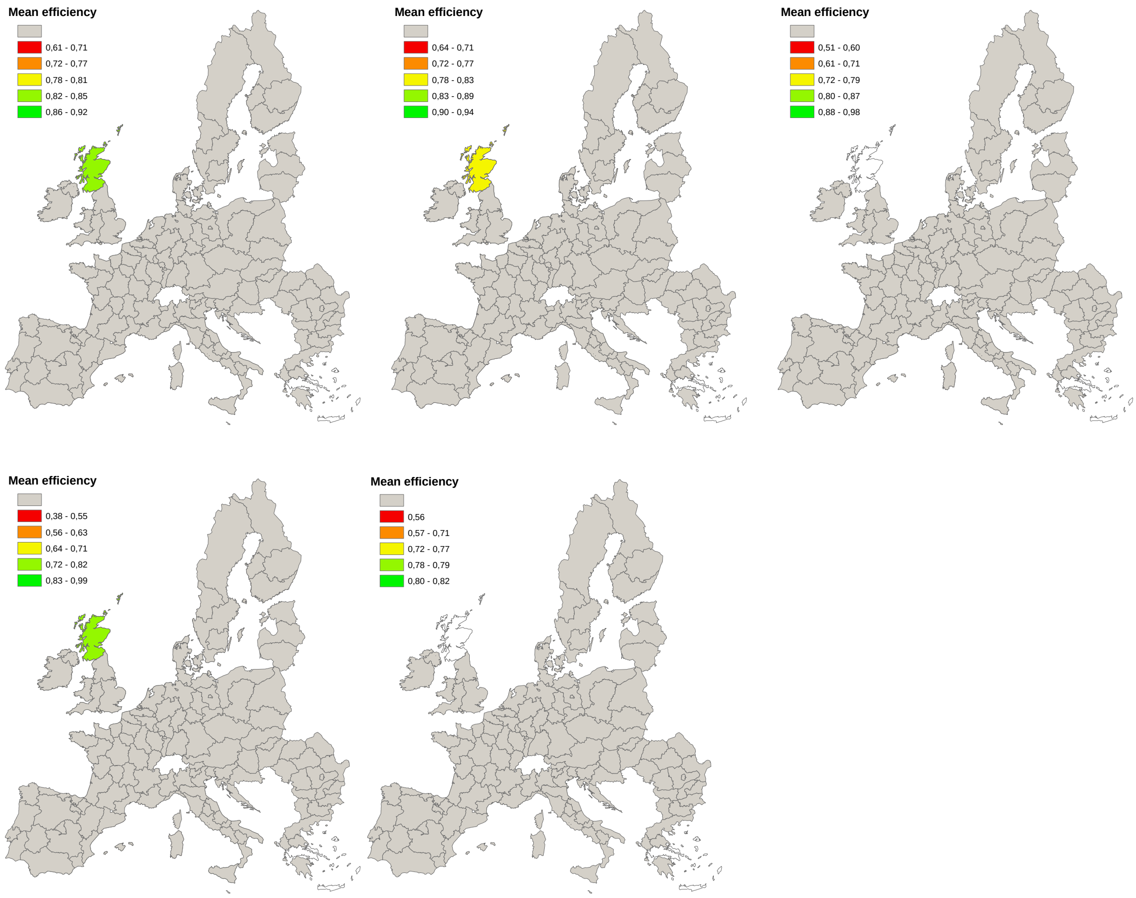
Crop	Mean efficiency
SWHE	0.80
BARL	0.78
MAIZ	0.75
POTA	0.69

SOYA	0.74

Data source: EU-FADN – DG AGRI.

The regional comparison of mean efficiencies in Figure 20 shows that soft wheat and barley efficiencies tend to be higher in North and Central Europe, whereas average efficiencies for maize and potatoes are lower in parts of France and Italy, but again higher in Spain. Soybean production takes place in just a few southern regions.

Figure 20. Mean efficiencies in soft wheat, barley, maize, potatoes and soybean production (in clockwise direction)



Data source: EU-FADN – DG AGRI.

8.4.2 Yield gap estimates

From the explanatory variables affecting frontier yields, trend and precipitation both positively impact yields of all considered crops, whereas the impact of radiation differs across crops (positive for soft wheat and potatoes, negative for the rest) (Table 10). Temperature negatively impacts all crops except soybeans that usually grow in warmer climates. As expected, all of the management variables positively affect all crops (please note that management variables are subtracted during the estimation thus that a negative sign in Table 10 in fact indicates a positive correlation).

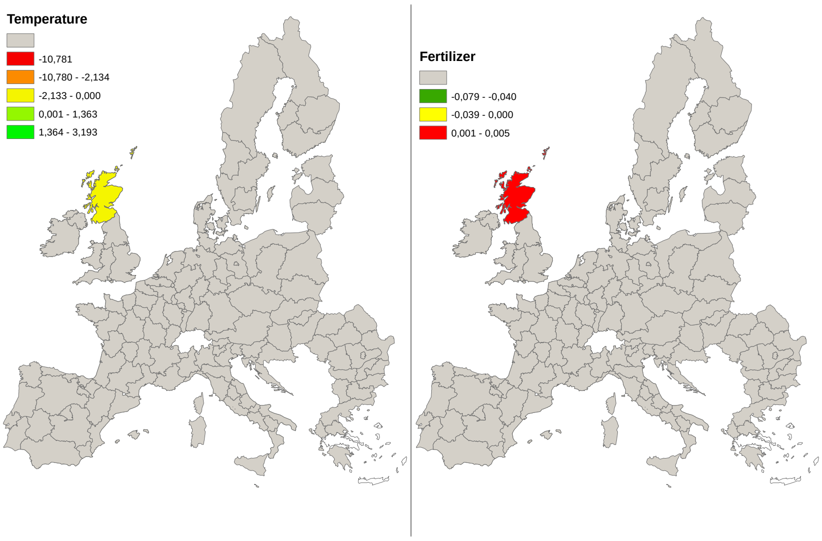
Table 10. Yield gap estimates, averages across the EU

	Mean values of estimates EU						
	Frontier variables				Management variables		
Crop	YEAR	PREC	RAD	TEMP	ESU	FERT	PROTEC
SWHE	0.019	0.085	0.219	-0.356	-0.003	-0.010	-0.025
BARL	0.020	0.060	-0.876	-0.461	-0.010	-0.046	-0.045
MAIZ	0.041	0.037	-0.224	-0.140	-0.003	-0.601	-0.052
POTA	0.009	0.060	0.089	-0.130	-0.346	-0.159	-0.550
SOYA	0.076	0.190	-1.420	0.582	-0.060	-0.223	-0.196

Data source: EU-FADN – DG AGRI.

Exemplarily, the regional distribution of the effect of one climate variable (temperature) and one management variable (fertilizer) on soft wheat yields are shown in Figure 21. As for temperature, the effects are slightly negative to slightly positive across the EU except for Spain, where they are clearly negative reflecting the warmer climate. With a few exceptions the effects of fertilizer are largely positive throughout the EU.

Figure 21. Temperature and fertilizer effects (estimates) on soft wheat production



Data source: EU-FADN – DG AGRI.

8.5 Case study fruits and vegetables in Italy

The average efficiencies in tomato, oranges and lemon production in Italy (Table 11) are a bit lower than the EU-wide mean efficiencies of the other crops (Table 10). This might also reflect a generally higher heterogeneity in fruits and vegetable production, for example, in terms of variants, conditions and crop management. The trend, climate variables and farm size have mixed effects depending on the crop considered. Fertilizer and plant protection clearly have positive effects on the yields of tomatoes, oranges and lemons.

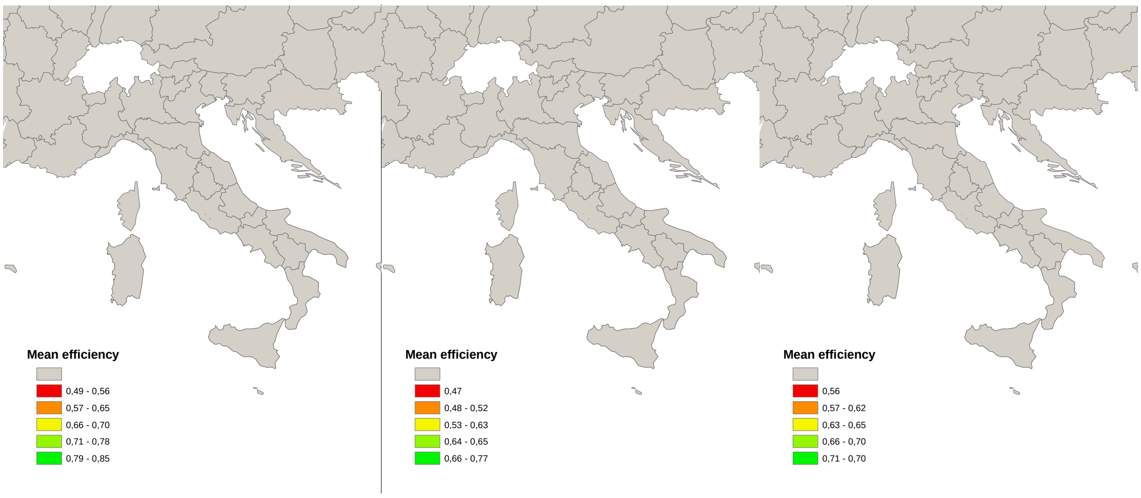
Table 11. Mean efficiencies and yield gap estimates of fruits and vegetables in Italy

Crop	Mean efficiency	Frontier variables				Management variables		
		YEAR	PREC	RAD	TEMP	ESU	FERT	PROTEC
TOMA	0.689	-0.027	0.114	1.859	0.866	-0.224	-0.029	-0.016
ORAN	0.611	-0.033	-0.186	-1.572	-0.782	0.004	-0.004	-0.007
LEMO	0.648	0.007	-0.135	1.447	-1.186	-0.012	-0.007	-0.008

Data source: EU-FADN – DG AGRI.

Efficiency in tomato production appears to be higher in northern and southern Italian regions (Figure 22). Orange and lemon production takes place in the south and on Sicily and Sardinia (Figure 22).

Figure 22. Mean efficiencies in tomato, orange and lemon production in Italy



Data source: EU-FADN – DG AGRI.

9 CONCLUSIONS

The first qualitative part of the analysis 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 final crop production is determined by crop yields and land use. Whereas land use is explicitly being treated by the agricultural sector models in WP9, the second part of the paper provides empirical analyses of crop yields.

Crop yield trends are positive throughout the EU. However, depending on the time horizon considered, cereal yield growth tends to decelerate in the Western Member States, whereas they appear to accelerate in the Eastern Member States perhaps reflecting a catching-up from generally lower yield levels in the East. These finding should be treated with caution as the analysis also very clearly shows the sensitivity of the results depending on the time period considered. Trends in potato, sugar beet and soybean production are positive in the EU. With increasing yields, the variability of yields tends to increase as well.

The EU average efficiency in yield exploitation is around 70% for potatoes and up to 80% for soft wheat with efficiencies often being lower in southern parts of the EU and higher in the central and north. Regional frontier yields are driven by breeding (represented by a trend variable) and local climate. The technology trend is clearly positive in the EU average, whereas climate can have different effects depending on the crop and region considered. All considered management variables (economic farm size, fertilizer and plant protection expenditure) clearly positively affect yield gap exploitation. A fruits and vegetables case study for Italy generally confirms the EU-wide results for the other crops in terms of yield determinants. Average efficiencies are between 61% for orange yields and 69% for tomato yields in Italy.

The study was limited by data availability. Particularly, the yield gap study could substantially gain from extended climate data time series, especially for adding results for the East European Member States. The analysis was targeted to the explanation of physical yields, however, the framework could further be used for an assessment of economic efficiency.

The commonly shared hypothesis is that intensification is the preferred option over expansion of area under crops. Though intensification is land-sparing, it could lead to other environmental (or even health) risks through overfertilization and adverse effects of plant protection such that crop land use can also be too intense. In some areas even an extensification could be the most logical path towards sustainable resource use. As environmental and other externalities cannot be shown with our approach alone, the results of this study will be further used to improve the spatial analysis of environmental indicators in D4.6 and to improve supply side reactions in the agricultural sector model CAPRI in WP9. The improved input-output coefficients in CAPRI will help in identifying risks and trade-offs between ex- and intensification for food production and environment.

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ANNEXES

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:

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

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 12. 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 12. 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.

Document	Indirect driver 'technological change'	Direct driver 'available technology'	Comment
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 (D4.2)	- Historical development and the interplay between farmed and fished seafood - Technical innovations in society enabling growth	- 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	The distinction here is 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

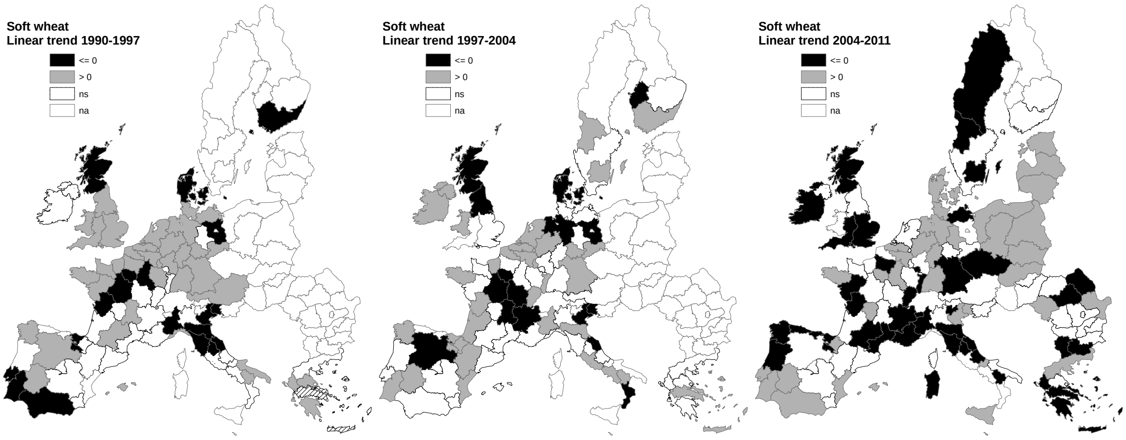
Document	Indirect driver 'technological change'	Direct driver 'available technology'	Comment
		efficiency incl. by-product utilization	
Crop (D4.4/D4.5)	- Public and private research (breeding, fertilizer and plant protection, machinery)	- Management	This translates into the concept of technical progress 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

Decomposition of yield trends for soft wheat and maize

Soft wheat

Figure 23 decomposes the trends in soft wheat yields from 1989 to 2011 into three subsequent time periods: (a) 1990 to 1997, (b) 1997 to 2004 and (c) 2004 to 2011. Depicted are the linear trends only. Whereas in 1990 to 1997 positive linear trends dominated, yield growth turned negative or insignificant in more regions in 1997 to 2004 with even more regions showing negative trends in 2004 to 2011.

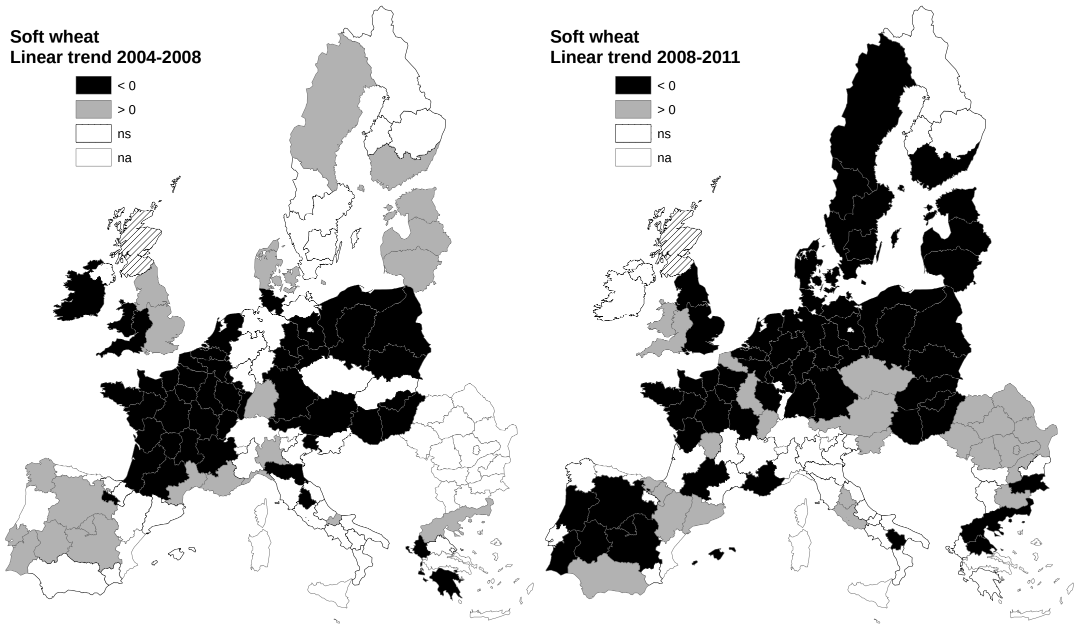
Figure 23. Linear trends in soft wheat yields, rolling regression 1990-2011



Data source: EU-FADN – DG AGRI.

Further decomposing just the last time period 2004 to 2011, trends are negative almost throughout the EU (Figure 24).

Figure 24. Linear trends in soft wheat yields, rolling regression 2004-2011

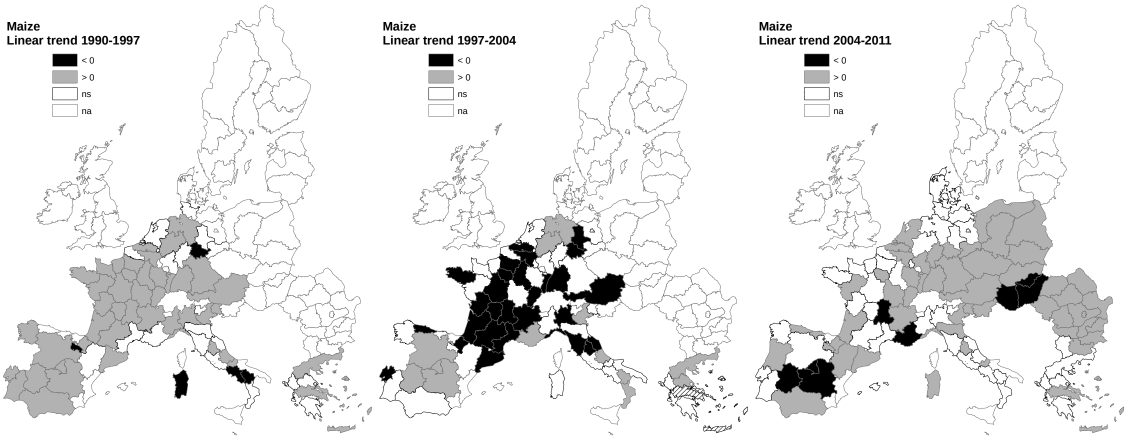


Maize

For maize yields the pattern over time is slightly different. In 1990 to 1997 trends are clearly positive throughout the EU, as for soft wheat they turn negative or insignificant in 1997 to 2004. Different from soft wheat trends,

trends in maize yields are again positive in the time period 2004 to 2011 (Figure 25).

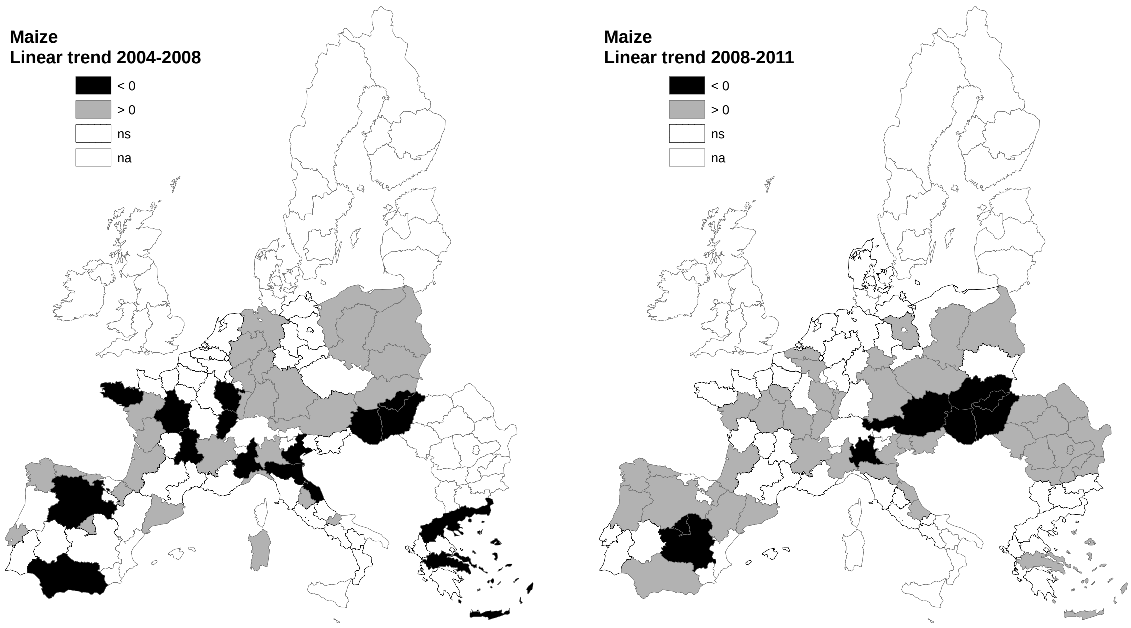
Figure 25. Linear trends in maize yields, rolling regression 1990-2011



Data source: EU-FADN – DG AGRI.

Decomposing the last time period into trend estimations for 2004 to 2008 and 2008 to 2011, a clear pattern of changing trends cannot be observed. In 2008 to 2011 trends tend to be positive in slightly more regions than in 2004 to 2008 (Figure 26).

Figure 26. Linear trends in soft wheat yields, rolling regression 2004-2011



Data source: EU-FADN – DG AGRI.

Definition and calculation of climate variable sums

This section describes the calculation of the climate variables for the yield gap estimation.

1. A subset of the climate variables according to growing periods was built for the two groups (1) wheat and barley (November to June) and (2) maize, potatoes, sugar beet and soybeans (April to October).
2. The climate variable sums are calculated per growing period subset.
3. For the temperature sums, the crop specific threshold temperature was subtracted from the daily mean temperature. For Barley, wheat and sugar beet the threshold temperature was set to 0°C, for maize and soybeans it was set to 10°C and for potatoes it was set to 7°C.