CPVO
Community Plant Variety Office

EUIPO
EUROPEAN UNION
INTELLECTUAL PROPERTY OFFICE

www.euipo.europa.eu

IMPACT OF THE COMMUNITY PLANT VARIETY RIGHTS SYSTEM ON THE EU ECONOMY AND THE ENVIRONMENT

April 2022

IMPACT OF THE COMMUNITY PLANT VARIETY RIGHTS SYSTEM ON THE EU ECONOMY AND THE ENVIRONMENT

ISBN 978-92-9156-318-0   doi: 10.2814/467391   TB-05-22-112-EN-N

Foreword

Innovation is a key component of the sustainable growth strategy adopted by the European Union and its Member States. The aim is to create a more competitive European economy while at the same time achieving the objective adopted by the European Commission to make Europe the first climate-neutral continent by 2050. The achievement of these goals depends on several factors, but an effective system of intellectual property rights (IPR) undoubtedly ranks among the most important factors, given IP’s capacity to encourage innovation throughout the economy.

To help achieve the goals of the European Green Deal, CO_2 emissions from agriculture must be reduced in the coming years. Other environmental considerations call for less intensive use of pesticides, fertiliser and other chemicals, while at the same time maintaining and increasing food production to cope with the demands of the European and global markets. This multifaceted challenge can only be met by creating new varieties of crops that use fewer resources while enhancing productivity of European agriculture. And given that climate change is already happening, these new varieties must also be able to cope with the changing climate. A great deal of innovation in breeding of plant varieties is therefore required.

Innovation in plant breeding is underpinned by a system of Plant Variety Rights (PVR) in EU Member States and by the Community Plant Variety Rights (CPVR) on the EU level. The CPVR, managed by the Community Plant Variety Office (CPVO) is, together with the EU Trade Mark and the Registered Community Design, managed by the European Union Intellectual Property Office (EUIPO), one of three unitary IP rights that currently exist in the EU, valid in all Member States.

Our two agencies cooperate in several areas. It gives us great pleasure to present this report that highlights the very significant contributions made by the CPVR system to the economy and to the environment during the past 25 years, thereby supporting the EU's economic and environmental goals.

Christian Archambeau
Executive Director, EUIPO

Francesco Mattina
President, CPVO

Acknowledgements

This report was prepared by Nathan Wajsman and Francisco García-Valero of the EUIPO, in cooperation with Francesco Mattina, Dirk Theobald, Orsola Lamberti and Ángela Martínez of the CPVO. The analysis of the contribution of the CPVR system to growers in Chapter 4 was carried out by HFFA Research GmbH under the leadership of Dr. Steffen Noleppa. Päivi Mannerkorpi of the European Commission's Directorate-General for Health and Food Safety provided comments on an earlier draft of the report.

CPVO stakeholders the association of the European seed sector (Euroseeds), the International Community of Breeders of Asexually Reproduced Horticultural Plant Varieties (Ciopora) and the Dutch association for the plant reproduction material sector (Plantum) also provided valuable input prior to the publication of this report.

This study was included in the Work Programme of the Observatory for 2021. The Terms of Reference were discussed with the Economics & Statistics Working Group of the Observatory, held online on 20 October 2020.

Table of Contents

Executive Summary

The European Union (EU) Community Plant Variety Right (CPVR) system, administered by the *Community Plant Variety Office* (CPVO), provides for uniform EU wide protection of plant variety rights in the EU.

This study quantifies the economic contribution in the European Union of the CPVR system. While it is analogous to the EUIPO studies on the economic contribution of the other IP rights (1), it considers specific aspects of agriculture and horticulture, such as the contribution of the PVR system to the global competitiveness of EU farmers and growers.

The study also considers the potential for the CPVR system to help meet the European Commission's Green Deal objectives, in particular:

- Climate neutral Europe;
- Ecosystems & biodiversity, to address protection of environment and to contribute to halting loss of biodiversity;
- Farm to Fork strategy, to ensure the production of sustainable, safe, nutritious and high quality food along the whole value chain while ensuring food security by seed security;
- R&D and innovation in climate-friendly technologies.

The potential contribution to the United Nations (UN) Sustainable Development Goals (SDGs) is also considered.

The study finds that the CPVR system has contributed to output growth in EU agriculture since 1995, despite the fact that input use during that period has been decreasing by 0.5% per year for arable crops and by 1% per year for horticulture (fruit and vegetables) and ornamentals. While part of this progress is due to plant breeding in general, the study calculates the proportion that can be attributed to the CPVR. The central finding with respect to output is that in the absence of the CPVR system,

---

(1) See Observatory IP Contribution studies.

in 2020 production of arable crops in the EU would be 6.4% lower, production of fruit would be 2.6% lower, that of vegetables 4.7% lower, and finally, the output of ornamentals would be 15.1% lower. Expressed another way, the additional production brought about by plant variety innovations supported by the CPVR is sufficient to feed an additional 57 million people world-wide (arable crops), 38 million in the case of fruit, and 28 million for vegetables.

From a macro-economic point of view, without the added production attributable to CPVR-protected crops, the EU's trade position with the rest of the world would worsen (for some crops, the EU might even switch from being a net exporter to a net importer), and EU consumers would face higher food prices. The additional value added (that is, contribution to GDP) generated by CPVR-protected crops amounts to 13 billion EUR (7.1 billion EUR for arable crops, 1.1 billion EUR for fruit, 2.2 billion EUR for vegetables, and 2.5 billion EUR for ornamentals). Furthermore, the additional production of such crops translates into higher employment in the EU agriculture. The arable crops sector employs 25 000 additional workers as a result, the horticulture sector 19 500, and the ornamentals sector 45 000 additional workers, for a total direct employment gain of almost 90 000 jobs. Considering the indirect effects, that is, the employment gain in upstream and downstream sectors (for example, farm supply or food processing) increases the employment gain by as many as 800 000 jobs.

Not only does the CPVR system contribute to employment, but the jobs created are also better remunerated than they would have been in the absence of this system. Specifically, wager of workers in the arable crops sector are 12.6% higher than they would have been in the absence of this system, while wages in the horticulture sector are 11% higher.

The farmers/growers across the EU thus benefit from the innovations supported by the CPVR system. The breeders which carry out the R&D leading to those innovations also generate employment and economic activity. It is estimated that companies protecting their innovations by registering CPVRs employ more than 70 000 workers and generate a turnover of more than 35 billion EUR. While this economic contribution is modest on the scale of the EU as a whole, it is significant in certain Member States and regions within those Member States, for example the Delft en Westland region in the Netherlands.

Many of the companies protecting their innovations with CPVRs are small and medium-sized enterprises (SMEs). These small companies (including physical persons who hold CPVRs) account for more than 90% of the registrants of CPVRs and hold 60% of all CPVRs currently in force.

The CPVR system makes not only an economic contribution to the EU economy, but also contributes to the fulfilment of the EU's environmental objectives. The annual greenhouse gas (GHG) emissions from agriculture and horticulture are reduced by 62 million tons per year. This corresponds to the total GHG footprint of Hungary, Ireland or Portugal. Furthermore, water use in agriculture and horticulture is reduced by more than 14 billion m^3, an amount of water equivalent to 1/3 of the volume of Lake Constance.

Finally, by reducing the environment impact and resource use of agriculture and horticulture, by increasing farm incomes, and by keeping prices lower for the consumers, the CPVR system also contributes to the UN's Sustainable Development Goals.

1 Introduction to the Community Plant Variety Rights system and to the marketing of plant varieties in the European Union

The EU counts on a *sui generis* IP right for industrial protection of plant varieties, known as the Community Plant Variety Rights (CPVR). The CPVR system was established based on Council Regulation (EC) No 2100/94 of 27 July 1994 on Community plant variety rights ("Basic Regulation") as "the sole and exclusive form of Community (EU) industrial property rights for plant variety rights (2). It must be noted in this regard that the substantive part of the Basic Regulation models on the International Convention for the Protection of New Varieties of Plants (UPOV Convention) (3). In addition, some specific aspects of the CPVR system are governed in more detail by further CPVR-related legislation (4).

---

(2) Article 1 of the Basic Regulation. Pursuant to Article 27(3)(b) of the TRIPS Agreement, the European Union must "provide for the protection of plant varieties either by patents or by an effective *sui generis* system or by any combination thereof", where the EU has opted for the option of putting in place a *sui generis* system.

(3) The UPOV Convention was adopted in Paris in 1961, establishing the *Union Internationale pour la Protection des Obtentions Végétales* (UPOV). UPOV is the intergovernmental organisation competent for the harmonisation of the international legal framework for the protection of plant breeders' rights, with headquarters in Geneva (Switzerland). UPOV has legal personality and enjoys the legal capacity necessary for the fulfilment of the UPOV obligations in the territory of its Contracting Parties [Article 24(2) UPOV]. UPOV currently counts on 78 Contracting Parties, where the membership is open not only to States, but also to intergovernmental organisations. On 29 July 2005, the EU joined UPOV in the quality of "intergovernmental organisation" and, as of that date, the UPOV Convention became an integral part of the legal order of the EU. In addition, 23 EU Member States are Contracting Parties to UPOV: all EU Member States except Cyprus, Greece, Luxembourg and Malta. Finally, it should be noted that the UPOV Convention was revised in 1972, 1978 and 1991, with some Contracting Parties being members of the "UPOV 78 Act" and others the "UPOV 91 Act"), which means that there is not full harmonisation among all national PVR systems. The list of UPOV Members, as updated on 3 November 2021, is available at https://www.upov.int/edocs/pubdocs/en/upov_pub_423.pdf.

(4) The following three implementing regulations of the European Commission develop certain provisions in the Basic Regulation:

- Commission Regulation (EC) No 874/2009 of 17 September 2009 establishing implementing rules for the application of Council Regulation (EC) No 2100/94 as regards proceedings before the Community Plant Variety Office ("Proceedings Regulation");
- Commission Regulation (EC)g No 1238/95 of 31 May 1995 establishing implementing rules for the application of Council Regulation (EC) No 2100/94 as regards the fees payable to the Community Plant Variety Office;

The CPVR system coexists with the national PVR systems of the 23 EU Member States that have put in place a national PVR system. However, cumulative protection (that is, simultaneous protection of a variety under a CPVR and a national right) is prohibited in the terms stipulated in Article 92 of the Basic Regulation (5).

1.1 The CPVO

The CPVR system is managed by the Community Plant Variety Office (CPVO), set up for this purpose (6). The CPVO is an official decentralised agency of the EU with seat in Angers (France), independent legal status, fully self-financed and operational since 1995. The mission of the CPVO is *to deliver and promote an efficient Intellectual Property Rights system that supports the creation of new plant varieties for the benefit of Society* (7).

More precisely, the CPVO is responsible for the granting and management of CPVRs, which are entered into the CPVO Register of CPVR (8), and are valid and enforceable throughout the EU on account of the so-called “principle of unitary character” (9). Indeed, one of the most advantageous features of the CPVR system is that, with one single application before the CPVO, one examination procedure, and one technical examination, a single decision is taken by the CPVO on whether a CPVR can be granted, and, if such is the case, this right will be valid throughout the whole territory of the 27 EU Member states.

- Commission Regulation (EC) No 1768/95 of 24 July 1995 implementing rules on the agricultural exemption provided for in Article 14 (3) of Council Regulation (EC) No 2100/94 on Community plant variety rights.

The cited legislation is available on the CPVO website at https://cpvo.europa.eu/en/about-us/law-and-practice/legislation-in-force.

(5) Article 92 of the Basic Regulation (“Cumulative protection prohibited”) reads as follows:

> *1. Any variety which is the subject matter of a Community plant variety right shall not be the subject of a national plant variety right or any patent for that variety. Any rights granted contrary to the first sentence shall be ineffective.*
>
> *2. Where the holder has been granted another right as referred to in paragraph 1 for the same variety prior to grant of the Community plant variety right, he shall be unable to invoke the rights conferred by such protection for the variety for as long as the Community plant variety right remains effective.*

(6) Article 4 of the Basic Regulation.

(7) The statement is available on the CPVO website at https://cpvo.europa.eu/en/about-us/what-we-do/our-mission#:~:text=CPVO%20mission:,by%20the%20European%20Commission%20legislation.

(8) Pursuant to Article 87 of the Basic Regulation.

(9) Article 2 of the Basic Regulation.

Picture of the main building of the CPVO (garden perspective) © CPVO

The CPVO is managed by its President, currently Mr Francesco Mattina ([10]). The budgetary authority and body competent for the monitoring of CPVO activities and of the management of the President of the CPVO is the Administrative Council of the CPVO. In essence, the major functions of the Administrative Council are advising on matters for which the Office is responsible, or issue general guidelines in this respect, the submission to the European Commission of proposals for amendment of EU legislation on PVRs, the entrustment of the Examination Offices of the CPVO as well as adoption of their technical protocols and, where necessary, the issuance of rules on working methods of the CPVO. The Administrative Council is composed of a representative of each EU Member State, a representative of the European Commission, and the Observers.

([10]) To learn more about the structure of the CPVO in terms of organisation, see the Organisation chart available on the CPVO website at https://cpvo.europa.eu/en/about-us/who-we-are/cpvo-staff/organisation-chart.

1.1.1 Subject matter of protection of a Community plant variety right (CPVR)

The subject matter of a granted CPVR is a plant variety, where "variety" is commonly understood as "a plant grouping within a single botanical taxon of the lowest known rank" (11).

For the sake of clarity, the commonly used taxonomic ranks in the classification of plants are, in descending order: Kingdom, Division, Class, Order, Family, Genus, Species and Varieties. In other words, each variety belongs to a species, each species to a genus, each genus to a family, and so on.

Varieties of all botanical genera and species may be protected by a CPVR, including, inter alia, hybrids between genera or species (12).

1.1.2 Requirements that must be met for a variety to be eligible for CPVR protection

Any physical or legal person can apply for a CPVR before the CPVO (13). The person entitled to the CPVR is the person who bred, or discovered and developed the variety (or his/her successor in title) (14).

In order to be eligible for CPVR protection, a variety must meet the following requirements (15):

---

(11) *See*, for instance, the full definition of "variety" within the meaning of the of the Basic Regulation. Pursuant to Article 5(2) of the Basic Regulation, a "variety" can be defined as "a plant grouping within a single botanical taxon of the lowest known rank, which grouping, irrespective of whether the conditions for the grant of a breeder's right are fully met, can be: i) defined by the expression of the characteristics resulting from a given genotype or combination of genotypes; ii) distinguished from any other plant grouping by the expression of at least one of the said characteristics; and iii) considered as a unit with regard to its suitability for being propagated unchanged".

(12) Article 5(1) of the Basic Regulation. There is no official definition of the notion of "botanical genera and species", so this notion is subject to interpretation by the CPVO.

(13) Articles 12 and 49 of the Basic Regulation.

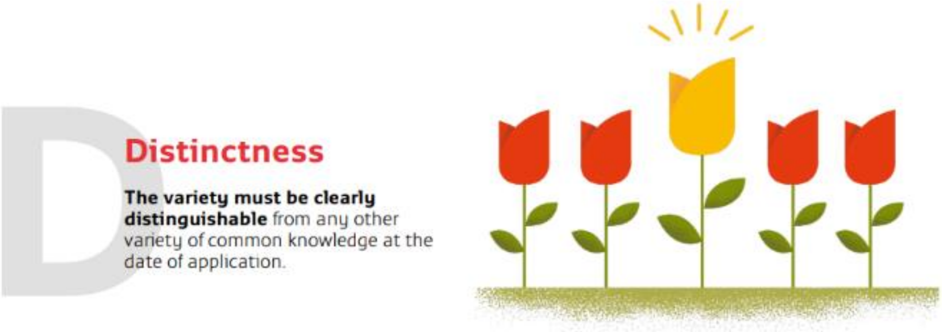
(14) Article 11(1) of the Basic Regulation. According to the second indent of this same article, if two or more persons bred, or discovered and developed the variety jointly, the entitlement shall be vested jointly in them or their respective successors in title.

(15) Pursuant to Article 6 of the Basic Regulation.

- Distinctness;
- Uniformity;
- Stability;
- Novelty; and
- The designation of a suitable denomination.

In regard of the cited requirements, the following clarifications can be made ([16]):

- A variety is deemed distinct if it is clearly distinguishable by reference to the expression of the characteristics that results from a particular genotype from any other variety whose existence is a matter of common knowledge on the date of the application ([17]).



- A variety is deemed uniform if it is sufficiently uniform in the expression of its characteristics ([18]).

- A variety is deemed stable if the expression of the characteristics remains unchanged after successive propagations or multiplications (or, in the case of a particular cycle of propagation, at the end of each such cycle) ([19]).

([16]) The "distinctness", "uniformity", and "stability" requirements are jointly known as "DUS requirements".
([17]) Pursuant to Article 7 of the Basic Regulation.
([18]) Pursuant to Article 8 of the Basic Regulation.
([19]) Pursuant to Article 9 of the Basic Regulation.

- A variety is deemed new if, at the date of application, variety constituents or harvested material of the variety have not been sold, or otherwise disposed of to others, by or with the consent of the breeder for the purposes of the exploitation of the variety:
i) earlier than one year before the application date, within the EU territory; or
ii) earlier than 4 years (6 years in the case of trees or of vines) before the application date, outside the EU territory ([20]).

- A variety denomination is suitable, if there is no impediment against it pursuant to paragraphs 3 or 4 of Article 63 of the Basic Regulation ([21]).

([20]) Pursuant to Article 10 of the Basic Regulation. It must be further clarified that, within the meaning of the of the Basic Regulation, the notion of "novelty" is understood as "commercial novelty", that is, the concept is linked to the availability of the plant material on the market for its commercial exploitation.

([21]) Article 63(2) of the Basic Regulation, in conjunction with its indents third and fourth. It is for the applicant to propose a denomination for the variety, in accordance with Article 50(3) of the Basic Regulation. The proposal for a denomination can, but needs not, be submitted at the time of the CPVR application. A "provisional designation" serving as reference does need to be submitted in any case). The proposal for a denomination must in any event be filed with the CPVO at the latest by the time of receipt by the CPVO of the results of the technical examination of the variety concerned. Otherwise, the application will be refused based on the lack of designation of a suitable denomination.

1.1.3 Examination of applications for CPVR protection

Applications for a CPVR must comply with the set of conditions laid down in Article 50 of the Basic Regulation and the payment of the application fee (22). An application for a CPVR is subject to a triple-fold examination, encompassing a formal examination (23), a substantive examination (24), and a technical examination (25).

The formal and the substantive examinations are carried out by the CPVO itself. The formal examination concerns formal aspects of the application, while the substantive exam is aimed at the verification of fulfilment of the required conditions relating to entitlement, novelty, and the designation of a suitable denomination.

The CPVO delegates the technical examination to one of the Examination Offices of the CPVO. The CPVO counts on a network of Examination Offices distributed throughout the EU (26) and entrusted by the Administrative Council of the CPVO for concrete species, that is, each Examination Office is competent for the technical examination of several specific species (27).

---

(22) Article 113(2) of the Basic Regulation. The CPVO has put at disposal of applicants and for guidance purposes, its "Notes for applicants", available on the CPVO website at https://cpvo.europa.eu/sites/default/files/documents/notes_for_applicants_en_2020_0.pdf.

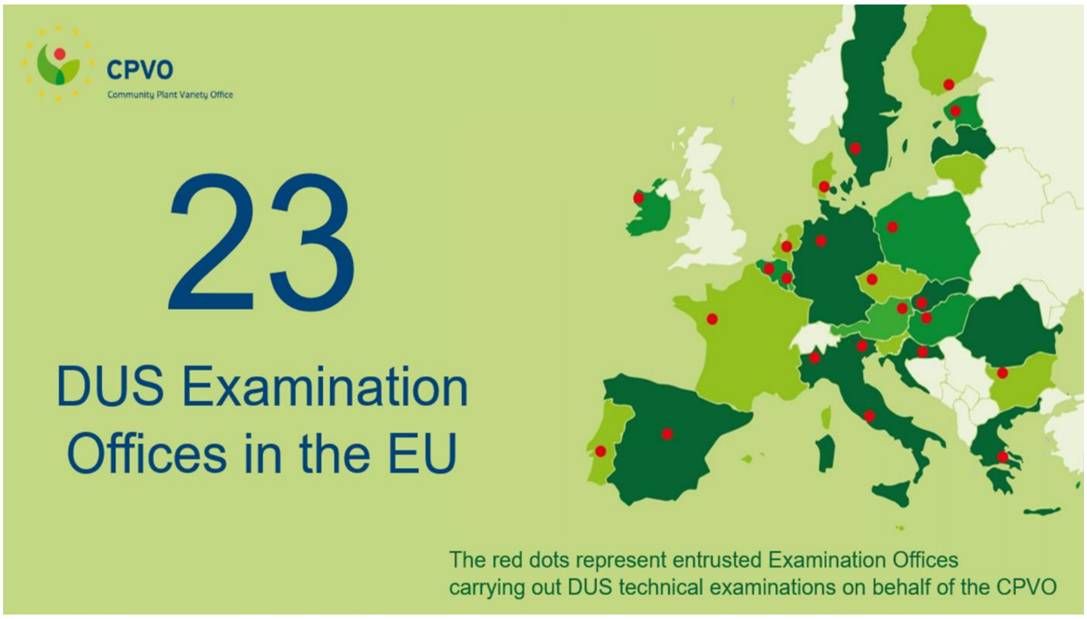
(23) Article 53 of the Basic Regulation.

(24) Article 54 of the Basic Regulation.

(25) Article 55 of the Basic Regulation.

(26) Where there is no Examination Office for a concrete species, the CPVO can outsource the technical examination to an Examination Office of a third country under certain conditions.

(27) The Examination Offices must offer certain quality guarantees to be entrusted. In addition, they are regularly audited by the Quality Audit service of the CPVO.



The red dots represent entrusted Examination Offices carrying out DUS technical examinations on behalf of the CPVO

Map of Examination Offices carrying out technical examinations on behalf of the CPVO

The technical examination serves to verify that the plant variety at stake meets the DUS requirements and is conducted in accordance with the so-called CPVO Technical Protocols, laying down the specific conditions in which the examination must take place as well as a compulsory list of characteristics which must be assessed ([28]). The Technical Protocols are specific for each species. Once the technical examination has been completed, an examination report is issued. If positive, the examination report will include a description of the variety based on the characteristics as assessed during the technical examination.

Once it has been verified that all the requirements for a CPVR to be granted have been complied with in accordance with the Basic Regulation, the CVPR is granted ([29]). To this end, a certificate of the CPVR is issued, along with the so-called “official variety description”, a description of the specific characteristics of the variety concerned as identified throughout the course of the technical examination.

([28]) The CPVO Technical Protocols are available on the CPVO website at https://cpvo.europa.eu/en/applications-and-examinations/technical-examinations/technical-protocols/cpvo-technical-protocols.

([29]) Article 62 of the Basic Regulation.

It should also be noted that, between the time of publication of the application for a CPVR and the granting date of the title, objections may also be lodged against the granting of the CPVR in question before the CPVO by any person (30).

1.1.4 The exclusive right granted under a CPVR and the enforcement thereof

A granted CPVR is valid for a term of 25 years (30 in the case of some species) (31) following the year of the grant (32).

The holder of the CPVR is granted the exclusive right (in respect of variety constituents or harvested material of the protected variety) to authorise or prohibit the following acts:

i) production or reproduction (multiplication);
ii) conditioning for the purpose of propagation;
iii) offering for sale;
iv) selling;
v) exporting from the EU;
vi) importing to the EU;
vii) stocking for any of the cited acts.

Granted CPVRs can be subject to nullity (33) or cancellation (34) administrative proceedings before the CPVO (35). The CPVO has the exclusive authority to declare the nullity or to cancel a granted CPVR.

---

(30) Article 59 of the Basic Regulation.

(31) These species are the following: vine, potato, trees, and the species and group of species covered under the scope of Regulation 2021/1873. Regulation 2021/1873 is available at https://eur-lex.europa.eu/eli/reg/2021/1873.

(32) Article 19 of the Basic Regulation. An annual fee must be paid yearly for the CPVR title to be maintained.

(33) Article 20 of the Basic Regulation. If the action prospers, the CPVR title is declared null and void (*ex tunc* effects).

(34) Article 21 of the Basic Regulation. If the action prospers, the CPVR title is cancelled (with effect *in futurum).*

(35) The decisions arising from these proceedings can then be appealed before the Board of Appeal of the CPVO, whose decisions can in turn be appealed before the General Court, and as last instance before the CJEU. The Board of Appeal of the CPVO is regarded as a body independent to the CPVO and of a quasi-judicial nature, which is responsible for taking decisions of administrative nature on appeals lodged against certain types of legal decisions taken by the CPVO. The Board is made up of a Chairman and alternate, and members chosen by the Chairman from a list (drawn up on the basis of a strict regulatory procedure) depending on the cases under consideration. The members of the Board of Appeal are independent. To learn more about the Board of Appeal of the CPVO, see the section "Board of Appeal" available on the CPVO website at https://cpvo.europa.eu/en/about-us/law-and-practice/board-appeal.

The exclusive right granted under a CPVR is subject to the derogation enshrined in Articles 14 ("agricultural exemption") and the limitations listed in Article 15 of the Basic Regulation.

The "agricultural exemption", also known as "farmers' privilege" or "farm-saved seed concept", means that farmers are authorised to use for propagating purposes, in the field, on their own holding, the product of the harvest which they have obtained by planting, on their own holding, propagating material of a variety which is covered by a CPVR ([36]). The exemption is applicable only in regard of the 21 species listed in the second indent of Article 14 of the Basic Regulation ([37]). In practice, under the agricultural exemption, farmers must pay an equitable remuneration significantly lower than the amount charged for the licensed production of propagation material, and small farmers are not required to pay any remuneration at all ([38]) to the holder of the CPVR. The agricultural exemption is aimed at establishing a reasonable balance between the interest of CPVR holders (or breeders, more generally) and those of farmers, and the need for proportionality between the purpose of the relevant condition and the actual effect of its implementation ([39]).

The limitations to a CPVR listed in Article 15 of the Basic Regulation, include for instance "acts done privately and for non-commercial purposes" and "acts done for experimental purposes". However, the most noteworthy limitation listed is the so-called "breeders' exemption". This exemption allows anybody to use, without requiring the holder's consent, a protected variety for the purpose of breeding, or discovering and developing other varieties. The breeders' exemption is considered as a cornerstone of the CPVR system, because it fosters the development of new varieties and thus leads to innovation in the plant breeding sector.

A CPVR holder can enforce its right against anybody carrying out without its authorisation any of the acts listed in Article 13 of the Basic Regulation concerning the CPVR-protected variety or the

---

([36]) Except for a hybrid or synthetic variety.

([37]) These species belong to four categories: fodder plants, cereals, potatoes, oil and fibre plants.

([38]) The aspects of the agricultural exemption enshrined in Article 14 of the Basic Regulation are developed in more detail in Commission Regulation (EC) No 1768/95 of 24 July 1995 implementing rules on the agricultural exemption provided for in Article 14 (3) of Council Regulation (EC) No 2100/94 on Community plant variety rights.

([39]) *See* Article 2 of Commission Regulation (EC) No 1768/95 of 24 July 1995 implementing rules on the agricultural exemption provided for in Article 14 (3) of Council Regulation (EC) No 2100/94 on Community plant variety rights.

denomination by which such a variety is designated, by suing the infringer to enjoin the infringement or to pay reasonable compensation or both ([40]). Provisional protection is also recognised to the holder for the period between the publication of the application for a CPVR and the grant thereof, period in respect of which reasonable compensation may be claimed ([41]). The jurisdiction in legal actions relating to civil law claims concerning CPVR titles lies with the national courts of the Member States ([42]). The competent courts have jurisdiction in respect of infringements alleged to have been committed in any Member State ([43]).

As regards criminal law, Member States must take all appropriate measures to ensure that the same provisions are made applicable to penalise infringements of CPVRs as apply in the matter of infringements of corresponding national rights.

1.1.5 CPVO Statistics ([44])

Since its inception until 1 January 2022, the CPVO has processed applications for varieties belonging to more than 2000 different species, in total 75 500 applications for CPVRs, of which 59 400 have resulted in granted CPVR titles. There are currently about 29 600 CPVR titles in force. Figure 1.1 shows the flows of CPVR grants and terminations since 1996.

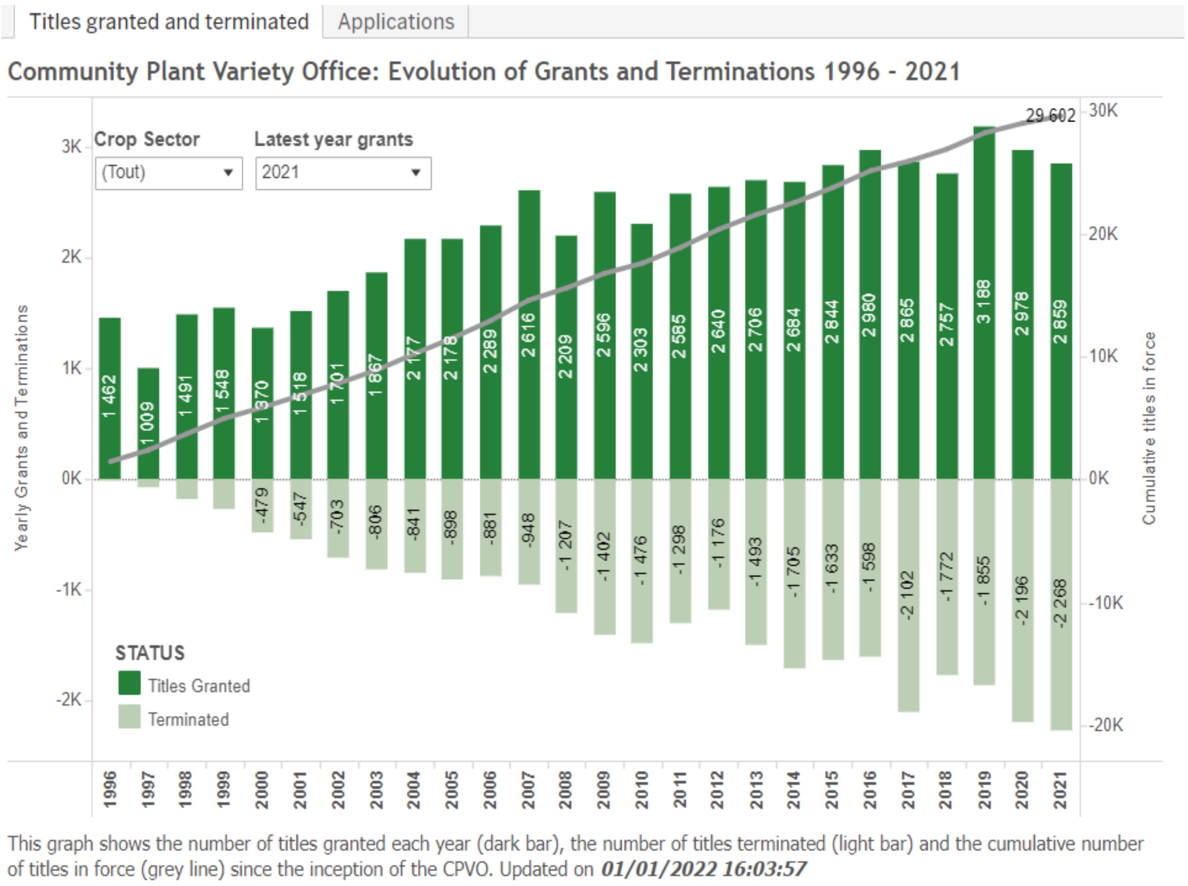
([40]) Article 94 of the Basic Regulation. The possibility to launch infringement actions is time-barred in accordance with the deadlines established in Article 96 of the Basic Regulation. In *José Cánovas Pardo*, the Court of Justice of the European Union provided an interpretation of Article 86 of the Basic Regulation [*see José Cánovas Pardo*, C-186/18, ECLI:EU:C:2021:849].

([41]) Article 95 of the Basic Regulation. In *Club de Variedades Vegetales Protegidas*, the CJEU clarified that this provisional protection must be regarded as a merely compensatory mechanism, as opposed to the proper enforcement remedy recognised in accordance with Article 94 of the Basic Regulation once the CPVR title has been granted [*see Club de Variedades Vegetales Protegidas* (C-176/18) [2019], ECLI:EU:C:2019:1131.

([42]) The Basic Regulation sets out some basic conditions regarding civil claims, infringements and jurisdiction (Articles 94 to 107 of the Basic Regulation. The provisions of Directive 2004/48/EC on the enforcement of IPRs are complementary to those concerning enforcement in the Basic Regulation.

([43]) Article 101 of the Basic Regulation. The competent courts must apply the rules of procedure of the relevant State governing the same type of action relating to corresponding national property rights (Article 103 of the Basic Regulation).

([44]) See section on "Statistics" on the CPVO website, available at https://cpvo.europa.eu/en/statistics.



Community Plant Variety Office: Evolution of Grants and Terminations 1996 - 2021

This graph shows the number of titles granted each year (dark bar), the number of titles terminated (light bar) and the cumulative number of titles in force (grey line) since the inception of the CPVO. Updated on ***01/01/2022 16:03:57***

Figure 1.1: Community Plant Variety Rights granted and terminated

Figure 1.2 shows the composition of applications among the major categories: agricultural crops, fruit, vegetables and ornamentals. Historically, more than half of applications have been for ornamentals, with agricultural crops accounting for about a quarter of applications, vegetables 15% and fruit 7%.

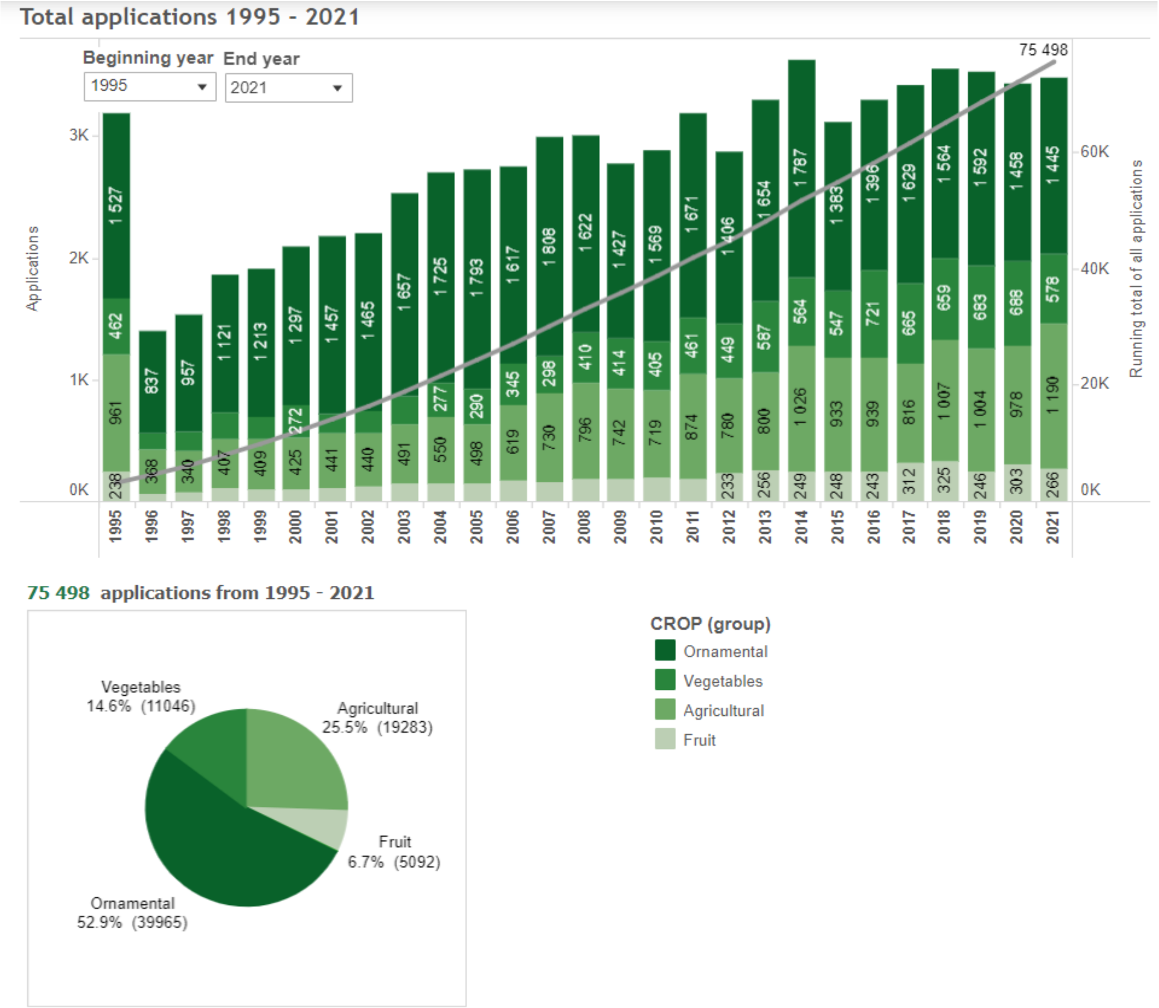


Figure 1.2: **CPVR applications by plant variety type**

1.1.6 CPVO databases

The CPVO maintains several databases, which are listed and described below.

- **CPVO applications and titles in force**: this database contains information on CPVO files and is made up of a client area for applicants, holders and representatives to consult and exchange electronically, and a public area allowing the consultation of public details of the

CPVO files (45). The information in this database corresponds to the two Official Registers held and maintained by the CPVO, containing data on applications for CPVRs and on CPVRs, respectively (46).

- **Variety Finder**: this database, which does not have an official character, contains information on registers of more than 60 countries with a general search tool (47). It also includes a similarity search tool to test the suitability of denominations (48).

- **PVR Case Law**: this database contains official judgements (and the corresponding summaries) in cases of PVR legal matters issued by national courts, as well as judgements of the Court of Justice of the European Union and legal decisions of the CPVO Board of Appeal. In addition, legal decisions relevant to the CPVR system issued by the Boards of Appeal of the European Union Intellectual Property Office and of the European Patent Office are also included (49).

1.2 The marketing of plant varieties in the EU internal market

The marketing of plant material in the EU internal market is governed by a set of legislations that is rather fragmented, attending to specific crop sectors. Following the outcome of a study carried out by the European Commission on request of the Council, this whole set of laws is currently undergoing

---

(45) The CPVO database "CPVO Applications and titles in force" is available on the CPVO website, at https://cpvoextranet.cpvo.europa.eu/mypvr/#!/en/publicsearch.

(46) See Article 87 of the Basic Regulation.

(47) More precisely, Variety Finder contains the following registers: Plant Breeders' Rights data; CPVRs' data published in the Official gazette of the CPVO (QZ PBR); National data of protected varieties (PBR); National listings data and common catalogue data (NLI); Some commercial registers (COM); EU registered trademarks for class 31 (EUTM); Plant Patents (PLP); and Other types of registers (codified as "ZZZ Other registers" or "REF reference List").

(48) The CPVO database "Variety Finder" is available on the CPVO website, at https://online.plantvarieties.eu/#/home.

(49) The CPVO database "PVR Case law" is available on the CPVO website, at https://cpvo.europa.eu/en/pvr-case-law-database.

a revision process with the aim of submitting a legislative proposal to the European Parliament and the Council by end of 2022 (50).

This section describes the systems currently in place for the authorisation of the marketing of agricultural plant species and vegetable seed species, of fruit species, and of vine propagating material.

1.2.1 The EU Common Catalogues for agricultural plant species and vegetable seed species

Council Directive 2002/53/EC of 13 June 2002 on the common catalogue of varieties of agricultural plant species, and Council Directive 2002/55/EC of 13 June 2002 on the marketing of vegetable seed (51) (jointly known as "Common Catalogue Directives") concern the authorisation for the marketing in the EU of varieties pertaining to agricultural and vegetable species, respectively.

According to these directives, the marketing of variety constituents (52) of agricultural and vegetable species is subject to the prior registration of those varieties in official registers of varieties of the EU Member States (53). Each Member holds one or more catalogues of the varieties officially accepted

---

(50) To learn more, see "Future of EU Rules on plant and forest reproductive material", available on the Commission's (DG SANTE) website, at https://ec.europa.eu/food/plants/plant-reproductive-material/legislation/future-eu-rules-plant-and-forest-reproductive-material_en.

(51) For vegetable material other than seed, a different directive applies, namely, Council Directive 2008/72/EC on the marketing of vegetable propagating and planting material other than seed.

(52) Based on the definition provided in Article 5(3) of the Basic Regulation, "variety constituents" can be defined as "a plant grouping consisting of entire plants or parts of plants as far as such parts are capable of producing entire plants". In simpler terms: "propagating material" such as seeds or vegetative parts intended for the production of specific plants.

(53) The aim underlying these directives is ensuring that the varieties that are authorised for marketing in the EU internal market fulfil the necessary requirements to be commercialised. For a variety to be accepted in the commercial catalogues, it must be distinctive, stable, and sufficiently uniform (DUS requirements). In the case of agricultural crops and within the scope of application of the Council Directive 2002/53, a variety must, in addition, be of "satisfactory value for cultivation and use" . This basically means that the variety must represent a clear "value", when compared to other existing varieties, either for cultivation or for uses which can be made of the crops or the products derived therefrom. In practice, the value of a variety for cultivation and use is assessed based on criteria such as the yield, resistance to harmful organisms, response to the environment, or quality characteristics of the variety. The acceptance of varieties by the national competent authorities based on all the above cited criteria must be based on the results of official technical examinations. *See* "Plant variety catalogues, databases & information systems", Food Safety, website of the Europan Commission, available at https://ec.europa.eu/food/plants/plant-reproductive-material/plant-variety-catalogues-databases-information-systems_fr.

for certification and marketing in its territory, and the varieties in those catalogues are subsequently entered into the so-called “EU Common Catalogues”. The EU Common Catalogues are maintained by the European Commission and compile the varieties listed in the national catalogues of the EU Member States. The varieties listed in the EU Common Catalogues for marketing in the territory of the EU are then published in the “C Series” of the *Official Journal of the European Union*. With effect from the publication in the *Official Journal of the European Union*, the seed of the authorised varieties can be freely marketed and is subject to no marketing restrictions relating to the variety (other than those explicitly stipulated in the directives).

This system of authorisation of the marketing of plant material is independent from the CPVR system as such, that is, a variety that is authorised for marketing can be commercialised regardless of whether or not it enjoys PVR protection (54).

1.2.2 FRUMATIS (Fruit Reproductive Material Information System)

For marketing of varieties of fruit species in the EU, the applicable EU legislation is Council Directive 2008/90/EC on the marketing of fruit plant propagating material and fruit plants intended for fruit production, and Commission Implementing Directive 2014/97/EU implementing Council Directive 2008/90/EC as regards the registration of suppliers and of varieties and the common list of varieties. These directives apply to the marketing of fruit plant propagating material and fruit plants intended for fruit production within the EU.

Based on the national variety registers of fruit genera and species, the European Commission maintains an EU variety register named “FRUMATIS” (Fruit Reproductive Material Information System) (55), the aim of which is to improve the traceability and promote the dissemination of information on fruit varieties that can be marketed in the EU.

---

(54) The registration of varieties in the common catalogues or commercial registers of varieties does not confer the variety holder under any circumstance an exclusive right for the protection of the variety. To be recognised such an exclusive right, a breeder must turn to the authorities competent for the granting of plant variety rights.

(55) FRUMATIS is available on the European Commission’s website at https://ec.europa.eu/frumatis/.

The FRUMATIS register contains the varieties with an official description as well as varieties with an officially recognised description, which must have been tested to verify that they meet the DUS requirements (56). In accordance with the indicated legislation, an application for a CPVR qualifies a variety to enter the FRUMATIS register and thus to be authorised for marketing in the EU.

1.2.3 Common catalogue of varieties of vine propagating material

For marketing of vine propagating material, the applicable legislation is Council Directive 68/193/EEC of 9 April 1968 on the marketing of material for the vegetative propagation of the vine.

Based on the national catalogues of vine varieties held by the EU Member States, the European Commission maintains a Common Catalogue of Vine Varieties to improve the traceability and promote the dissemination of information on the varieties that can be marketed in the EU.

Every variety that is listed in a national catalogue of vine varieties must have been tested to verify that it meets the DUS requirements (57).

---

(56) To learn more about FRUMATIS, see 'Plant variety catalogues, databases & information systems', Food Safety, website of the Europan Commission, available at https://ec.europa.eu/food/plants/plant-reproductive-material/plant-variety-catalogues-databases-information-systems_fr#forest-tree-species.

(57) To learn more about the Common catalogue of varieties of vine propagating material, *see* "Plant variety catalogues, databases & information systems", Food Safety, website of the European Commission, available at https://ec.europa.eu/food/plants/plant-reproductive-material/plant-variety-catalogues-databases-information-systems_fr#forest-tree-species.

2 Literature review

This chapter provides an overview of arguments in the relevant literature on the economic and environmental impact of the Plant Variety Right (PVR) system in the European Union (EU). How do relevant innovations economically affect farmers and growers in key sectors such as arable crops, fruit, vegetables, and ornamentals, as well as consumers of these products? How do these innovations affect the environmental aspects of production? What facts can be found in the literature about the extent to which the system supports a sustainable agriculture and food system? These are major questions to be answered in the literature review.

To ensure an effective critical analysis, this chapter will present both positive and negative impacts of the EU PVR system as found in the literature. The discussion of major findings from the literature will begin by identifying the driving forces behind plant breeding innovations in general, then look at policy demands at the international and EU levels, and continue with a brief discussion of how the EU seed market reacts to these demands. Next, the impact of EU plant variety protection (PVP) mechanisms will be discussed. Finally, specific positive and negative aspects of PVP will be discussed, and a very brief summary will be given.

2.1 Driving forces behind plant breeding innovations

2.1.1 General demand and actors creating the demand

To understand the economic and environmental effects of plant breeding and the protection of its intellectual output, or PVP, one must first understand the changing needs and demands of our global society regarding agricultural production. As FAO et al. (2009) put it:

> With regard to ‘responding to the challenges of a changing world’, it can be said that this is the raison d’être of plant breeding … The role of plant variety protection in responding to the challenges of a changing world is to provide a legal framework that encourages plant breeding.

With the onset of the Green Revolution after World War II, agricultural production almost tripled, guaranteeing the growing world population's supply of food, fibre, and other relevant commodities for their daily needs. This production increase was due to improved technologies in the field, mechanisation of the production chain, and an increased application of plant protection products (PPP) and fertiliser. New high-yield plant varieties also played an important role in this development (Bharadwaj, 2016).

However, this increase in agricultural production also caused adverse environmental effects, like the dependency of modern agricultural production on fossil fuels, soil degradation, groundwater contamination, declining biodiversity, and toxic hazards for humans and animals due to high levels of chemical input in industrialised agricultural production. Climate change poses an additional challenge to the agricultural sector, which is already suffering from more extreme weather events such as excessive rainfall, snow, drought, windstorms, and other natural disasters resulting from changing environmental conditions (Bharadwaj, 2016). In light of a growing world population, likely to number more than 10 billion people in 2050, the demand for food and raw material will continue to increase (van Dijk et al., 2021).

Alongside such predictions, supported by Noleppa and Cartsburg (2021), Stamp and Visser (2012) argue that to achieve food security by 2050, primary production must be almost doubled, or raised to at least 80 %, by increasing production per unit of land. If agriculture aims to double yields by 2050, this will mean that annual breeding progress must increase 2.5 times faster than the current rate (Stamp and Visser, 2012). However, the increasing demand for food from a growing world population will trigger an increase in food production that causes a much higher use of water as well as fertilisers and PPP, thereby posing ever-growing challenges to the environmental sustainability of agricultural production (58). These trends therefore affect farmers' expectations of farmers, the agricultural and food value chain, and consumers towards new plant varieties and, by extension, plant breeders.

Consequently, today's crop varieties must deliver a number of qualitative improvements. In short, these varieties must support low-input agriculture and better environmental protection in agriculture.

---

(58) Bharadwaj (2016), for instance, argues that the use of agricultural water between 2000 and 2050 will almost double. In addition, the author states that fertiliser consumption may increase by up to 40 %, and the use of PPP may almost triple.

This means that they should not only produce higher yields per hectare, due to the more limited availability of land, but should also have a higher degree of pest and disease resistance. This leads to lower PPP input and better adaptation to biotic as well as abiotic stresses (59) such as droughts and other weather events, helping to tackle the growing use of water in agricultural systems (Bharadwaj, 2016; Miflin, 2000).

Moreover, breeding programmes are already focusing on more effective fertiliser application. High fertiliser input in today's agricultural systems results in higher production costs for farmers and risks environmental pollution. Therefore, plant varieties with improved mineral nutrition traits can reduce crop production costs and lower the risk of pollution, while at the same time benefitting animal and human nutrition. In fact, nutrient-efficient plants will play a major role in addressing the problematic increase in total fertiliser use (Fageria et al., 2008).

At the same time, the risk of crop failure is increasing due to more severe and frequent fluctuations in the climate. Increasing temperatures, decreasing water availability, salinisation, and soil erosion, as well as changing pathogens in the form of plant diseases and/or pests, are just a few of the factors that will make agricultural production increasingly difficult. According to IPCC (2020), global warming has already led to shifts in climate zones in many world regions. Consequently, the seasonal activities of plant species and varieties have experienced changes in their ranges, abundance, and timing.

Especially in regions with a large amount of dryland, projections suggest that agricultural productivity will be reduced, since climate change and desertification decrease biodiversity and modify the plant species mix. The use of varieties and genetic improvement for heat and drought tolerance are therefore listed among the practices that contribute to climate change adaptation and mitigation in cropland (IPCC, 2020). Therefore, a key strategic objective of plant breeding will be to support an agricultural system in which natural ecosystem services and agricultural crop output are maintained simultaneously (Bharadwaj, 2016; Miflin, 2000).

---

(59) Biotic stress refers to damage done to an organism by another living organism. This can be due to plant diseases, pests, viruses, and/or nematodes. Abiotic stresses are environmental factors, such as drought, cold, salt, or metal, that negatively affect a living organism (van Elsen et al., 2013).

All the different demands are communicated along the supply chain, influencing farmers' choice to grow a given variety in their fields. However, depending on the specific crop sector, different actors have different levels of influence on the demand for specific plant varieties. According to Deloitte (2016), it is mainly wholesalers, processors, and manufacturers who directly or indirectly influence farmers and growers in their choice of which crops to grow and which product specifications to consider, often based on contractual relationships. These product specifications are then the basis on which the grower chooses a suitable plant variety that has the best chance of interacting as optimally as possible with the local environmental conditions. Plant breeders play a crucial role here, since they assist farmers and growers with variety selection.

Therefore, in the case of agricultural crops, varieties are tailored by plant breeders to the commodity market, and breeders – given the demands mentioned above – focus on developing varieties with a high yield potential and optimised yield stability due to selected traits that guarantee better resistance against biotic and abiotic stresses. For farmers, the goal is to ensure the highest economic return in terms of yield and the prevention of potential yield loss in their fields (van Elsen et al., 2013).

In the more specialised fruit and vegetable sector, the demands of end consumers have a bigger influence than in the arable sector, because most types of fruit and vegetables are directly sold to consumers as fresh products. Retailers or wholesalers define the desired varieties based on consumer testing and focus groups and request growers to cultivate them based on contractual relationships. A list of compliant varieties is then presented to the horticultural farmer, ensuring that these varieties meet the relevant criteria, such as size, shape, colour, texture, and sweetness. Retailers ask farmers and wholesalers for strict quality control and product handling to maximise crop yield and quality (Deloitte, 2016). Therefore, not only yield quantity, but numerous other qualitative criteria play a key role in fruit and vegetable production (van Elsen et al., 2013) (60).

In the ornamental crop sector, breeders' active marketing activities toward wholesalers and retailers notably play a much bigger role, including using variety names or tradenames as a means to create a demand for new varieties. In the case of niche or highly specialised crops, a partnership between

---

(60) Furthermore, Baldock and Hart (2021) stress that consumption patterns to improve public health and well-being will lead to a shift toward more plant-based products and changing demand for plant breeding in the fruit and vegetable sectors.

the breeder and a small number of specific growers and merchants can jointly present the new varieties and trademarked names to the market (Deloitte, 2016).

2.1.2 Specific requirements in the food and non-food sectors

The demands of the different actors described above are related to three key points that influence the requirements for new plant varieties in the food sector: food security, or the availability of food; food safety, or the assurance that food will not cause harm to the consumer; and food quality, or the characteristics of food acceptable to end consumers.

Especially under today's conditions of increasing climate change, high yields for maintaining and improving food security are closely related to other qualitative plant characteristics. Therefore, food security does not depend solely on high-yield crops, but also on high-quality crops with resistance to different forms of stress. Regarding food security, van Elsen et al. (2013) explain how a yield increase can be achieved not only via higher-yield varieties, but also via more stable varieties. Here, yield increase is generated through improved plant varieties that show better resistance, especially to biotic stress, which includes virus, fungus and insect damage, as well as nematode and bacterial attacks.

However, alongside biotic stress-resistant varieties, breeders are also working on varieties that have better resistance to abiotic stresses. These plant varieties would present yield stability under, for instance, salt stress, cold stress, drought stress, and stress due to high concentrations of metals in the soil. Another option for stabilising or increasing yields, in addition to the breeding of varieties with biotic- and abiotic-stress resistance, is the breeding of cultivars that have a better capacity to absorb fertilisers in the soil (van Elsen et al., 2013).

Next to food security, food safety also increases demands on plant breeding. To ensure food safety, reducing possible food threats in crops and raw materials has been a growing concern for the plant breeding sector. While heavy metals, PPP residues or other chemicals can pose risks to food safety, increasing contamination from highly concentrated mycotoxins in cereals is also an increasing risk (Redman and Noleppa, 2017). Here, producers must conform to the very high EU regulation standards, which form another relevant criterion in the selection of varieties. Breeders reacted to this demand by developing *Fusarium*-resistant or -tolerant plants (van Elsen et al., 2013). Another breeding objective related to food safety is to reduce and eliminate toxic molecules such as glycoalkaloids, glucosinolates, and trans-fatty acids from, for example, oilseed crops (van Elsen et al., 2013).

In addition, expectations regarding food quality are evolving. Current plant varieties must not only enable better food production, but must also have a higher nutritional content. In this respect, the development of tailor-made plant varieties with an improved ability to produce plant compounds that are beneficial for human health is acquiring a growing relevance in the plant breeding sector (van Elsen et al., 2013). Conventional breeding mainly seeks to improve traits with relevant economic value, with a focus on existing markets. By contrast, Pfeiffer and McClafferty (2007) describe so-called ‘biofortification’ as a plant breeding concept that aims to produce crops the value of which is measured in terms of the health outcome for the target population (61). This approach to plant breeding is a very valuable tool in addressing micronutrient malnutrition. So-called ‘hidden hunger’ is estimated to affect more than half of the world population, mainly women and children of pre-school age. To address these health conditions, biofortification combines conventional plant breeding with modern biotechnology to boost the micronutrient density of staple crops (Pfeiffer and McClafferty, 2007).

Changing demands for crop and especially food quality are also seen in the relevant criteria for variety registration. Food security and the related goal of increasing agricultural production have been the focus of the EU plant breeding regulatory framework since World War II. Relevant variety registration criteria have focused on yield and crop productivity and have therefore been included in the testing for Value for Cultivation and Use (VCU). According to van Elsen et al. (2013), national authorities have, since the turn of the millennium, started to slightly modify the criteria for variety registration in national catalogues to respond to new agricultural challenges – specifically food safety and environmental issues. Therefore, traits with better disease resistance, product composition, and/or nutrient profile have more influence on the plant variety composition in the market.

---

(61) For example, the benefits to human longevity of the respective daily intake of fruits and vegetables have been confirmed by Wang et al. (2021).

Alongside the concepts of food security, food safety and food quality, another driving force has emerged in recent decades to influence demands on the crop markets: the bio-based economy. The bio-based economy focuses not only on plant-based food and feed to produce food of animal origin, but also on non-food and non-feed production for bioenergy and bio-based chemicals (van Elsen et al., 2013). Van Elsen et al. argue that plant breeding is crucial in setting up bio-based production chains for a much broader spectrum. In particular, the development of new crops as alternative sources of biomass could have an important role in reducing the demand on food crops (van Elsen et al., 2013) (62).

As the abovementioned aspects show, the driving forces behind plant breeding innovations are numerous and complex. Changing environmental conditions, changing consumption patterns, and the changing needs of agricultural and bio-based production chains lead to new challenges for plant breeders and higher expectations from society in general as well as farmers and growers specifically. These expectations and demands are also expressed in a number of key policy documents that will be presented in the next section.

2.2 Policy demands at international and European levels

Plant breeding activities are increasingly debated in a political context. Blakeney (2012) states:

> [t]his disputation over the patenting of the products of plant breeding, as well as plant breeding methods themselves, emphasizes the increasingly politicized environment in which experimental botany is occurring.

The abovementioned needs and demands of society towards the agricultural and horticultural sectors, as well as those of the various value chains, are also reflected in a growing number of policy documents that formulate this demand in a strategic or even legally binding way. In the following analysis, only the impact on plant breeding and related PVP of the documents most relevant to the

---

(62) In this respect, ornamentals might also be considered part of the bio-based economy, but are not explicitly mentioned by the cited authors. In fact, with a focus on the non-food sector, the specific impact of the bioeconomy on the ornamentals sector still needs to be analysed in more detail by researchers.

EU will be discussed. These policies are the United Nations' (UN) Sustainable Development Goals (SDG) as well as the European Commission's (EC) Green Deal and its related Farm to Fork (F2F) and Biodiversity strategies.

2.2.1 Sustainable Development Goals

The creation of a sustainable agricultural system that functions in line with local environments is the key to several different SDGs, such as SDG 1 (no poverty), SDG 2 (zero hunger), SDG 8 (decent work and economic growth), SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land) (Hehanussa and Ilge, 2018). In cereal production, the contribution to food security and the achievement of the SDGs by the EU heavily depends on breeding new plant varieties that not only contribute to the competitiveness of its seed and agricultural sector, but also help to meet society's changing demands and to find solutions to sustainability challenges (Mariani, 2021). In particular, SDG 2.5 clearly formulates objectives that are relevant to plant breeding:

> [b]y 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.

This paragraph stresses the relevance of the genetic diversity of seeds and adequate access to and sharing of the benefits of existing genetic resources. However, it does not describe in detail how plant breeding could contribute to achieving the relevant SDGs.

2.2.2 Green Deal

To achieve the SDGs in an EU context, the EU's Green Deal and its Farm to Fork and Biodiversity strategies are central to the agenda in EU Member States (EC (2020a)). The Green Deal documents also describe the role of plant breeding in more detail. While the Communication does not specifically refer to plant breeding, it does refer to the role of innovative technologies, and plant breeding is certainly a key area of innovation in the agricultural sector (EC (2019)):

> [t]he EU needs to develop innovative ways to protect harvests from pests and diseases and to consider the potential role of new innovative techniques to improve the sustainability of the food system, while ensuring that they are safe.

The two European Green Deal documents that are chiefly relevant to the agricultural sector are a) the F2F strategy and b) the Biodiversity strategy; both will be addressed below.

The F2F strategy is described by the EC itself as central to achieving the UN's SDGs (EC (2020a)). In particular, it defines a new role for research and innovation as key drivers of a transition to sustainable, healthy, and inclusive food systems throughout the value chain. By demanding, among other things, a reduction in the use of PPP by 50 % and the use of fertilizer by 20 % by 2030, the F2F strategy sets very ambitious goals that will have strong implications for the production of arable crops, fruit, vegetables, and ornamentals. At the same time, the strategy recognises new threats to plant health posed by climate change (EC (2020a)):

> [f]armers need to have access to a range of quality seeds for plant varieties adapted to the pressure of climate change …

This stresses the key role that plant breeding will play in fulfilling the EU's ambition to implement its F2F strategy and to develop high-yield, pest-resistant and climate-resilient plant varieties (Mariani, 2021).

The Biodiversity strategy also stresses the links between genetic diversity and health benefits through more varied and nutritious diets, as well as the relevance of biodiversity to achieving the UN's SDGs (EC (2020b)). Accordingly, the use of traditional crop varieties is not only an important tool in fighting the decline in genetic diversity but also in ensuring a healthy and varied human diet. Against this background, the EC states in both the F2F and Biodiversity strategies its ambition to facilitate seed variety registration, including for organic farming, and to ensure that traditional and locally adapted varieties have easier access to the market (EC 2(020a); EC (2020b)).

The EC has further elaborated its ambition to update and better align current EU legislation on the production and marketing of plant reproduction material with the Green Deal (2021e) in its study on the EU's options for doing so. It particularly acknowledges the importance of seeds and other plant propagating material in achieving a more sustainable, productive, and diversified EU agriculture, their contribution to the Green Deal and the F2F strategy in providing sustainable food systems, and their key role in supporting plant breeders and farmers in addressing society's new demands:

> [n]ew and improved plant varieties are essential for farmers to ensure better productivity and improved food quality, for adaptation to climate change and for fighting plant pests with a reduced use of plant protection products. Plant breeding in general, and more in particular the development of new seed production as well as innovation in plant breeding play an important role in developing new plant varieties and thus are essential in contributing to seed diversity and food security.

At the same time, the EC (2021e) stresses the role of genetic diversity as the reservoir for plant breeding, thereby underlining the threat posed to the sector by an increasing loss of agrobiodiversity. The current legislation on the production and marketing of plant reproductive material (PRM) in the EU does not adequately support the Green Deal's objectives of creating and facilitating the use of plant varieties that can adapt to and mitigate the impact of climate change while also contributing to sustainable agri-food production, food security, and the protection of biodiversity.

Against this background, the EC (2021e) defines a number of measures that should be introduced, strengthened, and harmonised with regard to the Green Deal and the F2F strategy and their ambition to strengthen sustainable agriculture in the EU. These measures include (EC (2021e)): incorporating sustainability criteria into VCU testing; extending the scope of conservation varieties to other PRM sectors; facilitating the registration and marketing of conservation varieties and easing rules for variety mixtures; addressing the needs of organic varieties; taking actions to address *in situ* conservation and sustainable use of plant and forest genetic resources; and conserving and promoting agrobiodiversity and possible participatory testing schemes.

While this study specifically aims to assess the impact of the EU PVP system, the EC (2021e) stresses that plant breeding and other relevant EU seed regulations have a significant impact on the Green Deal's ambitious objectives. Moreover, it stresses that the political importance of plant variety production and marketing, as well as their contribution to sustainable EU agriculture, will increase in the coming years.

The relevance of plant breeding to the objectives of the F2F and Biodiversity strategies have been analysed in other studies that demonstrate their important contribution to agriculture that covers all the pillars of sustainability, namely social, environmental and economic sustainability.

- Noleppa and Cartsburg (2021), for instance, state: ‘In this respect, plant breeding and the two strategies can be considered congenial partners that depend on each other and can reinforce each other’s positive effects …’

- Golay and Batur (2021) stress their hope that the F2F strategy’s influence on future plant breeding will have a positive impact on biodiversity by strengthening the recognition of farmers’ traditional knowledge and their contribution to the conservation, sustainable use, and management of biodiversity in the field.

Clearly, policy factors, and especially the EU’s Green Deal, offer opportunities for plant breeding, but also pose challenges to be mastered by breeders in general and the EU PVR system in particular.

Before discussing in more detail arguments in the literature on the observable and potential economic and environmental effects of the EU PVP system, the following section will offer a short description of the EU seed market and its relevant legal foundations.

2.3 The EU seed market

In the historical perspective of industrialised countries, it has been seed multipliers and farmers who have demanded seed laws that protect them from the negative effects of dishonest and speculative seed suppliers. Therefore, compulsory variety registration was developed in Europe during the first half of the 20th century. The objective was to overcome the lack of clarity regarding names and varietal identities. As a response to these calls for more transparency on the seed market, a first variety register was created in 1905 by the German Agricultural Society. Such seed registers became mandatory with the enactment of national seed laws in many European countries in the 1940s

(Winge, 2012) and remain a good basis for the description of the EU seed market, as will be shown below.

Most recently, DG GROW (2016) has estimated that there are around 7 200 European breeding and seed companies (63). When compared to other world regions, therefore, the European plant breeding sector may still be characterised as diverse, with companies applying very different business models: some companies concentrate on research and development (R&D) and breeding, while others focus on seed production and marketing.

There are also differences in the business models with regard to crop portfolios, with broad ranges from a few crop varieties up to large multi-crop portfolios.

The market shares of crops differ significantly according to data listed by DG GROW (2016). Almost 40 % of the total estimated value of the EU seed market, worth approximately EUR 7 billion excluding seed multiplication for export, belongs to the sector of small-grain cereals, while maize represents more than 25 %, seed potatoes 14 %, vegetables 11 %, oil crops and fibre crops 4 %, sugar beet 4 %, and grasses 3 %.

Several different factors are crucial for the prevalence of this diverse seed market, and especially in supporting the funding of breeding activities in small- and medium-sized enterprises (SME) and their innovation in the sector: shared risk models or in-kind contributions of public research; public-private partnerships; financial instruments for product development and demonstration plants; and cost-efficiency of the seed registration system (64). Apart from cost-efficiency, transparent processes for accessing intellectual property rights are crucial, according to ETP (2015).

The numbers of available varieties on the EU seed market differ notably among sectors. As illustrated by Figure 2.1, based on information from the CPVO (2022), the number of Community PVRs granted in the past 25 years totals almost 60 000, but shares by sector vary from 30 960 in the ornamental

---

(63) A more recent statistical survey is not available.

(64) This includes registration costs for new varieties as well as any other cost incurred in preparing an application for a variety to enter the EU seed market (ETP, 2015).

crop sector down to 3 079 in the fruit crop sector. However, only approximately half (29 600 as of January 2022) of these titles are currently in force.

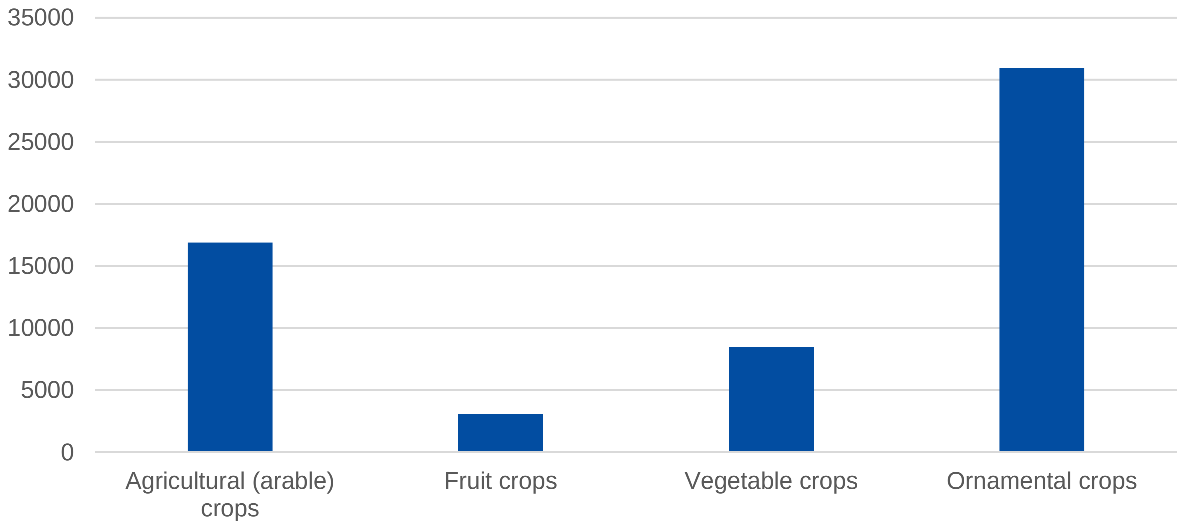


Figure 2.1. Number of Community plant variety rights granted since 1996

DG Grow (2016) argues that the reason for the differing numbers of protective rights in the various crop sectors may be explained by diverging demands on different crops. More explicitly, it states:

> [c]onsumer or farmer demands for new characteristics might be very different from crop to crop and thus the breeding goals and the kind of traits breeders are looking for in the different segments of plant breeding are varying to a large extent. While in cereals for example yield is the key characteristic to breed for, in many vegetable crops disease resistances are the traits breeders are working for. This is part of the reasons why there are more patents in certain crops than in others.

A considerable number of these rights are still in effect. In fact, the number of PVRs in force has been continuously increasing since the introduction of the PVP system at the EU level. This is shown in Figure 2.2, with a specific focus on the most recent 5 years, and is based on information obtained from CPVO (2022). In the light of this development, DG GROW (2016) argues that the constant flow of new varieties into the EU market would diminish fears that the reduced variability of starting material will result in fewer and less diverse varieties. A key variable that regulates the range of EU plant breeders' access to new varieties is the institutional setting of the EU seed market. This institutional setting, and its potential effects on the economic and environmental profitability of new varieties as discussed in the literature, will be presented in more detail in the following section.

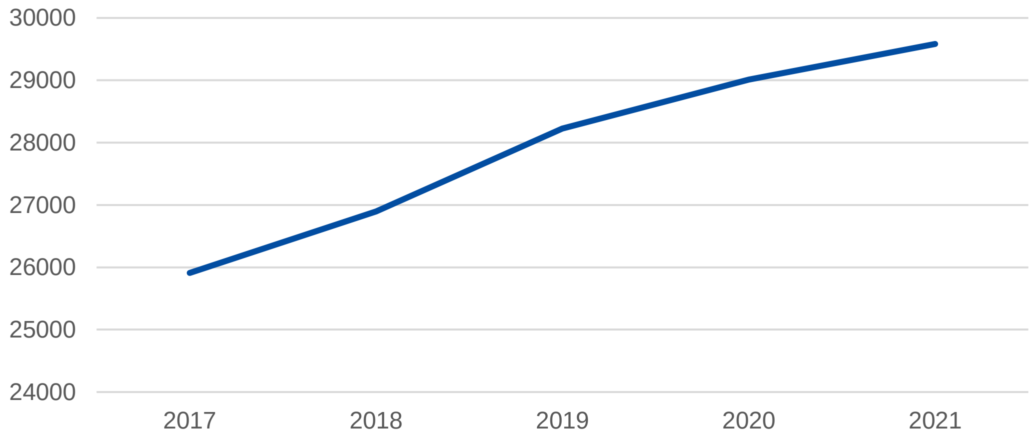


Figure 2.2. Evolution of the number of Community plant variety rights in force between 2017 and 2021

2.4 The EU plant variety protection system and EU legislation on plant reproductive material

There are two major legal systems established in the EU to support plant variety development: the Plant Variety Protection system at the EU level, as well as EU legislation on plant reproductive material. Both systems influence how the development and marketing of new varieties are finally reflected in crop planting. A purely separate economic evaluation of the EU PVP system that ignores its interdependence with EU seed legislation is not possible. Therefore, for the sake of transparency, both systems and some of their specific legal aspects, as well as relevant legal exemptions for farmers and/or growers, are presented here to afford a better understanding of the interaction between the EU PVP system and EU seed legislation.

2.4.1 Impact of the European Plant Variety Protection system

In accordance with the ‘social contract’ theory of intellectual property rights, plant breeders can protect their innovative varieties and obtain a return on their investment in developing them. This encourages them to continue investing in their plant breeding programmes and ultimately results in benefits for farmers, consumers, and society as a whole. In this respect, the aim of the PVP system is clarified at the international or global level in the mission statement of the International Union for the Protection of New Varieties of Plants (UPOV):

> [t]o provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of society.

Therefore, innovation in plant breeding lies at the heart of the international PVP system. While the term ‘society’ refers to the full range of actors that profit from such innovation, FAO et al. (2009) stress that seed growers and seed-consuming farmers in particular deliver the benefits of new varieties to society. Consequently, while innovation in plant varieties is certainly essential to economic development as a whole and goes beyond the agricultural sector, in line with the focus of this study it should be stressed that growers and farmers are the first beneficiaries of new varieties, because they offer a higher income through improved yields, improved quality and the opening-up of new market possibilities (FAO et al., 2009).

The EU has been a party to the UPOV Convention since 29 June 2005. Consequently, the EU PVP Basic Regulation is modelled on the text of the UPOV Convention. However, some EU Member States are not currently parties to the Convention (i.e. Greece, Cyprus, Luxembourg, and Malta), while others have only ratified the UPOV 78 Act (i.e. Italy and Portugal). Nevertheless, all property titles awarded by the Community Plant Variety Office (CPVO) following the requirements of the EU PVP Regulation are valid and enforceable throughout the territory of the EU, that is, in all EU Member States (Golay and Batur, 2021).

Considering the major research question of this study – 'what are the economic and environmental effects expected from the EU PVP system, with a specific focus on growers and farmers?' – EC (2020d) lists the expected positive effects of an EU PVP system in line with the UPOV Convention as follows:

- increased breeding activities,
- greater availability of improved varieties,
- increased quantity of new varieties,
- diversification of types of breeders (e.g. private breeders and researchers),
- support for the development of new industry sectors,
- improved access to foreign plant varieties and enhanced domestic breeding programmes,
- development of industry competitiveness on foreign markets ([65]).

These assumptions have been analysed and discussed in UPOV (2005) and were also summarised and presented in FAO et al (2009). Both sources stress that the impact of a PVP must be evaluated in its regional setting and will also vary according to different crops. As UPOV (2005) puts it:

> [i]t is apparent that the impact of PVP will vary country-by-country and crop-by-crop …

([65]) See also Mariani (2020).

Against this background, UPOV's (2005) findings concerning the impact of PVP can be summarised as follows (see also FAO et al., 2009).

- Increased breeding activity may be related to the introduction of the UPOV system, which has resulted in the creation of new types of breeders, including private firms, researchers, and farmer-breeders.
- In addition, new partnerships including public-private cooperation have been linked to the introduction of a PVP system.
- The introduction of a PVP system is also associated with the development of new, protected varieties as indicated by the individual country studies. This is specifically advantageous for growers, farmers, industries, and consumers.
- Regarding the ornamental sector, UPOV membership has furthermore been associated with an increase in the number of varieties introduced by foreign breeders.
- PVP also improves the development of international markets, strengthening competitiveness in foreign markets due to the increasing number of new and improved plant varieties.
- Finally, PVP under UPOV membership enhances access to foreign plant varieties and consequently leads to an increase in technology transfer. Access is ensured here by the specific feature of the breeders' exemption.

However, UPOV (2005) also stresses that it is not the role of a PVP system to regulate the marketplace and that the impact of a PVP system can unfold independently of such market regulation. More precisely,

> [f]or that reason, it was considered essential that any study on the impact of PVP systems should not be intertwined with consideration of systems regulating production, certification and marketing. It is further noted that the success of PVP does not depend on the existence of systems regulating production, certification and marketing, as

> illustrated by the success of PVP in sectors which are not regulated by systems such as national listing and seed certification.

Therefore, Article 18 of the UPOV 91 Act explicitly stresses that breeders' rights are independent of any measure taken by a member to regulate the production, certification, and marketing of material of varieties, as well as the import or export of this material within its territory (UPOV, 2005). At the same time, a variety that is authorised for marketing can be commercialised regardless of whether it enjoys PVR protection, and vice versa. This demonstrates the independence of the two different legal regimes – the EU PVP system and EU seed legislation.

This leads to the question of how the impact of a PVP system can be measured independently of other factors, especially seed legislation on marketing. UPOV (2005) argues that this impact can chiefly be measured by the number of applications and titles received under the respective regime.

> Therefore, the fact that, in general, breeders do not pursue protection on varieties which are unlikely to be successful or where protection is not important, would seem to offer further confirmation that the number of applications and titles are good indicators of the benefits of a PVP system.

Here, the explicit argument by UPOV (2005) as well as FAO et al. (2009) is that the overall impact of an effective PVP system can be evaluated by the number of new varieties, represented by the number of applications and titles granted.

Therefore, the mere prevalence of protected varieties proves the importance of the PVP system. Since the key function of a PVP system is to encourage the breeding of new varieties, it may be argued that in a market economy plant breeders will protect those varieties that they expect to be commercially successful. Moreover, in light of the significant cost of obtaining protection, UPOV (2005) argues that breeders will only accept these costs if, first, they believe protection is necessary, and, second, the variety is expected to have real market value. Among farmers and growers, although in most cases a royalty payment is expected, the uptake of new and protected varieties is in general rather strong. This demonstrates the high expectations among farmers and growers in terms of the agronomic benefits and innovation of these new varieties.

As explained in UPOV (2005) and FAO et al (2009), following the introduction of a PVP system, farmers have a choice between protected and non-protected varieties. Therefore, the suitability of protected varieties may be assessed on economic or other grounds. An additional aspect that increases the competitiveness of growers and farmers lies in the attraction of a high number of variety applications by foreign (non-resident) breeders through the introduction of a PVP system, especially within the ornamental sector, thereby bringing successful new varieties to the domestic market of a given territory (UPOV (2005)).

While UPOV (2005) focuses on the impact of the EU PVP system in a number of different countries, it can also be shown that, in addition to an increase in the total number of applications to the CPVO, the number of necessary applications for equivalent or wider protection within the EU could be substantially reduced to breeders. Due to the simplified administrative procedure (as opposed to a situation where an application would have to be filed in each country and its respective language), breeders located outside the territory of the EU would have an additional incentive to protect their varieties in this region. Consequently, not only breeders but also growers and farmers could access the best varieties produced by breeders throughout UPOV member territories (UPOV (2005)) (66).

A report by the EC (2020d) regarding the protection and enforcement of intellectual property rights in third countries refers to the number of UPOV publications in assessing the impact of the introduction of PVP in different countries. In particular, it argues:

> [f]or example, a study on Vietnam estimated the impact on the country's Gross Domestic Product (GDP) at around USD 5 billion per year, which is more than 2.5 % of its national GDP. The Kenya Plant Health Inspectorate Service (KEPHIS) explained how the UPOV system enabled Kenya to develop a USD 500 million cut-flower industry that employs 500 000 Kenyans. In Australia, 95 % of wheat breeding programmes were funded by the public sector before accession to the UPOV 1991 Act; following UPOV membership, wheat breeding is completely funded by the private sector due to the income generated

---

(66) For example, these positive effects of a simplified administrative procedure and wider geographical impact of a PVP title became visible when Poland joined the EU. A clear decrease in the number of applications in the Polish national PVP system has been observed from 2002 onwards. According to UPOV (2005), this was a reaction of breeders to the upcoming opportunities provided under the EU PVP system, which offers the clear advantage of extending protection to all EU Member States.

by End Point Royalties. In Canada, the ratification of the UPOV 1991 Act has resulted in new investments from the private sector in wheat breeding, foreign-domestic partnership in cereal breeding, development of a public-private-producer breeding consortium to fund Canadian Prairie Spring Red Wheat (CPSR) and an increased number of new plant variety rights applications.

The advantages deriving from the introduction of a PVP system are further emphasised by the disadvantages that the absence of such a system entails. The EC (2020d) stresses that the absence of a PVP system in countries outside the EU leads to diverse problems for European stakeholders, especially for SMEs. The main concerns raised by stakeholders according to the EC (2020d) can be summarised as follows:

- absence of effective plant variety legislation,
- non-functioning administrative procedures,
- lack of an effective system for royalty collection and enforcement,
- high enforcement costs,
- weak or non-existent border enforcement,
- inaccessible dispute resolution mechanisms.

When a country possesses a PVP system, but the system is not effectively enforced, the relevant actors in the breeding sector encounter several challenges. Negative effects related to the infringement of PVR include the delayed introduction of new and improved varieties and reductions in investment in plant breeding, as well as in the quality of seeds, plants, and fresh products. This in turn endangers agricultural productivity (EC (2020d)). Clearly, the protection and enforcement of PVRs constitutes an intrinsic part of a well-functioning PVP system. From an EU perspective, therefore, a number of different variables can be identified that affect the overall impact of the EU PVP system in a given context and with regard to the different actors involved.

In any case, efficient enforcement of the PVP system, including the effective collection of royalties to financially reward seed innovations, is key. This argument is also made by Curtis and Nilsson (2012). The authors carried out a study for the International Seed Federation (ISF) on the collection systems for wheat royalties in 14 territories. The results show an extremely wide range of efficiency in the collection of potential royalties, ranging from 20 % (in Canada) to more than 94 % (in Sweden).

The authors summarise their findings as follows: '[t]he results indicate that the presence of a *sui generis* IP protection system for plant varieties is not enough, on its own, to assure efficient collection of royalties as many countries with such legislation in place do not demonstrate efficient collection procedures'.

The authors also argue that enforcement tools, including mandatory certification procedures, seed laws and strong government support, are crucial for an effective PVP system, as demonstrated by the most efficient territories identified, such as Sweden and the United Kingdom. They argue in particular that different enforcement systems, such as contractual collection systems and mandatory reporting systems, can work equally well. At the same time, the authors argue that the most efficient royalty collection occurs in territories where remuneration for farm-saved seed is collected in addition to certified seed royalties.

Indeed, the issue of farm-saved seed is sensitive when discussing the economic impact of a PVP system on growers and farmers. For example, the EC (2020d) argues that various third countries have introduced broad restrictions on breeders' rights by allowing farmers to sell or exchange seeds among themselves for commercial purposes. Such exceptions have been held to undermine the PVP system and to hinder the propagation and marketing of new species in the countries concerned (EC (2020d)).

Since the aspect of farm-saved seed is related to one of the central political debates over the impact of PVP systems, the issue of the agricultural exemption (also known as the farmers' exemption) as a legal exemption to the scope of the EU PVR system will briefly be discussed below.

2.4.2 Impact of the agricultural exemption

According to the OECD (2018), all seed was originally farm-saved. Today, there are in theory three different sources for the seed used by farmers: (1) farm-saved seed, (2) seed purchased from public plant breeders, and (3) seed purchased from the private sector. However, the seed sector has shifted over the last 150 years from its publicly dominated character to a situation where – especially in high-income countries – the private sector dominates global markets.

Despite the privatisation of the seed sector in most parts of the world, the so-called 'farmers' exemption', 'farmers' privilege' or 'agricultural exemption' (67) is still one of the key legal features of the *sui generis* PVP system at a global scale. It is also the provision that stimulates the greatest controversy (Eaton, 2002). It is therefore noteworthy that the agricultural exemption still prevails in most countries and their PVP systems. Especially in the context of developing countries, the topic is discussed and framed from a human rights perspective, with a special focus on the right to food and the rights of farmers (e.g. Correa, 2017; Correa et al., 2015; Peschard, 2021; Esquinas-Alcázar, 2005; Hehanussa and Ilge, 2018; Tansey and Rajotte, 2008; Golay and Batur, 2021; Golay and Bessa, 2019; Cabrera Medaglia et al., 2019; Oxfam, 2018; Oxfam Plantum and Euroseeds, 2019).

From the perspective of farmers' rights, seed legislation is often perceived as a barrier, since requirements for registration and certification may not adequately address the specific characteristics of traditional varieties. Winge (2012) stresses that these challenges are not only relevant to developing but also to industrialised countries. Referring to the UN Special Rapporteur on the Right to Food, Winge (2012) particularly argues that all states should ensure that their seed legislation does not exclude farmers' varieties, and that these varieties should be included in national lists authorising the marketing of varieties in the respective jurisdiction ('national lists').

The extent of the agricultural exemption has changed over time under the UPOV. The UPOV Convention of 1961 and the UPOV 78 Act still permitted farmers to sell or exchange seeds with other farmers for propagation purposes. Governments were therefore allowed to permit seed saving by farmers of varieties covered under PVR, as long as it was not for the production of seed for marketing. The interpretation of this agricultural exemption, however, changed with the UPOV 91 Act. This limited farmers' seed-saving privilege, first, to private and non-commercial use by the farmer of protected varieties 'on their own holdings' (e.g. subsistence farming) and secondly 'within reasonable limits and subject to the safeguarding of the legitimate interests of the breeder'.

It is up to each country to interpret in detail the expression 'the legitimate interest of the breeder'. However, the UPOV argues that such exceptions should be limited to certain crops. Ornamentals, fruit, and vegetables that are asexually propagated horticulture crops should not be covered

---

(67) In the following the term 'agricultural exemption' will be used most frequently, since this is the terminology enshrined in CPVO legislation.

(Blakeney, 2012; OECD, 2018; Peschard, 2021). According to Peschard (2021), this limitation of the agricultural exemption is one of the central reasons for the decision by a number of countries not to join the UPOV 91 Act, since this would not allow them the required scope of flexibility to adapt their PVP system to the needs of their peasant and small-scale farmers.

How, then, can the impact of the agricultural exemption be evaluated from an economic perspective? The literature discusses two different economic effects of the agricultural exemption. The first is the question of whether this exemption reduces incentives for innovation and R&D. The second is the potential positive or negative effect of this exemption on famers themselves.

Opinions in the literature diverge. Certain studies from the 1990s argue that the agricultural exemption does not decrease incentives to invest in the development or improvement of new varieties. Other studies demonstrate the exemption’s negative effects on the economic benefits of new varieties (e.g., Moschini and Yerokhin, 2007). Eaton (2002) particularly stresses this ambivalent relationship between the PVP and the agricultural exemption, in which the latter might represent a clear disincentive to investment in breeding and thus a source of inefficiency within the PVP system. On the other hand, the same author argues that greater local experimentation by farmer-breeders (understood as persons who act as farmers and breeders simultaneously) was made possible by farm-saved seed or the so-called agricultural exemption. Moreover, the author acknowledges that restrictions on the agricultural exemption would have negative effects on resource-scarce farmers.

Against this background, Eaton (2002) as well as Coomes et al. (2015) locate the debate over farm-saved seed based on the agricultural exemption mainly within the context of developing countries. However, the authors stress that EU farmers are also engaged in this debate about access to and control over their internal seed exchange system. Indeed, the implementation of the agricultural exemption or farmers’ privilege is also discussed in the context of industrialised countries (e.g. Oxfam, 2018), where the implementation varies widely from country to country. As Oxfam (2018) summarises: ‘[s]ome countries, like France, have no “farmers’ privilege” at all (with the exception, in France, of soft wheat), while the USA until the 1990s allowed farmers even to sell protected seed to other farmers.’

Regarding the EU PVP system, Romero and Correa (2021) argue that the agricultural exemption is strong under EU law and provides a kind of best-practice example for developing countries. In particular, the authors state:

> [t]he establishment of the farmer's privilege under the European patent regime is an example that developing countries should consider in their own legal systems. Importantly, although it has been deemed debatable whether the farmers' privilege can legitimately be provided for consistently with Article 30 of the TRIPS Agreement, the compatibility of the EU exception has never been questioned in the context of the dispute settlement system of the World Trade Organization.

The authors also note that under the EU legal framework no remuneration is required under the agricultural exemption for certain crops and categories of farmers, and suggest that developing countries could extend this treatment to all farmers and crops when implementing the agricultural exemption under their patent or PVP laws. Furthermore, certain other conditions could be included in the relevant national legislation, such as a legal provision under which the farmers' privilege cannot be derogated by private agreement. In this way, farmers would not be burdened with payments that could potentially threaten their livelihood and food security (Romero and Correa, 2021).

To what extent farm-saved seed is relevant in the European seed market is a matter of debate. In an analysis by the OECD (2018), it was shown that farm-saved seed continued to play an essential part in the cultivation of certain crops. The total global share of farm-saved seed in Europe, for instance, was estimated by the OECD (2018) at somewhere between 20 % and 30 % 5 years ago, as seen in Figure 2.3.

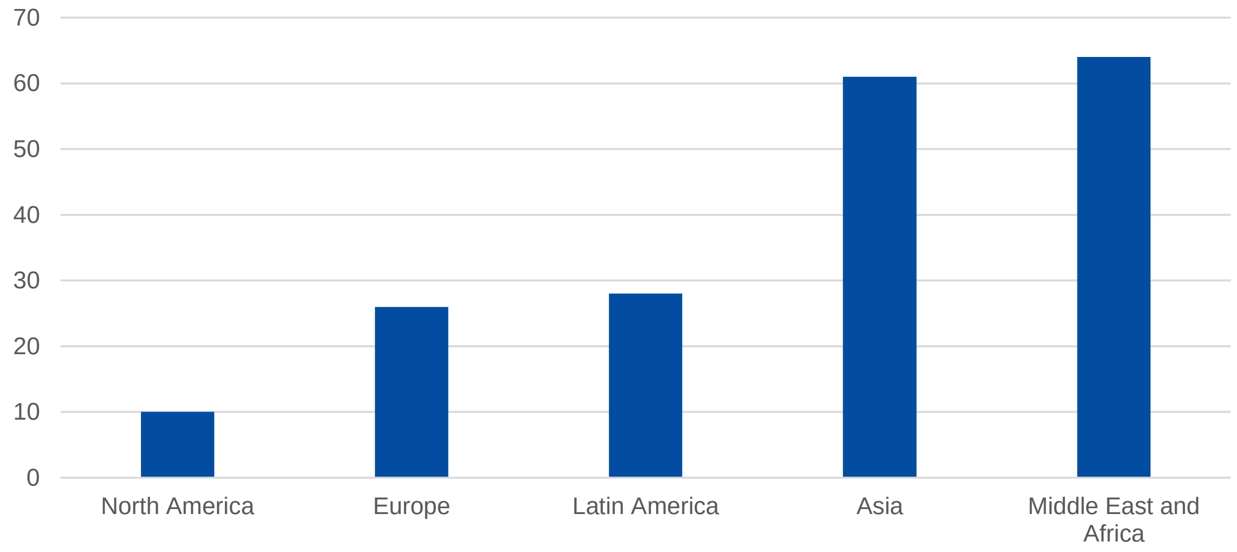


Figure 2.3. Farm-saved seed as a percentage of total seed, 2016

In a study for the CPVO, Rutz (2008) aims to assess the legal situation of farm-saved seed in the various EU Member States and the application of agreements between breeders (or collecting societies) and farmers, as well as to estimate the usage of farm-saved seed in the production of different crops. The author concludes that the overall agricultural structure, the size of the farm, and the tradition of using farm-saved seed, all have a higher impact on the usage of farm-saved seed when compared to a system of remuneration. The study also presents data on the usage of farm-saved seed in the production of several crops in various Member States. At the time of the analysis in 2008, these shares were very diverse across EU Member States and crops.

In an analysis of the EU PVP system's impact on cereals, Mariani (2020) confirms that farm-saved seed still plays an important role in high-income countries as well. However, its relevance differs between crops: the rate of farm-saved seed on the global seed market in the case of wheat, barley, and rice is estimated at around 60 %. For maize, it is estimated at less than 20 %. It must be stressed that the agricultural exemption in the EU PVP system only covers certain crops, mainly fodder plants, cereals, and potatoes. While stressing the public interest behind the rationale of the agricultural exemption for farm-saved seed in the context of the EU PVP system, Mariani (2020) therefore questions its effect on agricultural production:

> [h]owever, one might wonder whether the FSS practice, when it is carried on by 'industrial farmers' and it does not concern conservation varieties, is consistent with the rationale behind the EU seed legislation, whose purpose is fostering agricultural production by providing quality seed. Seed is a decisive input that dramatically affects agricultural production, and this is why seed producers are required to comply with specific registration and certification requirements. The spread of an uncontrolled FSS practice goes beyond the economic loss of the farmers: they concern farming sustainability and the quantity and quality of feed and food production.

Beyond this, Mariani (2020) stresses that the agricultural exemption still faces enforcement problems, since rights holders – and especially SMEs – have difficulty monitoring farmers' compliance, for example in paying the required amount of royalties. Due to a lack of access to information regarding farm-saved seed, breeders cannot be sure about the dimension of infringement of their protected varieties. Therefore, to ensure that the EU PVP system can fulfil its role as an 'innovation booster' in plant breeding, access to information on farm-saved seed should be facilitated for breeders, and more effective rules for royalty collection should be established. As Mariani (2020) states: 'Indeed, the weak enforcement possibilities in the case of FSS hinder a return on investment through royalty payments, discouraging innovation.' Furthermore, the dedication of a significant part of EU jurisprudence on PVP matters to the implementation of the agricultural exemption, and more precisely to its monitoring by breeders, shows that this issue has considerable relevance for the functioning of the EU PVP system from the perspective of breeders as well as farmers and other relevant actors (68). Therefore, the economic consequences of FSS systems for the different actors involved should be evaluated in more detail in future research.

This short overview of the existing literature on the economic effects of the agricultural exemption in general, and for the EU PVP system in particular, shows that this area is still a work in progress. As Coomes et al. (2015) state, it seems that the functioning of farmers' seed networks and their

---

(68) The relevant case law includes: 10/04/2003, C-305/00, Schulin, EU:C:2003:218; 14/10/2004, C-336/02, Brangewitz, EU:C:2004:622; 17/10/2019, C-239/18, Saagut-Treuhandverwaltung, EU:C:2019:869.

economic contribution to agricultural output is still beset by a lack of research, especially in terms of interdisciplinary evaluations of their social, institutional, and economic functioning.

2.4.3 Impact of the EU PRM legislation, with special emphasis on the VCU criteria

Clearly, the legal environment of seed in the EU is complex. Not all its aspects can be fully considered in the following evaluation. However, at least one very specific legal aspect must be taken into account when discussing the economic and environmental effects of the EU PVP system: EU seed legislation. As Mariani (2021) explains: '… the rationale of Community PVP is to stimulate the breeding and development of new varieties, whereas the EU seed legislation has the purpose of ensuring the free marketing of quality seeds and propagating material throughout the EU territory.'

A key aspect of both the Community PVP and EU seed legislation are the Distinctness, Uniformity and Stability (DUS) criteria. These must be fulfilled for the registration of a new (novel) variety as well as registration in the national lists and/or Common Catalogues (for more details, see Subsection 3.2.1). In both cases, a variety must be identifiable by a suitable denomination that becomes its generic designation.

However, there are two criteria that are only relevant to one or other of the two legal systems.

- For PVP to be granted, a variety must meet the criterion of 'novelty' – understood, however, as commercial novelty, not absolute novelty as under patent law.

- For a variety to be authorised for marketing under the relevant EU seed marketing legislation, the abovementioned VCU criteria must be fulfilled as an additional requirement. However, this only applies to agricultural crops. Therefore, before the relevant variety is released to the market, breeders must demonstrate its merit. VCU is assessed in several years of official testing (or under official control) and data collection in several locations. VCU testing procedures vary among Member States (EC (2021e); Brown, 2008).

In any case, the VCU criteria are not required when granting PVP under the EU system. Table 2.1, based on Mariani (2021), illustrates the different requirements of the two distinct legal regimes – the Community PVP and EU seed legislation.

Community PVP	**EU seed legislation**
Novelty	
Distinctness	Distinctness
Uniformity	Uniformity
Stability	Stability
Variety denomination	Variety denomination
	Value for cultivation and use (*only relevant for agricultural crops*)

Table 2.1. Requirements for PVP and seed marketing in the EU

Nevertheless, EU seed legislation as a legal regime is closely linked to the EU PVP system, and both regimes influence one another. For the purposes of this study, it is especially relevant that EU seed legislation affects the effectiveness of the PVP system, as Mariani (2020) explains:

> Innovation in cereal varieties is conditioned by the EU legislation on the marketing of seeds. The seed legislation has a relevant impact on innovation because it establishes the requirements a variety shall meet in order to be marketed in the EU and, in doing so, it influences the effectiveness of the Community plant variety protection. The Community plant variety protection regime relies on the idea that an intellectual property right over a new plant variety entitles the breeder to claim for remuneration against the use of their new material: in this sense, the grant of a financial reward is a great incentive to stimulate further innovation. However, in order to obtain this financial reward, the protected material has to be marketed: this is when seed legislation ties its provisions with Community plant variety protection. It is indeed the seed legislation to regulate the marketing of reproductive material in the EU, therefore the requirements set out by the seed legislation impact the Community plant variety protection effectiveness. Consequently, it should be understood what the extent of such an impact is.

From a grower's and/or farmer's perspective, it can be argued that the VCU requirements have even more concrete value in the field because they provide information on the plant's agronomic traits, which are directly related to crop production and performance. In this respect, Mariani (2021) states:

> The purpose of this provision is to filter only those varieties having a specific economic value for farmers. It should ensure that only the finest varieties of agricultural species are registered, thus stimulating the breeding of improved crops. Therefore, only the varieties with a significant economic value are placed on the market, and this is deemed necessary to obtain a high-quality harvest to the greatest degree possible.

Therefore, the VCU requirements may especially contribute to the economic impact on growers, since they ensure that the variety is going to perform in the field according to expected yield potentials and other relevant factors. Although VCU requirements only apply to agricultural crops, their impact on economic performance in that sector should not be underestimated. Due to its relevance for farmers, it is not surprising that today's EU VCU testing system originates in the testing system of farmers' associations. The aim was to check if the claims of seed suppliers held up on the ground. Today, however, the tests focus on local adaptation potential and product value in terms of yield (e.g. Winge, 2012; Mariani, 2021; EC (2021e)).

However, while the VCU criteria positively affect farmers' agricultural productivity, they have been criticised for certain shortcomings. The EC (2021e) lists a number of such shortcomings, which are mainly due to the absence of sustainability criteria and the unharmonised implementation of the VCU criteria across EU Member States. Moreover, the EC (2021) stresses that the specific needs of organic varieties are not adequately addressed by differences in VCU testing for organic varieties in EU Member States (69). This would discourage the breeding of varieties specially adapted to organic cultivation and could thus threaten the F2F strategy's aim of placing 25 % of agricultural land under organic farming by 2030.

---

(69) See Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products. In accordance with Article 3(19), "organic variety suitable for organic production" should mean "a variety as defined in Article 5(2) of Regulation (EC) No 2100/94 which: (a) is characterised by a high level of genetic and phenotypical diversity between individual reproductive units; and (b) results from organic breeding activities as referred in Regulation (EU) 2018/848".

This study focuses solely on the economic and environmental impacts of the EU PVP system. The specific contribution of EU seed legislation and its VCU criteria will not form part of the analysis, nor can their effects be fully excluded from the analysis, because a large share of crops protected under a Community PVR have also been subject to EU seed legislation. Therefore, in presenting EU seed legislation and its links with the EU PVP system, it should be acknowledged that seed markets and their functioning are strongly dependent on a number of other factors and legal regimes apart from the EU PVP system, which also affect economic performance and the environmental contributions of seeds to the sustainability of different farming systems (OECD, 2018).

2.5 Pros and cons of plant variety protection

The debate regarding the economic, social-welfare and other effects of intellectual property rights (IPR) takes place at the intersection of law, economics, and social science. In particular, the scientific debate focuses on the economic impacts of IPRs, as stated by Bostyn (2013): ‘Intellectual property systems do not live in a vacuum, but are instruments of economic regulation, and also influence economic behaviour.’

The production and dissemination of knowledge will be essential to solving the enormous challenges that climate change, environmental sustainability, and other global issues pose to the constantly growing global community (Henry and Stiglitz, 2010). The key question is whether the global IPR regime will support or hinder the production of knowledge in the long run. The EC (2020d) stresses IPRs’ role in its economy as an intellectual booster:

> Efficient, well-designed and balanced intellectual property (IP) systems are a key lever to promote investment in innovation and growth. Intellectual Property Rights (IPRs) are one of the principal means through which companies, creators and inventors generate returns on their investment in innovation and creativity.

While this assumption regarding IPRs’ positive impact on society is certainly shared by many in science, politics, and business, the effects of the IPR protection of plants are extremely controversial (Bostyn, 2013). Plant breeding is closely linked to several human rights issues, such as the right to food. It also entails complicated questions of the public good, as expressed in more general debates over the patentability of nature and, more specifically, plant germ plasm resources as a ‘common heritage of mankind' (Bjørnstad, 2016). Therefore, the debate takes place in a politicised context and involves many relevant parties, perspectives and interests. As Metzger and Zech (2020) put it: '[f]rom an academic perspective, the plant sector is like a magnifying glass for problems of technology-driven IP rights in general.'

In terms of the main arguments found in the literature for or against the PVP system and PVR enforcement based on their economic and ecological effects, the following functional aspects are important.

- R&D and innovation function: this first aspect of the debate involves the question of whether PVP generates more innovation in plant breeding and thereby results in better varieties for farmers and producers.

- Diversity function: the second aspect of the debate focuses on the environment and asks how a PVP system affects biodiversity within agricultural and horticultural production schemes, and how the biodiversity effects of PVPs affect climate change adaptation in the field or the production site.

- Market functions: the third aspect of the debate concerns the PVP system's contribution to a functional crop market that allows farmers and PRM users access to the varieties best suited to their specific economic interests and local environment at a reasonable cost.

All three aspects are treated very differently by different sources. Researchers have posed a number of questions regarding the economic and environmental effects of PVP systems – with sometimes contradictory outcomes, as summarised by Heald and Chapman (2011):

> Butler and Marion (1985) concluded that the PVPA has stimulated the development of new varieties of soybean and wheat but were unable to conclude that total R&D activity had increased. Knudson and Pray … also found that PVP has effects on private sector research priorities and breeding activity but did not relate PVP to yields. Likewise, Srinivasan (2004) and Diaz (2002) have found that the impact of Plant Breeders Rights in Europe has been to increase incentives for private firms to develop new varieties, but they too did not relate the effect of those new varieties on yields.

Clearly, PVP systems may have diverging effects. It will be insightful to have a closer look at the debate before introducing new calculations and results. Some of the main arguments found in the literature concerning PVP systems’ impact on farmers (as the main beneficiaries of PRM) and on the environment will be examined below from the three abovementioned functional perspectives – (1) R&D and innovation, (2) diversity, and (3) the market.

2.5.1 R&D and innovation

The literature presents varying arguments regarding the PVP system’s impact on innovation. To be clear, this overview will not focus on the PVP system’s effect on innovation per se, but rather on the effects of potentially increased innovation and its contribution to farmers and society at large.

First, the role of farmers and breeders within the plant breeding innovation cycle is diverse and has changed over time, as highlighted by Metzger and Zech (2020):

> [f]or thousands of years, farmers were the main innovators with regard to crops, vegetables and other agricultural plants. Their role changed fundamentally in the 19th century when the division of work between specialised breeders and farmers as mere growers evolved. Today most farmers grow plants based on seeds that have been developed and marketed by others. As such, farmers are a major group of users of innovative plants. Still, farmers play an important role in the cultivation of traditional varieties and as such support biodiversity. Conflicts between farmers and breeders arise when farmers use harvest from previous cycles of propagation for resowing.

Particular attention must be paid to farmers’ ambiguous position in a modern agricultural society based on the division of labour. On the one hand, they are the main beneficiaries or even ‘consumers’ of innovation in plant breeding. On the other, they have been ‘custodians of biodiversity’ (Correa, 2017). What does the literature say about the impact of R&D and innovation in the EU PVP system on farmers and breeders?

A number of arguments in the literature clearly stress the positive effects of an innovation-friendly PVP system. The first argument regarding PVP's benefits for farmers is made by DG GROW (2016):

> [a]t the end of a long and complicated innovation process lies the added value for the farmer in form of a new and improved variety. The final aim of plant breeding is to continuously adapt quality, diversity, and performance to human needs. Hence, the needs of farmers who multiply these crops on their fields are obviously the heart of the breeding process.

DG GROW (2016) further stresses that although new breeding techniques and complex molecular technologies based on innovative development in chemistry, biology, genetics, and information technology support the breeding process, the basic construct of crossing and selection still prevails, which is a time-consuming and high-investment business with a long-term goal. Therefore, this whole process – which ultimately aims to benefit the farmer and PRM user – can only continue if the breeder has access to the widest possible genetic diversity. As DG GROW (2016) states: '[i]f access to plant genetic material is not ensured, a negative effect on plant breeding and on the genetic diversity of new plant varieties is feared.' From this perspective, the EU PVP system and its breeders' exemption ensures that investment in this long-term innovation process yields a positive return.

A similar argument is presented by the European Technology Platform Plants for the Future (ETP) (2015), which also characterises plant-based innovation as a time-consuming and high-risk business. On average, plant breeders invest up to 20 % of their annual turnover in further R&D, one of the highest rates of investment among research-intensive businesses. To ensure that this investment pays off, a strong and effective PVP system is needed that also offers the necessary access to protected material for future research and breeding objectives. According to the ETP (2015), a transparent approach to intellectual property management and access to plant genetic resources are key to ensuring competitiveness for European farmers and sustainability for society at large in the long term. In addition, the ETP (2015) argues: 'Innovation is the underpinning principle of the legislation. In the future, an innovation-friendly approach to seed marketing legislation must be maintained so that farmers may benefit from continuous innovation, and breeders from a level playing-field.' Again, the benefits for farmers of such a protection system are stressed, but with a specific focus on seed marketing legislation.

Another factor contributing to positive economic returns for farmers is their integration along with customers into the innovation process. The ETP (2015) particularly stresses that such a participatory approach could help stakeholders understand expected consumer trends and novel uses as well as farmers' expectations regarding which crops to grow, where, and how. The horticultural sector presents a positive example in this regard.

The arguments of DG GROW (2016) and the ETP (2015) are also supported by Metzger and Zech (2020), who point out that the results of complex and long-term innovation by plant breeders can easily be multiplied at low cost, dramatically lowering profits for plant breeders so that their social contribution is no longer reflected in their return on investment:

> [t]he result may be that the future innovation process is retarded. States can avoid those undesirable effects of the non-rivalrous character of public goods by the creation of intellectual property rights, namely patents and plant variety rights in the different areas of plant innovation. Such intellectual property protection, whatever the exact character and shape may be, seems at least necessary to prevent competition through blunt imitation of innovative plants.

Interestingly, Metzger and Zech (2020) also note a peculiar double function – this time concerning plant breeders rather than farmers. On the one hand, breeders contribute to plant innovation by developing new varieties ('upstream innovation'). On the other, this is done using existing varieties ('downstream innovation'). These dependencies and links between the 'old' and 'new' work of plant breeders must be protected by a specialised organisation of access and sharing of benefits. This puts an emphasis on legal rules facilitating follow-on innovation in the plant sector (Metzger and Zech, 2020).

The EU PVP system's contribution to innovation in plant breeding has been analysed by Mariani (2020). This study aims to investigate the effectiveness of Community PVP in fostering innovation and stimulating plant breeding in the EU with a focus on cereal varieties (70). The study's conclusion is rather straightforward (Mariani, 2020):

> [i]n view of the legal outcomes and empirical findings, the answer is a 'qualified yes': this means that the Community plant variety protection has a significant role in fostering innovation in cereal varieties, however this role should be strengthened by the EU legislator in accordance with the aforesaid recommendations.

Mariani (2020) also stresses that farmers' demand is the driving force behind this innovation, highlighting their position as beneficiaries of the plant breeding innovation cycle.

Another concrete conclusion regarding the EU PVP system's positive effect on innovation is made by GHK Consulting (2011) in evaluating the Community PVR acquis. The system is defined as a 'stimulating tool' for innovation. More precisely, the study states:

> [t]he CPVR acquis has stimulated breeding and development and facilitated and improved the protection of new plant varieties in the EU … CPVR applications and rights granted are increasing over time … Stakeholders indicate that the CPVR acquis facilitates EU protection of new plant varieties and stimulates plant breeding.

GHK Consulting (2011) explains that the contribution of the CPVR acquis on EU agriculture is difficult to define due to inconsistent seed market data as well as different trends across sectors. However, referring to other literature, it is also argued that the positive innovation effects attributed to PVP, especially due to the breeders' exemption, are plausible. Moreover, a survey by GHK Consulting (2011) in EU Member States involving stakeholders from the plant breeding sector confirms that the CPVR acquis encourages and stimulates plant-breeding activities while facilitating continual investment and reinvestment in the development of new varieties. According to GHK Consulting (2011), most growers confirm stimulating breeding effects.

---

(70) The study examines the effectiveness of the PVP system both in itself and in connection with EU seed legislation. Therefore, the VCU criteria and their effects on innovation in arable crops are explicitly part of the investigation.

Various reasons are given in the literature that qualify the argument for PVP systems as innovation boosters. However, there is an inherent contradiction in the application of intellectual property rights and their fostering of innovation, as Moschini and Yerokhin (2007) note: '[t]he exclusivity conferred to inventors by intellectual property rights (IPRs) provides *ex ante* incentives for innovation, but the resulting market power entails an *ex post* inefficiency (because it limits use of the innovation)'. The authors argue that, as a consequence of these different *ex ante* and *ex post* effects of IPR, special research exemptions (like the breeders' exemption in PVP) have different economic effects depending on the costs of a given research project:

- when R&D costs are high, the *ex ante* incentive for private firms to innovate is weakened by the breeders' exemption, since the high cost of investment in innovation is unlikely to pay off;

- however, if R&D costs are low in comparison to the potential return on innovation, the breeders' exemption increases the likelihood that more innovators will enter the market, with follow-up inventions that widen this innovation's economic potential, even for society at large.

It may be concluded that the EU PVP system's impact, including its intrinsic legal breeders' exemption, depends on the specific ratio between R&D costs and the expected return on investment of a given innovation.

Other arguments question IPR's positive impact on plant genetic resources. While the studies cited above argue that there is a clear causality between PVP and innovation in plant breeding, Correa et al. (2015) conclude that the current PVP system under UPOV has clear disadvantages for developing countries in which the food systems still depend significantly on farmer-managed seed systems. If one acknowledges farmers' seed systems as equally important sources of innovation and agricultural diversity, this chain of innovation based on the free exchange of seeds between farmers may be said to be interrupted rather than furthered by a PVP system (UN, 2009). Consequently, the system should be regulated so that innovations leading to improved varieties and to new plant resources benefit all farmers, including the most vulnerable and marginalised among them (UN, 2009). However, the UN (2009) also stresses the relevance of both the breeders' and the agricultural exemption, which are both legal cornerstones of the EU PVP. Indeed, the UN (2009) encourages the strengthening of research exemptions, namely the breeders' exemption, in protection systems, as well as ensuring and promoting innovation in both the commercial and the farmers' seed system.

2.5.2 Diversity function

The debate surrounding the EU PVP system's effect on innovation is closely linked to the question of how and to what extent PVP contributes to crop and variety diversity. As Mariani (2021) emphasises, innovation will be crucial in reacting to trends in genetic erosion and the related risk of crop loss due to uniform crops' low degree of resistance to pests, pathogens, and environmental hazards. Van Elsen et al. (2013) further point out that a high degree of diversity among different crops must be maintained to satisfy the demand for different raw materials and ingredients along the supply chain as well as consumers' expectations concerning the different taste, nutrition, and convenience of fresh and processed food. However, it is complex to assess the amount of genetic erosion among existing agricultural varieties. GHK Consulting (2011) presents two important starting points for the debate over agricultural diversity and genetic erosion.

- First, there is a certain amount of evidence that agricultural diversity has reduced over time. Older and less popular varieties have been replaced by newer ones for which demand is higher. However, there is no clear documentation about the extent of this reduction.

- There is no clear meaning of the term 'genetic erosion'. Genetic erosion can happen at the allele (71) level, in the sense of a reduction in allelic evenness and richness, and at the variety level (e.g. mutations).

Therefore, different conclusions on PVP's role may be reached depending on how genetic diversity in agriculture is measured. The critical position in this debate is that PVP encourages plant breeders to promote only protected varieties. Consequently, fewer varieties are grown, leading to a loss of agricultural biodiversity. The contrary view is that PVP functions as an incentive to breed new

---

(71) The term allele denotes the variant of a given gene. In genetics it is normal for genes to show deviations or diversity: all alleles together make up the set of genetic information that defines a gene.

varieties, thereby promoting genetic diversity (GHK Consulting, 2011). Some arguments linked to these opposing positions will be presented below.

Concerning the links between PVP and agricultural biodiversity, GHK Consulting (2011) stresses that the number of varieties is not a safe indicator of genetic diversity. At the same time, the authors downplay assumptions about PVP's negative effect on agricultural biodiversity:

> … agricultural biodiversity is difficult to measure, as the most common means of assessing erosion is by counting named varieties, which do not directly correspond to genetic diversity. Little evidence, however, has been found to link the loss in agricultural biodiversity to the availability of plant variety rights.

GHK Consulting (2011) critically reflects on the assumption that increased revenues for breeders through PVR would automatically have positive effects on agricultural biodiversity. First, PVR would initially encourage breeding programmes to develop new varieties. This, however, would not be the same as the preservation of plant genetic resources. Second, even if more varieties were available for farmers to plant and for breeders to use in the development of additional varieties, GHK Consulting (2011) argues that the link between this increased availability of new varieties and positive effects on agricultural biodiversity has never been formally investigated.

Furthermore, GHK Consulting (2011) cites a meta-analysis of more than 40 publications, focusing on Europe and North America, and the impact on genetic variation of the replacement of landraces by modern cultivars:

> The results suggest an increase in genetic variation at the allele level, but a decrease in the number of marketed varieties.

Although the meta-analysis only covers the 20th century,

> … one could conclude that plant variety rights do not necessarily have a negative impact on genetic variation at the allele level.

Discussing the results of the same meta-analysis, the OECD (2018) highlights the study's conclusion

> … that farmers' choices among crops and varieties play an important role in determining the overall diversity in the field.

Citing other studies of plant breeding's impact on genetic diversity within a crop, the OECD (2018) shows that further research is still needed.

> Regarding the impact of modern plant breeding, Van de Wouw et al. (2010) concluded that it was not clear whether an active breeding programme contributes to maintaining a high level of diversity or on the other hand leads to genetic erosion, while Rauf et al. (2010) argued that the introduction of hybrids led to a reduction of genetic diversity. Fu (2015) has argued that a reduction in genetic diversity is plausible, but that the impact of modern plant breeding on genetic diversity is still poorly understood from both the empirical and the theoretical point of view.

The question of how diversity can be measured is also discussed by Eaton (2002). The author questions the claim that PVP contributes to the spread of monocultures and thus the erosion of genetic diversity on farms. Eaton (2002) argues that:

> … development of improved varieties contributes to increasing the genetic diversity in parent lines of the predominant varieties in particular areas.

Consequently, PVP's predicted effects on genetic diversity may vary depending on the scale of diversity under investigation: intraspecific genetic diversity, species diversity, or ecosystem diversity (Eaton, 2002).

Heald and Chapman (2011), for their part, argue that there is no direct or simplistic causality between patent law and an increase or decrease in crop diversity, as often suggested by various scientific disciplines.

> We also settle the debate between economists and social scientists on the role that patent law might play in destroying or enhancing crop diversity. Both sides appear to be

> wrong. Our data show that patent law has not reduced crop diversity, nor has it significantly contributed to the introduction of new varieties.

The authors argue that their data undermines the diversity erosion thesis, which has been the leading narrative in the debate over intellectual property's impact on diversity. They state that 70 % of the varieties commercially available in 2004 were not available in 1981, meaning that during this period more than half of the varietal stream has changed its content. Consequently, they conclude that the existing plant breeding system does not diminish crop diversity.

In contrast to these optimistic findings on the relationship between PVP and agricultural biodiversity, other studies offer more critical arguments. For example, Esquinas-Alcázar (2005) argues that recently – and especially since the beginning of the Green Revolution – a loss of diversity in plant genetic resources has taken place. The author particularly argues that IPRs' proliferation and expanded scope, as well as an increasing number of national laws, restrict access to and use of plant genetic resources for food and agriculture as well as related biotechnologies. As the author puts it:

> [n]o one can deny the importance of improving crop varieties and increasing production. However, in our eagerness to do this we might be robbing nature of genetic diversity – a safety mechanism that took millions of years to build up.

Consequently, the author stresses the importance of conserving and using plant genetic resources on a large scale, including traditional farmers' varieties and wild relatives of cultivated plants.

Golay and Bessa (2019) also emphasise the key role of traditional farmers' varieties in the preservation of genetic crop varieties. They address from a different angle the question of the EU PVR system's contribution to farmers' economic success, arguing that relevant EU seed legislation does not value the economic contribution of farmers' seed systems in terms of output for agricultural biodiversity. While acknowledging the contribution of the normative EU legal framework on seeds to the steady development of European industrial agriculture and the consequent growth in food production, the authors argue that these laws and regulations aggravate the genetic erosion of seed diversity by neglecting farmers' systems and traditional knowledge. According to the authors, the result is an undesirable increase in crop uniformity and *ex situ* seed banks.

GHK Consulting (2011) discusses two further points that are crucial for the EU PVP system and its impact on genetic diversity:

- minimum distance (72) resulting from the distinctness requirement of the DUS criteria,
- marketing of traditionally grown varieties and landraces.

To ensure that breeders can protect themselves against copies and close derivations, a minimum distance provision is included in the system. To fulfil the distinctness requirement, a measurable minimum distance between relevant plant varieties must be proved. GHK Consulting (2011) states that the minimum distance of certain indicators has significantly decreased over time between varieties: ‘One potential outcome of decreasing minimum distances between plant varieties is a reduction in the genetic diversity of available plant materials and ultimately a reduction in plant genetic resources.’

The second aspect concerns the challenges of marketing traditionally grown varieties and landraces. GHK Consulting (2011) argues that, due to the restrictions in the national lists and the Common Catalogue, these special varieties and landraces face problems in conforming to the DUS criteria and consequently cannot be listed and marketed within the EU. Directives No 2008/62/EC and No 2009/145/EC (73) address the potential loss of varieties on the market by allowing the marketing of agricultural and vegetable landraces and varieties without official examination if they meet certain minimum standards (GHK Consulting, 2011).

---

(72) GHK Consulting (2011) defines minimum distance as follows: ‘… the measurable distance between two plant varieties that is necessary for those varieties to be considered distinct under CPVR DUS rules. The minimum distance provision in the Basic Regulation is intended to ensure that breeders can protect their rights against copies and too-close derivations.’

(73) Commission Directive No 2008/62/EC of 20 June 2008 providing for certain derogations for acceptance of agricultural landraces and varieties which are naturally adapted to the local and regional conditions and threatened by genetic erosion and for marketing of seed and seed potatoes of those landraces and varieties and Commission Directive No 2009/145/EC of 26 November 2009 providing for certain derogations, for acceptance of vegetable landraces and varieties which have been traditionally grown in particular localities and regions and are threatened by genetic erosion and of vegetable varieties with no intrinsic value for commercial crop production but developed for growing under particular conditions and for marketing of seed of those landraces and varieties.

Mariani (2021) also mentions the DUS criteria's impact on genetic diversity among and within plant varieties:

> More specifically, the uniformity requirement has been the subject of severe criticism because it refers exclusively to the needs of conventional agriculture, encouraging dangerous homogeneity and discouraging the conservation and sustainable use of agricultural genetic diversity.

Furthermore, Mariani emphasises that organic seeds will play a much larger role in EU agriculture if the F2F's target of increasing the share of organic agriculture to 25 % by 2030 is achieved (see also EC, 2020b). The current VCU requirements, however, are considered an obstacle for the selection of varieties adapted to organic farming (Mariani, 2021), since low-input varieties are ignored by VCU trials and the marketing of heterogeneous groupings of plants is discouraged under the uniformity requirement. The DUS criteria's potential negative impact is also raised by Brown (2008).

> Often statutory authorities determine the degree of variability that is allowed in a cultivar. For example, all inbred cultivars released in the European Community countries, Canada or Australia must comply to set standards set for distinctness, uniformity and stability (DUS) in Statutory National Variety Trials. In these cases, it is common to have almost total homogeneity and homozygosity in released inbred cultivars.

According to Brown (2008), this homogeneity conflicts with some breeders' ambition to ensure a high level of heterogeneity for their developed varieties for the sake of a greater ability to function and react in different environments and under changing cultivation conditions.

Winge (2012) also discusses the DUS criteria's effects on genetic diversity and the role of heterogeneous landraces on fields in the EU, mainly in connection with EU seed legislation. The author cites several studies that support the claim that the test's central demand for uniformity has reduced genetic diversity in the EU and the number of varieties available to farmers. The restriction of access to seeds that do not pass the DUS test is a particular obstacle to on-farm conservation and participatory plant breeding (Winge, 2012).

Referring to the answers of some participants in a broad stakeholder consultation on the Community acquis regarding the marketing of seed and plant propagation material, Winge (2012) reports concerns that the distinctness requirement restricts the marketing of gradual improvements of the same variety. Moreover, it limits the marketing of adaptive populations with a much more diverse, and much less uniform and stable, genetic basis. These populations are mainly formed of conservation varieties, amateur varieties, and landraces. In addition, the overemphasis of uniformity under EU seed legislation conflicts with breeders' ambitions to use diversity to address plant diseases and marginal growing conditions (Winge, 2012).

Another author analysing the relationship between plant breeding and genetic diversity is Louwaars (2018). The author argues that several variables are responsible for driving the plant breeding system towards more uniformity, during the modernisation phase (currently in Africa and Asia, in Europe between 1880 and 1980), including mechanisation and its need for more uniform crops, as well as large-scale processing of agricultural produce. However, plant breeding itself could also be characterised by a natural desire for uniform traits (Louwaars, 2018): 'Plant breeding intends to combine as many "favourable traits" as possible in one genotype or maximise the presence of such traits in one population. Diversity within the variety is thus reduced'. However, in Europe crop diversity has been on the increase in recent decades for many crops due to plant breeding, and therefore partly attributable to the PVR and CPVR system.

The relevance of greater genetic diversity in farmers' management of their fields is also stressed by Lamichhane et al. (2018). The authors argue that Integrated Pest Management (IPM), a concept that combines diverse existing chemical and non-chemical crop protection strategies, is becoming increasingly relevant for sustainable agriculture. The deployment of cultivar resistance combined with agronomic practices is essential to avoid chemical treatments as far as possible.

Varieties chosen for IPM must have relevant diversified populations to suit crop diversification through rotation, intercropping and mixed cropping. To address this need, as well as additional demand from society and consumers for safe and secure food based on environmental-friendly and sustainable agriculture, breeding for IPM could benefit both conventional and organic farming. As

Lamichhane et al. argue, current EU legislation has so far supported genetically uniform varieties. This, however, does not fulfil the needs of IPM breeding. The authors conclude:

> … there will be a need for legal changes to the DUS paradigm if such breeding approaches have to be adopted in practical future breeding programs.

Several of the arguments presented above do not solely concern the EU PVP system, but also those of other jurisdictions as well as the closely related EU seed legislation regime. Moreover, the EC's recent ambition to facilitate the use of traditional crop and breed varieties to reverse the decline of genetic diversity will first of all involve a reform of European seed law, as expressed in the EU Biodiversity strategy (EC (2020b)):

> [t]he Commission is considering the revision of marketing rules for traditional crop varieties in order to contribute to their conservation and sustainable use. The Commission will also take measures to facilitate the registration of seed varieties, including for organic farming, and to ensure easier market access for traditional and locally adapted varieties.

This policy ambition is also emphasised in EC (2021e). Current seed legislation does not support the implementation of the EU Biodiversity strategy or the ambition to ensure the conservation and sustainable use of plant genetic resources. Therefore, EC (2021e) stresses the need for the following measures introducing, strengthening, and harmonising aspects of the law in line with the European Green Deal as well as the F2F and Biodiversity strategies:

- including sustainability criteria in VCU testing,
- extending the scope of conservation varieties to other plant reproductive material sectors,
- facilitating registration and marketing of conservation varieties, lighter rules for variety mixtures,
- addressing the needs of organic varieties, in situ conservation and sustainable use of plant and forest genetic resources,

- conserving and promoting agrobiodiversity and possible participatory testing schemes.

However, these policy ambitions are likely also to affect the EU PVP system, which shares at least the DUS criteria with EU seed legislation. In the past 15 years, the so-called ‘one key, several doors’ principle has been discussed and demanded by plant breeding organisations in an attempt to increase the European seed system’s efficiency and to avoid the duplication of costs for breeders and national authorities. The idea is that only one official DUS report would be needed for national listing, national PVP and EU PVP (Mariani, 2020). Therefore, attempts to strengthen genetic diversity through DUS testing should not be discussed solely with regard to EU seed legislation or the EU PVP system, but rather should take a holistic policy approach to guarantee farmers the most appropriate genetic and crop diversity.

2.5.3 Market function

This section will discuss additional points found in the literature concerning the PVP system’s effect on the EU seed market in more general terms. It will also briefly present more qualitative effects that may economically influence sustainable agriculture in the EU.

Discussing the EU PVP system’s effect on the functioning of the EU seed market, GHK Consulting (2011) states that it is difficult to define the Community PVR acquis’ contribution to the development of EU agriculture: ‘There is little evidence that directly links the CPVR acquis to the development of EU agriculture. Determining the current condition of the seed sector itself is a challenge due to inconsistent data sources and different views on trends across sectors.’ The study nevertheless states that the system may have positive effects on citizens and consumers in the EU. It lists the following examples of potential direct and indirect effects:

- higher yields (i.e. producing more food on less land),

- greater sustainability (e.g. fewer inputs such as pesticides and fertilisers),

- better adaptation to climate conditions (i.e. adaptation to climate change),

- higher nutritional value and content,
- cheaper, healthier, and higher-quality food,
- incentives for higher competitiveness of the EU in the agricultural sector, creating greater economic prosperity, food security, and environmental sustainability.

GHK Consulting (2011) confirms that the global seed market has grown steadily since the 1970s and that the EU seed market alone makes up around 25 % of the international seed market. Furthermore, in looking at data for specific EU Member States, the study indicates that Germany, France, and the Netherlands – the three Member States with the highest number of granted Community PVRs – also have comparatively high EU exports of crops and products derived from crops (67 %). In addition, it points out the correlation between the largest EU seed trading Member States, in particular Germany and France, and the number of Community PVRs granted.

The EU PVP system's effect on the different sectors of the EU seed market depends on the competitiveness of the crop sectors. This is particularly emphasised by Mariani (2020): 'The choice of a specific crop sector, upon which the effectiveness of Community plant variety protection is investigated, lies on the idea that each crop sector has its own peculiarities, and the protection regime may not foster innovation equally in each crop sector.' Variations in competitiveness between different crop sectors are also addressed, for instance, by Martínez López (2021), who argues that the return on long-term investment is crucial for crops with long variety development cycles. This supports the argument that PVRs are an essential economic tool for plant breeding. However, Clark et al. (2012) add that commercialisation opportunities and marketing strategies are also important for the success of a new variety. They specifically argue that a new variety (in the fruit sector) currently achieves its economic relevance not only through its level of protection, but also how well it is marketed. In fact, commercialisation arrangements – especially for fruits and vegetables – have become much more complex, particularly since the 'globalisation of the perishable food trade' has increased the competition. Breeders must therefore consider a complex set of variables. In sum, Clark et al. conclude that protection has become one of several increasingly important factors for the successful marketing of a new variety. According to Clark et al. (2012), another such factor is the increasing role of trade marks in variety marketing.

Trade marks (74) are used to indicate the source of certain goods and to distinguish them from other goods on the market (Clark et al., 2012). This particularly applies to ornamentals. In fact, trade marks' role as both a commercialisation strategy and a legal protection mechanism for a new variety has become increasingly important in the ornamental sector, where competition is even more complex (Royal Flora Holland, 2019 & 2020). With a variety development cycle of only 3 to 5 years, the ornamental sector clearly involves the highest degree of competition. Therefore, the time span for a return on investment is shorter for breeders in the ornamental sector. While a PVR may successfully offer protection, it is not enough for a proper return on investment because trade marks are usually awarded faster than PVRs (see Martínez López, 2021; Deloitte, 2016).

These specific observations on the ornamental sector pose the question of to what extent PVRs have already lost their relevance for the EU ornamental seed market and plant breeders' business models. This question cannot be answered fully in this study but must be left for future research. However, the available information suggests a situation in which trade marks play a role but should not be considered substitutes for PVR. According to Deloitte (2016), a variety's name (or denomination) in today's supply chain has a rather low marketing impact due to the large number of existing varieties. While formerly some variety names did possess a certain marketing impact (e.g. wine grape varieties such as Chardonnay, Merlot or Pinot Noir, and apple varieties including Golden Delicious and Braeburn), this seems to be less and less true in today's consumer markets. Today, it is the wholesaler or even the retailer that most often decides on the name under which a new variety is sold in modern supermarkets, usually choosing a relevant trade mark instead of the variety denomination. As a result, consumers are becoming less and less aware of variety denominations. Moreover, in the case of garden plants (belonging to the ornamental sector), botanical names seem to hold more relevance than variety denominations. In general, along the supply chain, variety denominations are still used to differentiate products, but in some cases they may simply be replaced by an alphanumeric code (as long as the use of the variety denomination is not mandatory under

---

(74) The scope of protection of a trade mark differs significantly from that of a PVR. While the essential function of a trade mark is to designate commercial origin, and the right lies in the sign to be used in connection with a given set of products and/or services (Clark et al., 2012), a PVR concerns a plant variety as its subject matter. Put simply, a PVR is enforceable against unauthorised propagation of variety constituents (propagation material) of the protected variety, while a trade mark right is enforceable against unauthorised sales where the sign enjoying protection is used.

Council Regulation 2100/94) (Deloitte, 2016). In fact, many variety denominations are presented in the form of a code, indicating their declining relevance as a marketing component.

One further market-related question associated with the EU PVP system concerns the concentration process on the seed market. It is frequently argued that there has been a concentration of companies on both the global and the EU seed markets. The OECD (2018) argues that the impact of stronger IPR on mergers and acquisitions is unclear, and explicitly mentions the UPOV regime's breeders' exemption as a positive example of granting access to diverse germ plasm. This makes mergers and acquisitions less attractive as a tool for gaining market access. Especially where intellectual property protection is deficient, mergers and acquisitions may be used to remove the risk of intellectual property theft or high litigation costs (OECD, 2018).

2.6 A brief interim summary

This literature review has concentrated on previously identified effects of PVP systems in general and that of the EU in particular. Some of the effects discussed are obvious, while others are debatable and less clear. However, all the abovementioned arguments have the following in common: whether they concern a) the system's impact on innovation in production, b) diversity and other sustainability criteria, or c) markets, they are often given in qualitative terms and are only seldom – if at all – supported by quantitative facts. Further analysis is required to assess the value of PVP in general and EU PVR in particular from various perspectives. The following chapters are another step in this direction, but do not claim to be exhaustive.

3 Methodology and data

This analysis aims principally to examine the various economic and environmental effects on EU arable and horticultural farming that can be attributed to the EU PVR system, with an emphasis on EU-level rights. This involves a methodology similar to that used by Noleppa and Cartsburg (2021). With a focus on crop yields (75), this can be achieved by using a gradual approach. First, the yield growth rates of arable crops, fruit, and vegetables as well as ornamentals are examined. Next, the innovation-induced yield growth is calculated in terms of hectare-related total factor productivity (TFP) for all crop clusters. After that, the plant breeding-induced yield growth of these crops is determined based on the share of plant breeding in innovation-induced yield growth. Finally, the share of varieties with EU-level PVR among all varieties registered in the EU is assessed to distinguish between effects that must derive from genetically induced yield developments in general and those that can be attributed solely to the EU PVR system.

Before discussing the results of this straightforward approach, the region, crops and timescale that are the focus of this study must first be clarified.

- This study focuses on the current EU-27. This means that the United Kingdom (UK), a former EU Member State, is excluded from the analysis of economic and environmental effects, although varieties developed in the UK and registered with an EU-level PVR before Brexit are still included in the system.

- As for crops, the objective is to cover at least 80 % of all varieties registered in the EU. Based on CPVO (2021) and EC (2021a & 2021c), and in order of importance (measured in terms of registered varieties), this includes at least corn, wheat, oilseed rape (OSR), potato, barley, sunflower, ryegrass, and durum wheat as arable crops. The relevant fruit include peach, strawberry, apple, wine, apricot, blueberry, raspberry, plum, and cherry. The vegetables include lettuce, tomato, pepper, melon, bean, pea, cucumber, cabbage, onion, spinach,

---

(75) Other characteristics of crops were already mentioned and covered in Chapter 2. Among others, this concerns issues such as the nutritional value of a product or resistance issues. In this regard, qualitative arguments, which do not need further methodological considerations, will once more be highlighted following the yield-related quantitative analysis in chapter 4.

endive, and leek. These crops are analysed using the approach applied by Noleppa and Cartsburg (2021) to arable crops (76), expanded in this analysis to include the nine named types of fruit and twelve vegetables. In terms of ornamentals, however, almost 100 crops must be integrated. The standard methodologies of agricultural and environmental economics already discussed in Noleppa and Cartsburg (2021) and in detail again below (Section 3.2) cannot handle this quantity. Therefore, all the ornamental crops are grouped into one cluster. This results in full (i.e. 100 %) coverage of this specific element in the analysis.

- The analysis covers the years from 1995 until 2019. Essentially, this approach is applied to a quarter of a century of plant breeding in general and to the application of the PVR system in the EU in particular. The various effects of this system on the current situation are then analysed.

Specifically, the research question is: 'What has been the impact of EU-level PVR granted between 1995 and 2019 on agricultural production etc. in and after 2020?' (77)

3.1 Converting statistically observable yield growth into plant breeding-induced yield development

As mentioned above, a gradual approach is needed to convert statistically observable yield growth rates into plant breeding-induced yield development. First, the yield growth of arable crops, fruit, and vegetables as well as ornamentals must be examined based on official statistics. Then, the innovation-induced yield growth must be calculated in terms of hectare-related TFP before the plant breeding-induced yield growth of these crops can be determined based on the share of plant

---

(76) In Noleppa and Cartsburg (2021), the following arable (groups of) crops are covered: wheat (including durum wheat), corn, other cereals (including barley), OSR, sunflower, other oilseeds, sugar beet, potato, pulses, and green maize. This already includes the eight crops listed above, except for ryegrass, and includes additional crops. Hence, the coverage with respect to arable crops is even higher than the requested 80 %.

(77) Modelling impacts always requires calibrating a reference situation. Given rather volatile systems, such as agriculture because it often heavily depends on external determinants such as weather and ad hoc policy making, it is a standard in agricultural economics to fit respective models with three-year averages. Depending on the available specific data sources (see below), this means the inclusion of the most recent three years prior to and/or including 2020.

breeding in innovation-induced yield growth. Applying this concept to the EU and the various crops mentioned above leads to the following results.

3.1.1 Statistically observable yield growth rates

Based on FAO (2021) data and, in the case of information for some pulses and ryegrass missing from that dataset, on Eurostat (2021a), McDonagh et al. (2016) and Grogan (2012), Table 3.1 displays the yield growth rates per year for the core arable crops of this study in the past quarter of a century in the EU. Therefore, statistically observable yields per crop between 1995 and 2019 have been translated into annual percentage yield increases. Mathematically speaking, an exponential trend can be observed.

CROP	YIELD GROWTH	CROP	YIELD GROWTH	CROP	YIELD GROWTH
Wheat	0.93	OSR	0.70	Potato	1.90
Corn	1.22	Sunflower	2.24	Pulses	0.44
Barley	1.07	Other oilseeds	0.29	Green maize	1.80
Other cereals	0.91	Sugar beet	2.13	Ryegrass	0.79

Table 3.1. Statistically observable yield growth rates for arable crops in the EU between 1995 and 2019 (per cent per year)

Table 3.1 shows that yields in EU arable farming are still increasing. However, crop-specific yield growth rates vary significantly. Sunflower, root crops (sugar beet, potato) and maize (corn, green maize) respectively show higher yield growths than wheat, barley, other cereals, oilseeds (including OSR), and pulses. When weighted by current hectare use, the average yield growth rate in EU arable farming is 1.08 % per year (78).

Using a similar approach, yield growth rates can be calculated for fruit (Table 3.2) and vegetables (Table 3.3). Again, it turns out that yields have increased in the past 25 years, with considerable

---

(78) Noleppa and Cartsburg (2021), referring to the period 2000-2019 instead of 1995-2019, calculate an average annual yield growth of 1.15 % for arable crops (excluding ryegrass).

variation between individual crops. A negative yield trend is observable only in the case of peas. On average, yields in fruit production rose by 0.83 % per year, whereas the figure for vegetables is 1.10 %.

CROP	YIELD GROWTH	CROP	YIELD GROWTH	CROP	YIELD GROWTH
Peach	1.21	Wine/Grape	0.60	Raspberry	0.58
Strawberry	1.23	Apricot	2.80	Plum	2.50
Apple	1.29	Blueberry	1.43	Cherry	0.49

Table 3.2. Statistically observable yield growth rates for fruit in the EU between 1995 and 2019 (per cent per year)

CROP	YIELD GROWTH	CROP	YIELD GROWTH	CROP	YIELD GROWTH
Lettuce	0.48	Bean	0.85	Onion	3.10
Tomato	2.17	Pea	-0.08	Spinach	0.28
Pepper	2.91	Cucumber	3.72	Endive	1.32
Melon	1.15	Cabbage	0.52	Leek	0.72

Table 3.3. Statistically observable yield growth rates for vegetables in the EU between 1995 and 2019 (per cent per year)

Ornamentals can be classified in various ways. According to Saraswathi et al. (2018), ornamentals are floriculture crops and nursery plants, shrubs, trees, and foliage plants for outdoor and indoor use, produced with the purpose of beautifying, decorating, or enhancing the environment. Therefore, plants intended for commercial food (and feed) production, such as arable crops, fruit, and vegetables, are excluded from this category. The production and yield of ornamentals are not usually measured in tonnage. Instead, the monetary value of production is frequently used to describe the status quo or development in the ornamental crop sector (e.g. CBI, 2017; EC, 2020; Hakeem, 2020; Mamias, 2018; Royal Flora Holland, 2019). Consequently, a monetary indicator will be used below to describe the statistically observable 'yield' growth of ornamentals as a whole(79).

---

(79) Arguably, the approach used for ornamentals could also be appropriate for some categories of vegetables, such as cherry tomatoes, baby leaf lettuce and snack peppers.

Production value growth data is taken from the EC (2020c) and Eurostat (2022a) and information regarding area developments from Eurostat (2021d). Both are then used to determine a trend describing the specific yield, that is to say, the production/area-ratio development between 1995 and 2019 for ornamentals. The data shows that total (monetary) yield per hectare of ornamentals in the EU rose by 0.21 % per year over the past 25 years.

3.1.2 Innovation-induced yield growth

Considering the complexity of managerial and technological processes in arable and horticultural farming, statistically observable yield growth rates are normally the product of many factors. Long-term observations can minimise (but not entirely exclude) the influence on the analysis of weather phenomena and other short-term distortions and externalities such as ad hoc policy interventions. However, yield growth can still be induced by agricultural intensification or innovation respectively (e.g. Sayer and Cassmann, 2013; Pretty et al., 2018).

'Agricultural intensification' essentially refers to a process whereby intermediate inputs, capital and/or labour are increased to raise productivity (in this case the yield), while 'innovation' means the introduction of new inputs and better services that add value to agricultural production. For example, higher yields depend on more inputs per hectare of land and/or better inputs such as PPP applied to a given area (Struik and Kuyper, 2017).

Economic assessments employ the concept of TFP (80) to demonstrate which parts of an observable change in overall productivity are induced by innovation and are not related to increased (or decreased) factor use intensity (e.g. Wang et al., 2020). This study uses a rather straightforward TFP calculation approach that requires comparatively few data points, originally developed by Lotze-Campen et al. (2015). It has proved effective, as it allows abstraction from land as a production factor. Therefore, TFP growth rates can be compared directly with changing yields per hectare. This

---

(80) Due to the numerous theoretical and practical applications of TFP, it is considered standard in socioeconomic science and particularly in agricultural economics (e.g. Alston and Pardey, 2014; Barath and Fertö, 2016; DEFRA, 2020; Fuglie and Toole, 2014; Fuglie, 2013; Piesse and Thirtle, 2010; Villoria, 2019).

simplifies the calculation and supports approximative determination of TFP for specific crops. A hectare-related TFP change rate is calculated as follows:

1. $dTFP/TFP = \Delta Q/Q - (\Delta I/I) * SI - (\Delta L/L) * SL$

where:

Q = index of production (i.e. yield),
I = index of all intermediate inputs used,
L = index of labour input,
S = expenditure shares of the specific production factors.

Equation 1 above shows that weighted change rates with respect to the various input factors (other than land) must be subtracted from yield changes to calculate meaningful TFP growth rates. In this approach, an indicator is applied that measures the land productivity (or yield) progress that would have occurred if improved (innovative) input had been applied. This will be referred to as innovation-induced yield growth. Consequently, developments in factor use must first be identified and then incorporated in the analysis by subtracting them from statistically measurable yields.

EC (2021b) data from the Farm Accountancy Data Network (FADN) is used to identify factor use developments and produces the specific growth rates displayed in Table 3.4 (81). This data not only allows the calculation of hectare-based input use developments in general but also a differentiation of these developments between arable and horticultural farming (82).

FARMING	SEEDS	FERTILISERS	PPP	LABOUR	CAPITAL
Arable	-0.20	-0.07	-0.60	-0.60	-0.44
Horticultural	-0.60	-2.30	-1.40	-1.00	-0.92

Table 3.4. Growth rates of input use per hectare for EU arable and horticultural farming between 1995 and 2019 (per cent per year)

---

(81) This is a significant step forward from Noleppa and Cartsburg (2021). The EC (2021b) data constitutes a completely new and more EU-focused database that was not available prior to the present study. This new information provides a more detailed and, most importantly, a very consistent dataset for further analysis.

(82) Some data available only in monetary terms had to be adjusted using inflation rates obtained from the World Bank (2021).

Examining these growth rates, the following can be observed. In the cases of both arable and horticultural farming, all input trends are decreasing. The growth rates are all negative, although often measuring 1.0 % per year or less.

This is also clear from the weighted averages, as depicted in Figure 3.1 showing the average annual growth rates of the overall input use – excluding land – in arable and horticultural farming in the EU between 1995 and 2019. The various use change rates of the three intermediate inputs, as well as of labour and capital, are weighted with the individual input shares of these production factors in the entire (monetary) input for arable and horticultural farming, also obtained from EC (2021b). This results in an average overall input growth rate of -0.50 % in EU arable farming (83) and -0.99 % in EU horticultural farming (84).

---

(83) Noleppa and Cartsburg (2021), referring to the period 2000-2019 instead of 1995-2019, calculate an average annual growth rate of -0.42 % for arable crops (excluding ryegrass).

(84) The finding that input use per hectare is decreasing is important at this stage of the analysis. It indicates that agricultural production on available acreage in the EU as a whole has not intensified in the past 25 years. This is particularly noteworthy considering the widespread public belief that EU agriculture is continually intensifying (UBA, 2015; Czyzewski et al., 2020; Fonderflick et al., 2020).

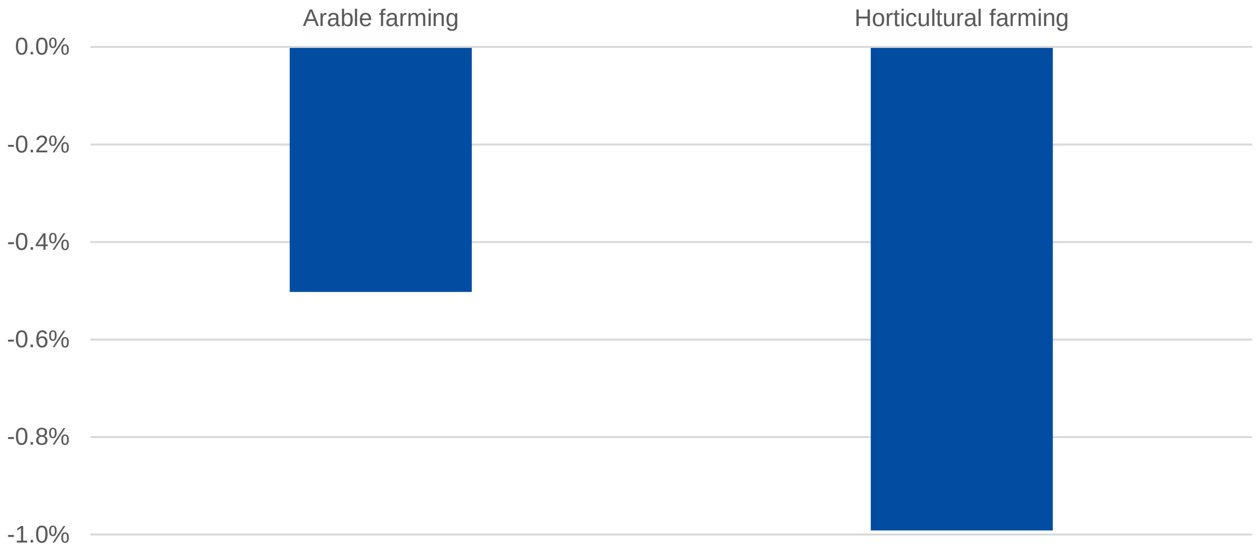


Figure 3.1. Annual growth rates of the overall input use (excluding land) in EU arable and horticultural farming between 1995 and 2019

Applying equation 1 – that is to say, subtracting the calculated overall input use growth rates (excluding land) from statistically observable yield growth rates – leads to the crop-specific annual innovation-induced yield growth rates for the EU in the past 25 years. The results are displayed in Table 3.5 for arable crops, Table 3.6 for fruit and Table 3.7 for vegetables (85).

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Wheat	1.43	OSR	1.20	Potato	2.40
Corn	1.72	Sunflower	2.74	Pulses	0.94
Barley	1.57	Other oilseeds	0.79	Green maize	2.30
Other cereals	1.41	Sugar beet	2.63	Ryegrass	1.29

Table 3.5. Innovation-induced yield growth rates for arable crops in the EU between 1995 and 2019 (per cent per year)

---

(85) The average annual overall input use growth rate of -0.50 % for arable farming was subtracted from the statistically observable yield growth rates for arable crops in Table 3.1; and the average annual overall input use growth rate of -0.99 % for horticultural farming was subtracted from the statistically observable yield growth rates for fruit and vegetables in Table 3.2 and Table 3.3, respectively.

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Peach	2.20	Wine/Grape	1.59	Raspberry	1.57
Strawberry	2.22	Apricot	3.79	Plum	3.49
Apple	2.28	Blueberry	2.42	Cherry	1.48

Table 3.6. Innovation-induced yield growth rates for fruit in the EU between 1995 and 2019 (per cent per year)

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Lettuce	1.47	Bean	1.84	Onion	4.09
Tomato	3.16	Pea	0.91	Spinach	1.27
Pepper	3.90	Cucumber	4.71	Endive	2.31
Melon	2.14	Cabbage	1.51	Leek	1.71

Table 3.7. Innovation-induced yield growth rates for vegetables in the EU between 1995 and 2019 (per cent per year)

When weighted by current hectare use, the average innovation-induced yield growth rate in EU arable farming between 1995 and 2019 was 1.58 % per year (86). In horticultural farming, it was 1.82 % for fruit and 2.09 % for vegetables.

The cultivation of floriculture and nursery plants, shrubs, trees, and foliage plants has more in common with fruit and vegetable production than with the cultivation of arable crops. Due to the absence of specific data on input use in EU ornamental production, therefore, the abovementioned input use change rate for horticultural crops (-0.99 %) is also used to convert the statistically observable total (monetary) yield of ornamentals into an innovation-induced yield growth rate for the specific group of crops included in this study. Since this study covers ornamentals as a whole, as opposed to specific ornamental crops, a single value applies. The annual innovation-induced yield growth rate in EU ornamental farming between 1995 and 2019 was 1.20 %.

---

(86) Noleppa and Cartsburg (2021), referring to the period 2000-2019 instead of 1995-2019, calculate an average annual innovation-induced yield growth of 1.68 % for arable crops (excluding ryegrass).

These findings on innovation-induced yield growth – or TFP growth – in arable and horticultural farming in the EU in the past 25 years is crucial for the rest of the analysis. Therefore, it must undergo a stress test. The calculations can be compared with the results of a meta-analysis that looks at science-based TFP calculations for EU agriculture in general, and crop farming in particular, from only the past decade.

Figure 3.2 shows the result of a comparison with 42 individual TFP growth rates identified for this purpose in a total of 17 publications, listed in Annex A. The outcome of calculating TFP growth rates for EU agriculture in general, and crop farming in particular, is highly dependent on the methodology and data used. However, it always results in a non-negative TFP growth rate, which simply indicates that ongoing innovation contributes to overall productivity growth. The above calculations of average innovation-induced yield growth rates for arable crops, fruit, and vegetables, and ornamentals are within the resulting range. Therefore, our own calculations pass the stress test and fit what can be considered condensed scientific wisdom. These specific rates will consequently be used for further analysis.

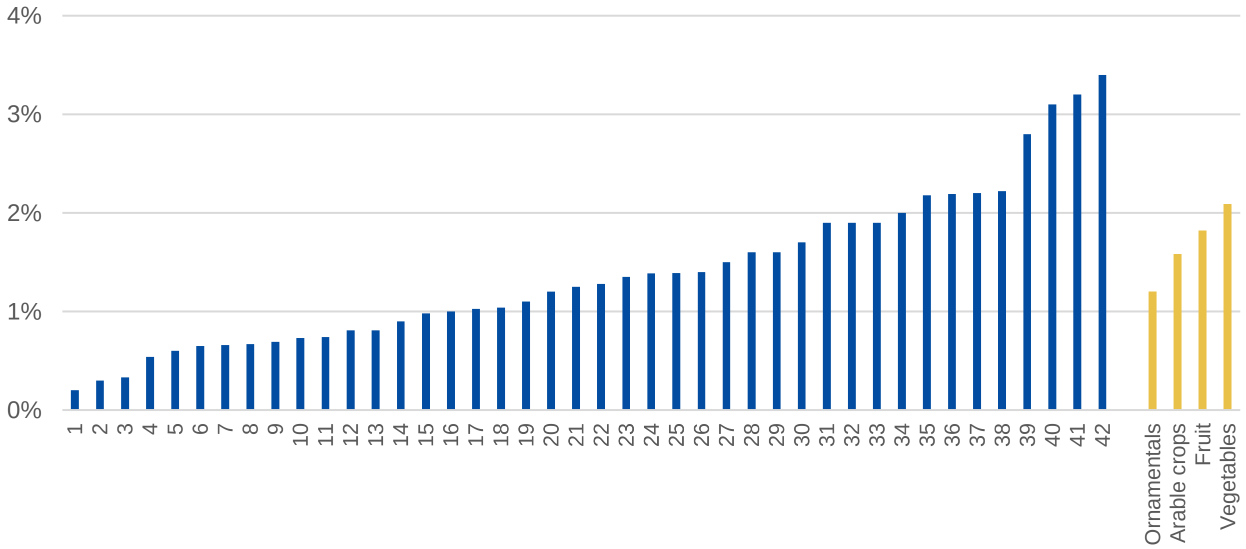


Figure 3.2: Annual TFP growth rates in EU agriculture versus own calculations for innovation-induced yield growth

3.1.3 Plant breeding-induced yield growth

Crop-specific innovation-induced yield growth rates in the EU are considered the most appropriate indicator of ‘real’ (unbiased) yield developments in EU arable and horticultural farming. However, the abovementioned improvements may result from innovations in plant breeding on the one hand, and from innovative approaches to crop nutrition, crop protection, irrigation, machinery, etc. on the other (HFFA Research, 2016; EC, 2016). To assess the contribution of plant breeding to sectoral innovation in total, that is to say, to calculate the plant breeding-induced yield growth for crops of interest, the relative importance of activities related to genetic improvements for yield growth in EU arable and horticultural production must be identified.

For this purpose, a meta-analysis was conducted of available scientific literature and expert wisdom published in the past 25 years (corresponding to the timeframe of the analysis as a whole) (87). In total, 124 sources of relevant information were identified and are listed in Annex B.

Several of these sources attribute, or allow the calculation of, a specific percentage of innovation-induced yield development to plant breeding in general. Other sources allow a direct comparison of real land productivity growth over time with the yield manifestation of crop-specific varieties (distinguishable in terms of the year of release). Still others allow a more indirect conclusion, such as when all forms of innovation other than plant breeding are discussed as drivers of productivity growth.

---

(87) The contribution of plant breeding, as opposed to other forms of innovation, to yield determination in EU crop production can be determined using expert opinion, numerous academic calculations, and several science-based and programmatic variety trials. Some of these sources are very crop-specific and region-specific, while others are more general, i.e. they cover several or even all crops, as well as broader regions such as the EU as a whole. In addition, they all apply different methodologies, which all have their pros and cons. Therefore, a single piece of information may not be perfect for the following analysis. However, the sources identified provide the most complete picture of the body of scientific and expert wisdom on what share of innovation can be attributed to plant breeding, and will be used accordingly.

Altogether, the sources provide 527 specific data points (88) (i.e. statements on plant breeding's contribution to innovation-induced yield growth) and constitute, to our knowledge, the most comprehensive database on the subject ever created. In particular, it provides a considerably larger evidence base than that recently delivered in Noleppa and Cartsburg (2021), as the number of data points has increased by more than 40 %.

The specific findings are summarised in Figure 3.3 and Figure 3.4. Extreme statistical outliers are excluded from the analysis (89); 498 of the abovementioned 527 data points are considered, which is still a significant number.

Figure 3.3 displays a box plot diagram of the frequency distribution of the innovation-induced yield growth attributable to plant breeding. Most of the identified data points (i.e. 355) place plant breeding's contribution to productivity within a range from 50 to 88 %, located within the inner fences of the box plot. The mean value is 65.9 %.

---

(88) Each data point refers to a specific contribution of plant breeding to innovation-induced yield growth for a certain crop or group of crops and region (i.e. within the crop-focused scope of this study and for the EU as a whole or one or more of its member states).

(89) Extreme outliers have been excluded from the following analysis because they push statistical indicators of tendency and/or spread in a certain direction. This leads to the overinterpretation of a particular analytical aspect. However, there is no scientific consensus on the definition of an 'extreme' outlier, so usually the analyst determines this. As a rule of thumb, a data point beyond the so-called outer fence on either side of the frequency distribution (i.e. the first quartile minus 3.0 times the interquartile range (IQR) as well as the third quartile plus 3.0 times the IQR) is considered an extreme outlier and may potentially be excluded from further analysis (NIST, 2012).

Figure 3.3. Box plot of frequency distribution of plant breeding's contribution to innovation-induced yield growth in EU arable and horticultural farming

A similar picture is drawn by Figure 3.4, which displays a histogram of the frequency distribution of plant breeding's contribution to innovation-induced yield growth. Again, specific shares are located within a rather broad range. However, almost four-fifths of all shares are within the narrower range of 40 to 90 % (90).

---

(90) In this frequency distribution, there are data points – 6.4 % of the total – that assess plant breeding's contribution at over 100 %. A share well above 100 % is possible due to improper management and at least two other major reasons. First, externalities must be considered. The TFP calculation approach used here (and TFP concepts applied in many other studies) is not able to filter out the impact of, for instance, devastating but infrequent climate change events such as drought, floods and/or cold spells on yields. Unfortunately, such events have become more common (Cammarelli et al., 2020; Jiménez-Donaire et al., 2020). These tend to lower real annual yield growth rates, and by subtracting input use developments from these rates, annual innovation-induced yield growth rates as well. Second, negative innovation is possible. The ongoing enlargement of organic farming and bans on certain PPP are examples of negative innovations. Furthermore, a lack of institutional reform and persistent market access problems can hinder yield on field (e.g. USDA, 2021), contributing to comparably lower yield growth rates.

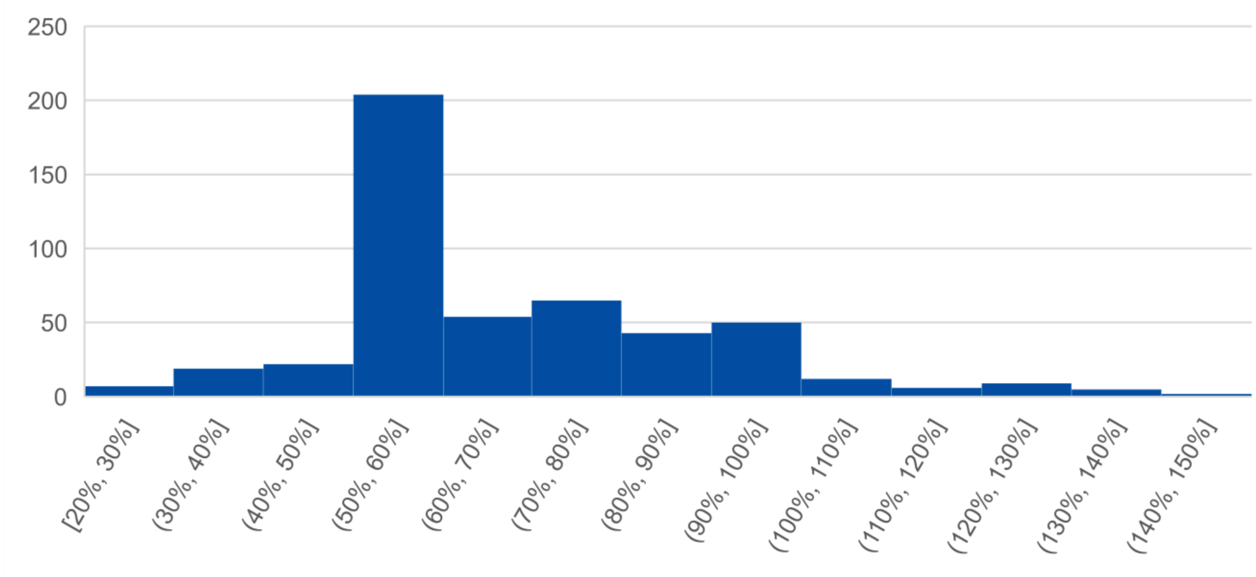


Figure 3.4. Histogram of frequency distribution of plant breeding's contribution to innovation-induced yield growth in EU arable and horticultural farming

The various sources and the information they contain also allow specific findings to be attributed to certain crops or groups of crops. Accordingly, the following two tables show the calculated average contributions of plant breeding to innovation-induced yield growth per crop or group of crops included in this study (91).

Table 3.8 displays the outcome of this specific analysis for arable crops. The importance of plant breeding to innovation in this sub-sector ranges between 54 and 74 %, depending on the arable crop in question.

---

(91) At least 20 data points per crop were needed to calculate an average value. Where fewer data points were available, crops were grouped together. Therefore, specific fruit and vegetables could not be separated, and sunflower had to be merged with other oilseeds.

CROP	SHARE	CROP	SHARE	CROP	SHARE
Wheat	67.3	OSR	73.8	Potato	62.1
Corn	69.2	Sunflower	71.5	Pulses	65.6
Barley	69.3	Other oilseeds	71.5	Green maize	65.8
Other cereals	72.3	Sugar beet	60.7	Ryegrass	53.5

Table 3.8. Contribution by plant breeding to innovation-induced yield growth of arable crops in the EU (per cent)

The average share for fruit and vegetables is comparatively low, as indicated in Table 3.9; in both cases it is around 59 %. Nevertheless, this still suggests a major contribution by plant breeding to innovation in the EU horticultural crop sector.

GROUP OF CROPS	SHARE	GROUP OF CROPS	SHARE
Fruit	58.8	Vegetables	59.0

Table 3.9. Contribution by plant breeding to innovation-induced yield growth of fruit and vegetables in the EU (per cent)

The meta-analysis could not identify specific quantitative assessments of plant breeding's contribution to the innovation-induced yield growth of ornamentals. Consequently, an 'average' share equivalent to the shares for the other horticultural crops (i.e. fruit and vegetables) is used. Plant breeding's share in the innovation-induced yield growth of ornamentals is therefore assumed to be approximately 58.9 %.

The following preliminary conclusion can be drawn. Considering academic literature and the noticeably broad consensus among experts, plant breeding across all arable and horticultural crops in the EU has a tremendous impact on innovation-induced yield growth in farming. In the past quarter of a century, genetic crop improvements have been responsible for the vast majority of innovation-driven progress.

The information on innovation-induced yield growth rates (see also Table 3.5 for arable crops, Table 3.6 for fruit and Table 3.7 for vegetables) and plant breeding's share in this innovation-induced change (see also Table 3.8 for arable crops and Table 3.9 for fruit and vegetables) can now be merged. Multiplying the innovation-induced yield growth rate by plant breeding's share produces the plant breeding-induced yield growth rate in EU arable and horticultural farming.

The results of this algebraic transformation are displayed in Table 3.10 for arable crops, Table 3.11 for fruit and Table 3.12 for vegetables. In addition, a plant-breeding induced yield growth of 0.71 % per year applies to ornamentals.

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Wheat	0.96	OSR	0.89	Potato	1.49
Corn	1.19	Sunflower	1.96	Pulses	0.62
Barley	1.09	Other oilseeds	0.56	Green maize	1.51
Other cereals	1.02	Sugar beet	1.60	Ryegrass	0.69

Table 3.10. Plant breeding-induced yield growth rates for arable crops in the EU between 1995 and 2019 (per cent per year)

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Peach	1.29	Wine/Grape	0.93	Raspberry	0.92
Strawberry	1.31	Apricot	2.23	Plum	2.05
Apple	1.34	Blueberry	1.42	Cherry	0.87

Table 3.11. Plant breeding-induced yield growth rates for fruit in the EU between 1995 and 2019 (per cent per year)

CROP	GROWTH RATE	CROP	GROWTH RATE	CROP	GROWTH RATE
Lettuce	0.87	Bean	1.09	Onion	2.41
Tomato	1.86	Pea	0.54	Spinach	0.75
Pepper	2.30	Cucumber	2.78	Endive	1.36
Melon	1.26	Cabbage	0.89	Leek	1.01

Table 3.12. Plant breeding-induced yield growth rates for vegetables in the EU between 1995 and 2019 (per cent per year)

The following three figures – Figure 3.5 for arable crops, Figure 3.6 for fruit and Figure 3.7 for vegetables – compare these plant breeding-induced growth rates with the statistically observable annual yield growth per crop for arable and horticultural farming in the EU. It turns out that, in all cases, plant breeding has an enormous impact that is often on a par with or even larger than statistically measurable yield progress. On average, weighted by current hectare, the following observations can be made:

- plant breeding between 1995 and 2019 accounts for an annual yield growth of 1.09 % in arable farming, slightly higher than the observed average yield growth for arable crops (1.08 %, see Table 3.1);

- moreover, it increases fruit yield by 1.07 % annually, somewhat more than that measurable in terms of harvested yield increases (0.83 %, see Table 3.2);

- furthermore, it contributes an annual yield growth of 1.31 % for vegetables, which can be compared to a statistically observable yield growth of 1.10 % (see Table 3.3);

- finally, although a rather low total (monetary) yield growth per year of 0.21 % is observed for ornamentals, a much higher annual yield growth of 0.71 % can be attributed to plant breeding in the past 25 years.

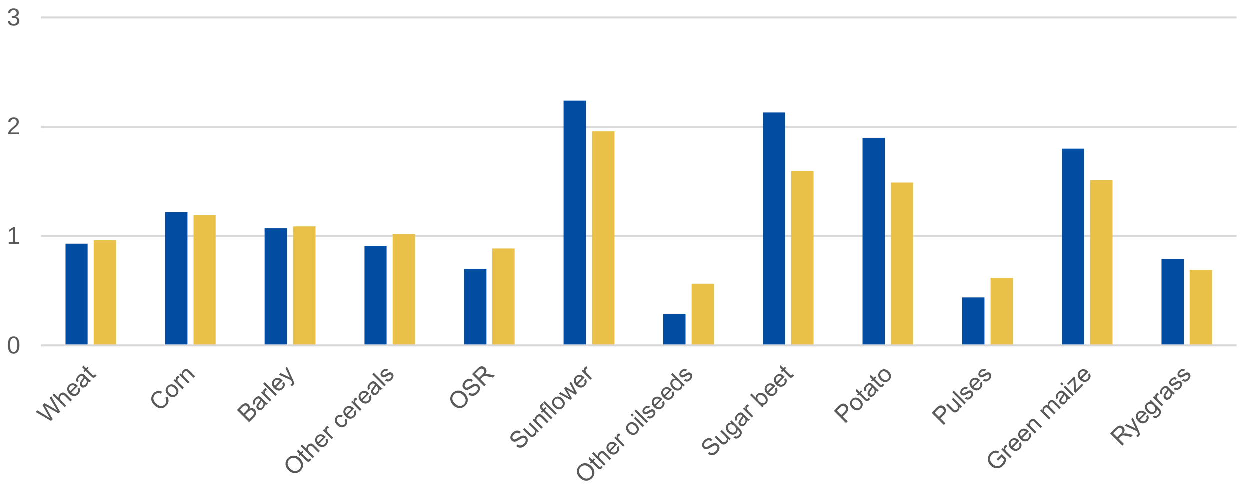


Figure 3.5. Comparison of plant-breeding induced yield growth rates and statistically observable yield growth rates for arable crops in the EU between 1995 and 2019 (per cent per year)

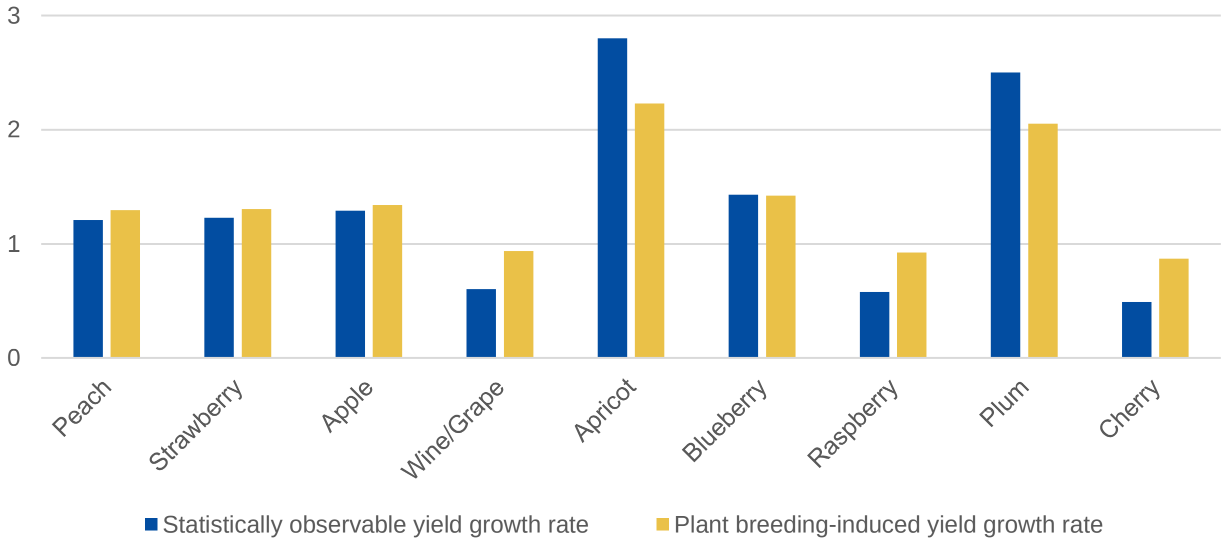


Figure 3.6. Comparison of plant breeding-induced yield growth rates and statistically observable yield growth rates for fruit in the EU between 1995 and 2019 (per cent per year)

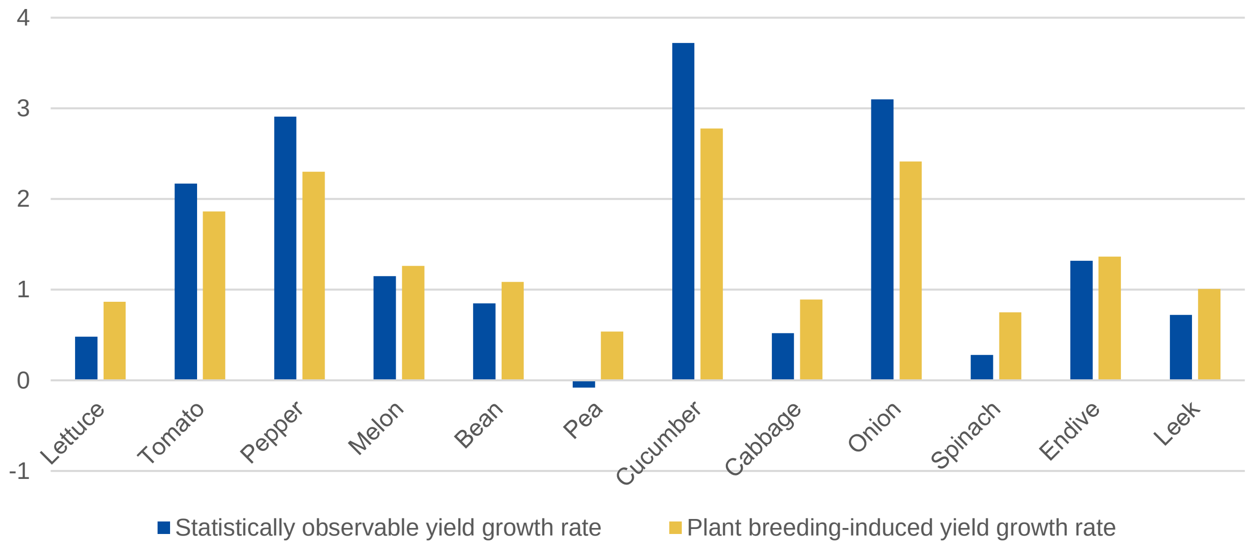


Figure 3.7. Comparison of plant breeding-induced yield growth rates and statistically observable yield growth rates for vegetables in the EU between 1995 and 2019 (per cent per year)

3.2 Determining economic and environmental impacts of the EU level PVR system

The plant-breeding induced yield growth of the various crops is determined based on statistically observable yield growth rates, meaningful TFP calculations and consolidated expert knowledge about plant breeding’s share in innovation-induced yield growth. However, the share of varieties with EU-level PVR among all registered varieties in the EU must still be determined in order to account for various economic and environmental effects that can solely be attributed to the EU PVR system. The methodologies employed, including sophisticated modelling techniques, are described below.

3.2.1 Shares of varieties with EU-level PVR among all registered varieties

The total number of varieties per crop and the shares of varieties with EU-level PVR are calculated based on CPVO (2021) – more precisely, on the CPVO Variety Finder database. This database includes, alongside the CPVO data on PVR varieties, information from other sources, most importantly in this case the national listings of EU Member States, the EU common catalogue data (EC, 2021a), and data from the Fruit Reproductive Material Information System (FRUMATIS) (EC, 2021c).

To determine the total number of registered varieties per crop, three different register types from the Variety Finder database (CPVO, 2021) are included in the analysis. First, the Plant Breeder's Rights (PBR) register, which contains the varieties that are covered by the EU-level PVR system; second, the National List (NLI) register, which contains agricultural and vegetable varieties that are eligible for marketing within the EU from the national listings of EU Member States and the EU common catalogue data; and third, the FRUMATIS register, which contains necessary information on fruit varieties within the EU.

The share of varieties with an EU-level PVR per crop is then determined by calculating the ratio of the varieties included in the PBR register to the varieties covered by the two other registers. More precisely, once double counting between the different register types is eliminated, the sum of varieties within the NLI and FRUMATIS registers per crop determines the total number of varieties per crop. The share of EU-level PVR varieties then depends on the number of varieties within the PBR register. The following three tables – Table 3.13 for arable crops, Table 3.14 for fruit, and Table 3.15 for vegetables, show the results of this analysis. The shares will be used in the following analysis(92).

---

(92) An alternative could be to use ratios of areas planted with protected and non-protected varieties. This would likely result in higher shares for protected varieties, since there are old varieties that are hardly used in cultivation and for which PVR protection was never obtained or has expired. The ratios used here can thus ve viewed as conservative.

CROP	REGISTERED VARIETIES	EU-LEVEL PVR VARIETIES	SHARE
Wheat	4 137	1 401	33.9 %
Corn/Green maize	10 942	2 537	23.2 %
Barley	2 109	650	30.8 %
Other cereals	2 502	593	23.7 %
OSR	2 431	884	36.4 %
Sunflower	3 037	686	22.6 %
Other oilseeds	1 875	370	29.7 %
Sugar beet	2 901	115	4.0 %
Potato	2 146	1 057	49.3 %
Pulses	1 075	167	15.5 %
Ryegrass	1 318	260	19.7 %

Table 3.13. Share of varieties with EU-level PVR for arable crops

Therefore, 25.3 % of all registered varieties of the arable crops that are the focus of this study are varieties with an EU-level PVR.

CROP	REGISTERED VARIETIES	EU-LEVEL PVR VARIETIES	SHARE
Peach	3 333	640	19.2 %
Strawberry	1 868	418	22.4 %
Apple	6 748	345	5.1 %
Wine/Grape	2 444	243	9.9 %
Apricot	1 069	199	18.6 %
Blueberry	412	129	31.3 %
Raspberry	709	138	19.5 %
Plum	295	83	28.1 %
Cherry	1 731	99	5.7 %

Table 3.14. Share of fruit varieties with EU-level PVR

In total, 12.3 % of all registered fruit varieties are varieties with an EU-level PVR.

CROP	REGISTERED VARIETIES	EU-LEVEL PVR VARIETES	SHARE
Lettuce	3 314	1329	40.1 %
Tomato	5 740	922	16.1 %
Pepper	2 967	383	12.9 %
Melon	1 540	284	18.4 %
Bean	1 807	245	13.6 %
Pea	1 523	369	24.2 %
Cucumber	1 664	220	13.2 %
Cabbage	3 050	332	10.9 %
Onion	1 359	194	14.3 %
Spinach	584	105	18.0 %
Endive	461	88	19.1 %
Leek	299	84	28.1 %

Table 3.15. Share of vegetable varieties with EU-level PVR

18.7 % of all registered varieties of the vegetables that are the focus of this study are varieties with an EU-level PVR.

Finally, the share of ornamental varieties with an EU-level PVR for ornamentals must be discussed. The results of the analysis are displayed in Table 3.16, and show that from a total of more than 15 500 varieties in this group of crops, almost all have an EU-level PVR (93).

CROP	REGISTERED VARIETIES	EU-LEVEL PVR VARIETES	SHARE
Ornamentals	15 588	15 094	96.8 %

Table 3.16. Share of ornamental varieties with EU-level PVR

---

(93) See also chapter 2, especially the arguments concerning PVP's market function, for an explanation of this demand for protection and the corresponding high share of ornamentals with an EU-level PVR.

3.2.2 Calculation tools to analyse various economic impacts

Three major standard tools of agricultural economics are applied in this context to calculate important economic impacts of the EU-level PVR system: market models, full-revenue-full-cost calculations, and multiplier analyses. The methodological particularities and specific data needs of each can be described as follows.

Market models

For this core analysis, a partial equilibrium model (PEM) is used. In this context, ‘partial’ means that only certain selected markets are depicted, as opposed to the entire economy and all its sectors. As such, a PEM is understood as a multi-market, multi-regional model that is standard in the economic analysis of agricultural processes. These models are especially useful for the consideration of alternative production, consumption, and policy scenarios (Sadoulet and de Janvry, 1995; Saunders and Wreford, 2005) and the analysis of the resulting quantities supplied, demanded, and traded at varying price levels (Francois and Reinert, 1997; Henning et al., 2021).

Here, we use an existing PEM of our own (Lüttringhaus and Cartsburg, 2018), modified and newly calibrated to fit the regional scope, market coverage, and timeframe of this study. In particular, the following regions and crops are covered:

- regions: the EU, North America, South America, Asia, Middle East and North Africa (MENA), Sub-Saharan Africa, Oceania, Commonwealth of Independent States (CIS), and the rest of the world (RoW);
- crops: all the arable crops, fruit, and vegetables listed above, and ornamentals as a whole.

Finally, the entire model framework is calibrated to properly reflect the current situation (in 2020). However, average data for the past three years of market supply and demand, as well as international trade and market prices, had to be used to reflect this situation and to avoid modelling inconsistencies due to market disturbances in single years.

The resulting PEM is a comparative static model. Two equilibria can be compared: an equilibrium in the reference situation and an alternative equilibrium (i.e. under conditions of shock). An important model assumption is that domestic and foreign goods are perfect substitutes. International trade, then, is modelled as the difference between domestic supply and demand in every region and market. The model is then 'closed' by the assumption of a market equilibrium. For this purpose, RoW is defined as the world excluding all other regions, with trade flows calibrated so that the global supply (of all regions, including RoW) equals global demand on all markets. This means that all regional markets clear at global scale and at reference (equilibrium) prices.

In essence, this model consists of a rather complex system of equations that must be solved simultaneously. A change of the market(s) caused by a move from the reference system to one of the alternatives (i.e. the shock scenarios) is the result of an iterative process that solves the system of equations. In this way, market change reactions per region are quantified via own-price and cross-price elasticities. The model used here is based on a similar concept already used in the 'Static World Policy Simulation' modelling framework (e.g. Roningen, 1986; 2004; Roningen et al., 1991), which has been applied in other studies as well (Jechlitschka et al., 2007; Blandford, 2015; Saunders and Driver, 2016).

The model makes use of isoelastic Cobb-Douglas functions. The application of Cobb-Douglas supply and demand functions has a long tradition in agricultural economic analysis (e.g. Ledebur, 2001). Markets are linked to each other by means of cross-price elasticities. This results in a consistent system of equations (linked via cross-price elasticities) that meets the homogeneity and symmetry conditions for proper modelling (Chiang and Wainwright, 2005).

In the context of this study, a change in supply due to plant breeding based on EU-level PVR is modelled by a pivotal adjustment, that is to say, by a multiplicative link of shift factors (changing the intercept of one or more equations). This is a tried and tested procedure in equilibrium modelling (e.g., Kazlauskiene and Meyers, 1993; 2003; Cagatay et al., 2003; Schwarz et al., 2011). The advantage of this approach is that shocks to the system may be straightforwardly quantified as a relative change rate.

This well-structured and straightforwardly programmed PEM is fairly data-intensive. Therefore, particular care has been taken in choosing reliable data and consistent information. Most data are from public sources. Random shocks are accounted for using 3-year averages of the most recent available information. Accordingly, prices are, for the most part, based on various dashboards from EC (2021d) and supplemented by IndexMundi (2021) information. Data on supply and demand quantities, as well as trade, are mainly based on FAO (2021) (94). In a very few cases where data were missing, additional information has been obtained from Eurostat (2021a; b). Elasticities are taken partly from the World Food Model (FAO, 2003) and the FASOMGHG model (Adams et al., 2005; Beach et al., 2010), but mostly from Sullivan et al. (1992) and relevant updates (e.g. Roningen, 2016).

Full-revenue-full-cost calculations

The approach used to calculate impacts on costs and returns in agricultural production, as well as labour effects at farm level, is basically a standardised full-revenue-full-cost calculation consistent with the concept of the constructed normal value (CNV) (e.g. Eidman et al., 2000; von Witzke and Noleppa, 2012; Hahn and Noleppa, 2013; Noleppa and Lüttringhaus, 2016).

The CNV-based approach used here allows a precise determination of market revenue, which reflects the price and yield situation in agricultural production, and of production costs consisting of operating costs, other farm costs such as depreciation, wages paid, etc. as well as unpaid (family) labour and own capital costs. This allows the calculation of various margins, namely a gross and/or net margin, and the economic return – or remaining net profit (for more information see KTBL, 2021).

Multiplier analyses

This study’s goal is not solely to analyse economic impact at the farm level as well as the sectoral agricultural market level. It also aims to assess the benefits for the rural sector and the economy as a whole. These benefits are attributed to farm input suppliers as well as downstream food and other industries, depending on farmers’ decisions. Changes affecting primary agricultural markets almost

---

(94) Following the publication of Noleppa and Cartsburg (2021), the FAO database was completely renewed. Therefore, our market modelling framework should be considered new and not comparable with older versions.

immediately affect the linked upstream and downstream sectors of an economy. This is because changing production also requires adaptation in processing, packaging, manufacturing, trading, retailing, etc. Against this background, gross domestic product (GDP) and labour (employment) effects are of particular interest.

Multiplier analyses allow these effects to be assessed. Multipliers are parameters that reflect the transmission of a particular sectoral change into an economy-wide change. They have often been applied in agricultural economic analyses (e.g. Breisinger et al., 2010; Mattas et al., 2009; Schwarz, 2010). Relevant multipliers for this analysis have been taken from a comprehensive meta-analysis of these parameters. In particular, the most recently calculated output and workforce multipliers for the EU farming sector and specific crops or groups of crops published by Fuentes-Saguar et al. (2017) are used, and are by and large supported by Cingiz et al. (2021).

3.2.3 Calculation tools to analyse various environmental impacts

Four specific methodologies are used in this study to calculate the various environmental impacts: a virtual net land trade model, a global greenhouse gas (GHG) emissions model, a global biodiversity loss model, and a virtual water use and trade model.

Modelling virtual net land trade

The virtual agricultural net land trade approach used here is based on the concept of virtual inputs first developed by Allan (1993; 1994). The basic idea is that the production of essentially any good requires inputs. These inputs are then considered a virtual part of the product. Therefore, when a product is traded internationally, the virtual input is traded simultaneously. By analogy, we define virtual land as the amount of land that is required to produce one unit of a given agricultural product. Therefore, the import of agricultural commodities adds land to the domestic resource base, while export continues to reduce it.

Eurostat (2021b) data are used to analyse the EU's virtual agricultural land trade. This analysis begins with international agricultural trade volume flows, that is to say, export and import tonnages, based on the Standard International Trade Classification (SITC). The SITC categories distinguish various degrees of processing, meaning that goods from identical raw material (e.g. wheat) may end up in different categories (e.g. wheat flour, food preparations, pasta). However, they can always be attributed to their raw material once again.

The conversion of agricultural trade data into land trade information is a rather complex methodological issue. The calculation of virtual land trade from agricultural trade statistics requires several intermediate steps for each SITC category.

- First, the agricultural goods traded must be converted back into their respective raw materials using consistent technical parameters and suitable conversion factors. Here, technical parameters have been obtained from FAO (2012) for proper conversion.

- The resulting 'primary' trade volumes (in terms of raw agricultural products) must then be set for annual regional yields. The relevant yield information is taken from FAO (2021) and allows the calculation of region-specified land used for exports or imports.

- Finally, net imports must be calculated in relation to net exports of virtual land for every single SITC category, that is to say, for every internationally traded agricultural product and for each trading partner of the EU.

Using this gradual approach based on SITC categories, it is possible to sort the traded agricultural goods into different crop groups of agricultural raw materials. The methodological concept used here – extensively described in Noleppa and Cartsburg (2015) – is also applied in Kern et al. (2012) and Lotze-Campen et al. (2015). Meier et al. (2014) and UNEP (2015) also use it as a reference system for their own research.

Modelling global GHG emissions

All other things being equal, and as increasing amounts of land are being used globally for agriculture, the additional virtual land needed by the EU must come from land use changes elsewhere, and particularly from converting natural or nature-like habitats into acreage. However, these habitats (which are not used for farming) are an important carbon sink. They sequester carbon not yet released as carbon dioxide (CO_2).

Knowing where and how much land would be converted (from the virtual net land trade model) allows GHG effects to be calculated on a global scale. Regional carbon release factors per converted hectare are used to calculate these effects and are obtained from Tyner et al. (2010). Other sources for carbon release factors, such as Searchinger et al. (2008), Searchinger and Heimlich (2008), Heiderer et al. (2010), Laborde (2011), and Marelli et al. (2011), are not used, since they tend to postulate higher release fractions of carbon and therefore may overestimate the GHG emissions from land use changes.

Modelling global biodiversity losses

The conversion of natural habitats into agricultural land also leads to a global loss of biodiversity. Although measuring biodiversity and its changes is a challenging task, a variety of methods have been developed, and a considerable number of biodiversity indicators have been published. All have their pros and cons. This is why there is no generally accepted science-based indicator for mapping biodiversity and the loss thereof. This study takes a pragmatic approach, applying two dissimilar but frequently used indicators to cope with the inherent uncertainty.

First, the Global Environment Facility Benefits Index of Biodiversity (GEF-BIO) is used (e.g. UNEP, 2009; Wright, 2011). It captures the status quo of biodiversity as well as its changes in each country. Therefore, it allows not only the pure accounting of different species, but also the mapping of species and their loss by regional distribution. This indicator is consistent with the targets of the Convention of Biological Diversity (CBD) and was originally developed by Dev Pandey et al. (2006). It is a well-tested composite index of relative biodiversity based on the species represented in a country, their threat status, and the diversity of habitats. Moreover, the index is easy to handle. It is standardised on the {0; 100}-interval. Brazil is the country with the maximum degree of biodiversity. Its natural habitats are rated at 100. On the other end of the spectrum is Nauru, an island nation in the Pacific Ocean. Its natural habitats are rated 0. Other countries are rated between these extremes. Therefore, 100 biodiversity points globally lost by converting land in a given place are comparable to the species richness found on one hectare of natural habitat in Brazil.

Second, the National Biodiversity Index (NBI), developed by the CBD (2001), is applied. It is used in the CBD's Global Biodiversity Reports. The NBI is based on estimates of a country's richness and endemism in four classes of terrestrial vertebrate and vascular plants, which are given the same weight in the index. Multiplied by 100, original NBI values range from 100 (the maximum value is assigned to Indonesia) to 0 (the minimum value is allocated to Greenland). Accordingly, 100 biodiversity points globally lost by the conversion of land in a given place are comparable to the species richness that can be found on one hectare of natural habitat in Indonesia.

Modelling changes in the use of (virtual) global water resources

To calculate impacts on virtual water use, production and associated trade change data (already used to detect changes in the use of global land resources for virtual net trade balances, as mentioned above) must be linked with regional water footprint data for EU and global agriculture. Water footprint data is given in Mekonnen and Hoekstra (2011a; b) by unit of production for every crop in this study and for each EU trading partner. Therefore, the multiplication of changing regional trade (import versus export) volumes with water footprint data – also extensively described in Noleppa and Cartsburg (2015) – reveals how much agricultural water is or will be used domestically and traded abroad in different scenarios.

4 Quantitative results – farmers/growers

In this chapter, the importance of the EU-level PVR system is assessed from the growers' point of view in terms of major economic and environmental indicators. These indicators are, respectively:

- market supply, net trade volumes, market prices, sectoral income, GDP contributions, food availability, farm income as well as farm and other labour (see Section 4.1).

- global land use, GHG emissions, biodiversity changes, and water use (see Section 4.2).

Throughout the analysis, results for arable crops, fruit, vegetables, and ornamentals will be discussed separately when appropriate. Moreover, qualitative arguments regarding the value of the EU-level PVR system will be addressed, since these arguments cannot easily be measured in terms of quantifiable indicators based on plant breeding-induced yield developments (see Section 4.3).

Finally, Section 4.4 describes the system of breeders that register CPVRs and quantifies the sector in terms of economic output and employment.

The following scenario calculations aim to explain the effect on various economic and environmental indicators today (in 2020) if plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR had not occurred. To do so, the quantity of crops that would not have been produced without plant breeding in the past 25 years must be assessed. Moreover, the hypothetical missing volume attributable to varieties with EU-level PVR must be calculated.

To calculate the impacts on certain indicators, the scenario definition must supply a shift factor that will produce a shock on various models of agricultural (and later environmental) economics. These models must be confronted with a parameter that describes crop production in today's EU arable and horticultural farming without plant breeding-induced yield growth since 1995 in varieties with an EU-level PVR in terms of all the varieties available. This shock parameter simulates a relative production change per crop expressed as the percentage change to be calculated.

This is done by accumulating the average annual plant breeding-induced yield growth rates (see Table 3.10 for arable crops, Table 3.11 for fruit, Table 3.12 for vegetables, and the fourth bullet point displayed below Table 3.12 for ornamentals) between 1995 and 2019, using the compound interest approach multiplied by the share of varieties with an EU-level PVR among all the varieties registered (see Table 3.13 for arable crops, Table 3.14 for fruit, Table 3.15 for vegetables and Table 3.16 for ornamentals) ([95]).

Arable crops

Figure 4.1 displays the simulated potential production loss for the chosen major arable crops without plant breeding in the EU in the last quarter of a century, as well as the share of this impact that can be attributed to varieties with an EU-level PVR.

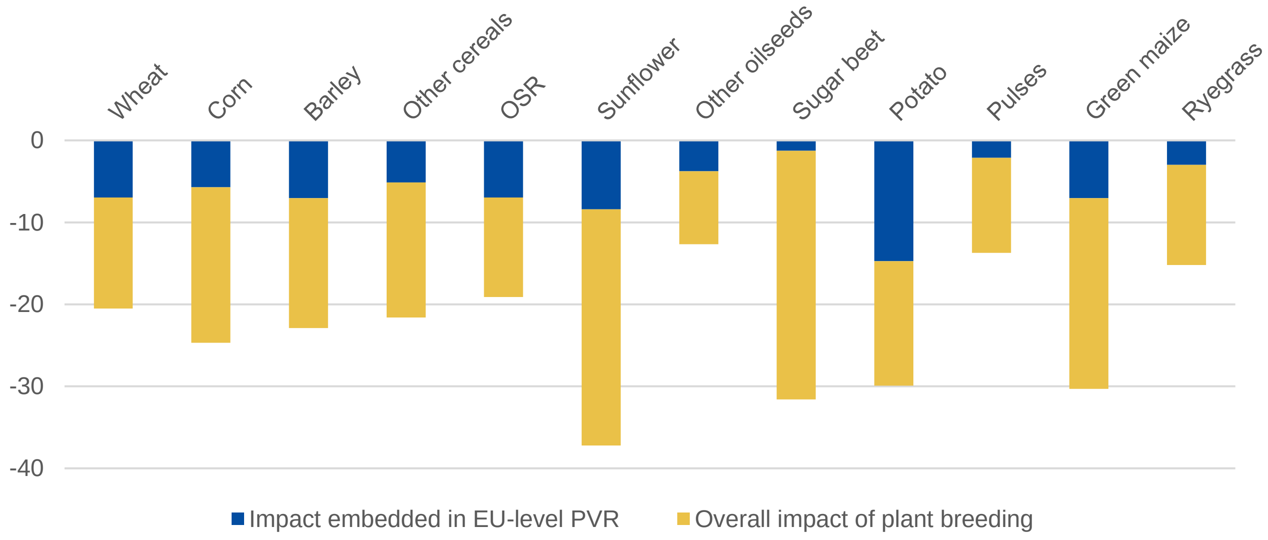


Figure 4.1. Simulated potential production loss for arable crops in 2020 without plant breeding progress between 1995 and 2019 in the EU and the share related to varieties with an EU-level PVR (per cent)

([95]) It is assumed that varieties with an EU-level PVR also have a seed market share that can be expressed with this ratio.

Had past genetic crop improvements not occurred, a remarkable drop in current arable production would be expected across all crops. For example, approximately one fifth of current EU wheat production would be missing. In the cases of sugar beet and sunflower, the loss would be around or even above one third. Inversely rated, EU arable farming today produces much more on arable land due to the plant breeding successes of the past 25 years. Weighted by current acreage, the production loss in 2020 associated with missing plant breeding progress between 1995 and 2019 would equal 22.6 % of total arable production in the EU (96).

The dark blue pillars in figure 4.1 show that almost one third of this production, or 6.4 % of the total, is attributable to the EU-level PVR on average and hectare-weighted. Accordingly, the crop-specific parameters given in table 4.1 – describing crop production in today's EU arable farming without plant breeding-induced yield growth since 1995 in the varieties with an EU-level PVR – will be used to shock the various models.

CROP	SHOCK FACTOR	CROP	SHOCK FACTOR	CROP	SHOCK FACTOR
Wheat	-6.95	OSR	-6.95	Potato	-14.74
Corn	-5.73	Sunflower	-8.41	Pulses	-2.12
Barley	-7.05	Other oilseeds	-3.76	Green maize	-7.03
Other cereals	-5.12	Sugar beet	-1.26	Ryegrass	-2.99

Table 4.1. Shock factors simulating potential production loss for arable crops in 2020 without plant breeding progress in varieties with an EU-level PVR (per cent)

Fruit

Similarly, Figure 4.2 shows the simulated potential fruit production loss without plant breeding progress in the EU over the past 25 years, as well as the share of this impact that is attributable to varieties with an EU-level PVR. Again, a considerable amount of EU fruit production would be missing without plant breeding-induced yield growth over the past quarter of a century, and particularly without the varieties with an EU-level PVR developed in this period. Weighted by current

---

(96) Noleppa and Cartsburg (2021), referring to the period 2000-2019 instead of 1995-2019, calculate an average production loss of 20.6 % for arable crops (excluding ryegrass).

land use, the production loss in 2020 associated with missing fruit-related plant breeding progress between 1995 and 2019 would amount to 22.4 %. More specifically, it is between 1.0 % and almost 11.0 %, averaging 2.6 % (hectare-weighted) for the fruit varieties with an EU-level PVR.

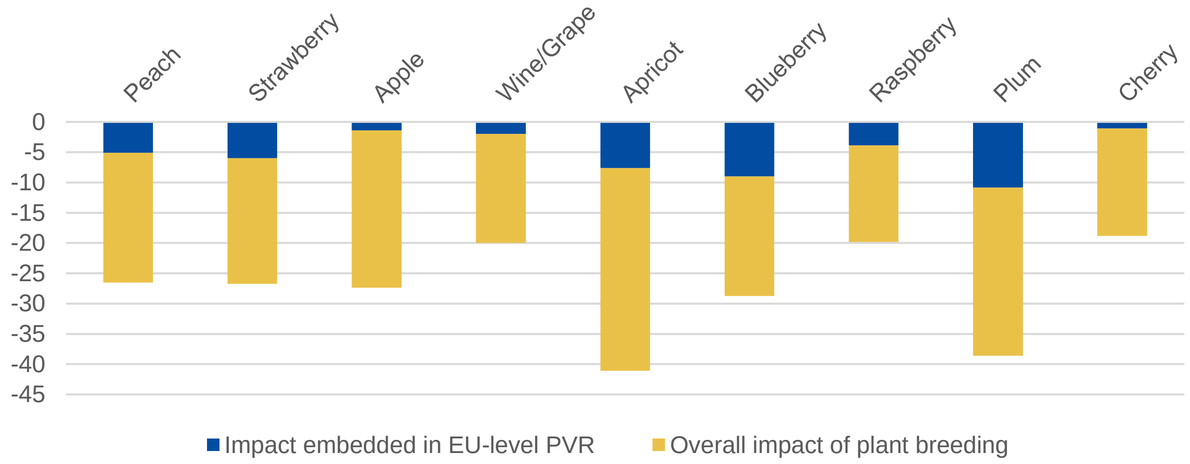


Figure 4.2. Simulated potential production loss for fruit in 2020 without plant breeding progress between 1995 and 2019 in the EU, and the share attributable to varieties with an EU-level PVR (per cent)

This potential production loss without plant breeding progress in varieties with an EU-level PVR per crop is shown in Table 4.2.

CROP	SHOCK FACTOR	CROP	SHOCK FACTOR	CROP	SHOCK FACTOR
Peach	-5.10	Wine/grape	-1.98	Raspberry	-3.86
Strawberry	-5.99	Apricot	-7.64	Plum	-10.85
Apple	-1.39	Blueberry	-9.00	Cherry	-1.07

Table 4.2. Shock factors simulating potential production loss for fruit in 2020 without plant breeding progress in varieties with an EU-level PVR (per cent)

Vegetables

The same figures can be calculated for vegetables, as Figure 4.3 and Table 4.3 show. The hectare-weighted average production loss amounts to 26.0 % for vegetables in general. For varieties with an EU-level PVR, the average is 4.7 % and the figures range between almost 2.1 and 7.5 %. Therefore, a remarkable drop of available food could be expected if vegetables with an EU-level PVR were missing.

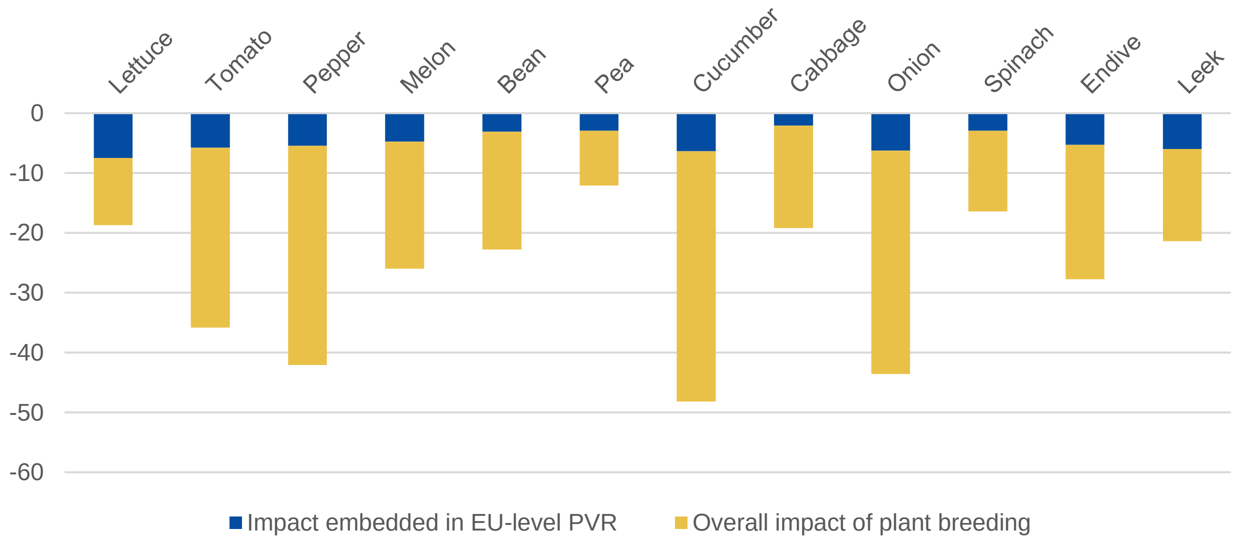


Figure 4.3. Simulated potential production loss for vegetables in 2020 without plant breeding progress between 1995 and 2019 in the EU, and the share attributable to varieties with an EU-level PVR (per cent)

CROP	SHOCK FACTOR	CROP	SHOCK FACTOR	CROP	SHOCK FACTOR
Lettuce	-7.50	Bean	-3.10	Onion	-6.23
Tomato	-5.76	Pea	-2.93	Spinach	-2.95
Pepper	-5.43	Cucumber	-6.36	Endive	-5.30
Melon	-4.78	Cabbage	-2.09	Leek	-6.01

Table 4.3. Shock factors simulating potential production loss for vegetables in 2020 without plant breeding progress in varieties with an EU-level PVR (per cent)

Ornamentals

The final calculation at this stage simulates the potential production loss for ornamentals, both in general and for varieties with an EU-level PVR in particular. The (monetised) yield progress is 0.71 % per year (see the fourth bullet point below Table 3.12), and the share of registered varieties with an EU-level PVR among all registered varieties totals almost 97 % (see Table 3.16). These translate into a simulated potential production loss of 15.6 % for plant breeding in general and 15.1 % for varieties with an EU-level PVR.

4.1 Economic impacts on growers, global competitiveness, and the society at large

Based on the models and tools of agricultural economics discussed in Subsection 3.2.2, the economic impacts of the EU PVR system on agricultural markets, farms and society at large can be assessed in terms of the indicators mentioned at the beginning of this chapter.

4.1.1 Market supply

Arable crops

Plant breeding progress in varieties with an EU-level PVR since 1995 has allowed the EU to supply additional (domestic) market volumes in 2020, which would otherwise have experienced the losses shown in Table 4.4 ([97]).

CROP	LOSS	CROP	LOSS	CROP	LOSS
Wheat	8.09	OSR	1.00	Potato	7.45
Corn	3.74	Sunflower	0.73	Pulses	0.09
Barley	2.89	Other oilseeds	0.60	Green maize	8.70
Other cereals	1.65	Sugar (raw)	0.26	Ryegrass	1.89

Table 4.4. Market supply loss for arable crops in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

For cereals as a whole, the market supply loss is over 16 million tons, and wheat alone accounts for 8 million tons. Oilseeds total 2.3 million tons, with OSR alone accounting for 1 million tons. Potatoes

---

([97]) Sugar beets are not traded internationally at the market level. Therefore, the impacts referring to raw sugar equivalents are described below. Furthermore, only domestic markets for green maize and ryegrass are assumed.

and raw sugar produced from sugar beets represent 7.5 and 0.3 million tons respectively. The supply of pulses has increased by approximately 0.1 million tons due to plant breeding progress, while almost 9 million tons of green maize and 2 million tons of ryegrass are available.

Fruit

Considerable quantities of EU fruit produce would be missing from the market without plant breeding progress in varieties with an EU-level PVR since 1995. The crop-specific amounts are displayed in Table 4.5. They show that today, for example, almost 0.5 million tons of grapes and 140 000 tons of apples would not be supplied by EU sources. In total, more than 1.0 million tons of fruit would be missing.

CROP	LOSS	CROP	LOSS	CROP	LOSS
Peach	0.17	Wine/grape	0.47	Raspberry	0.01
Strawberry	0.06	Apricot	0.06	Plum	0.16
Apple	0.14	Blueberry	0.01	Cherry	0.01

Table 4.5. Market supply loss for fruit in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Vegetables

The same applies to vegetables: a remarkable volume would not be on the market today without plant breeding progress in varieties with an EU-level PVR since 1995. The crop-specific volumes are shown in Table 4.6. For example, 1.2 million tons of tomato originating in the EU would be missing. In total, 2.3 million tons of mainly fresh vegetables currently supplied at EU market level would be affected.

CROP	LOSS	CROP	LOSS	CROP	LOSS
Lettuce	0.20	Bean	0.02	Onion	0.35
Tomato	1.20	Pea	0.02	Spinach	0.02
Pepper	0.15	Cucumber	0.16	Endive	0.02
Melon	0.21	Cabbage	0.08	Leek	0.03

Table 4.6. Market supply loss for vegetables in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Ornamentals

The domestic market supply loss analysis for ornamentals differs from those above because it is a monetary assessment (in euro). Keeping this in mind, the monetary market supply of this group of crops would shrink by EUR 2.5 billion based on data from the EC (2020c) and Eurostat (2022b). In fact, ornamentals have a rather high added value in horticultural production. The total EU production value is currently more than EUR 22.5 billion (EC, 2020).

4.1.2 Net trade volumes

Arable crops

Changing market supply affects trade volumes. The resulting changes – in terms of current EU-extra trade for arable crops – if plant breeding progress in varieties with an EU-level PVR since 1995 had not occurred are depicted in Figure 4.4. Here, the figures with EU-level PVR represent the status quo in terms of net trade, that is exports minus imports, using statistics provided by the FAO (2021).

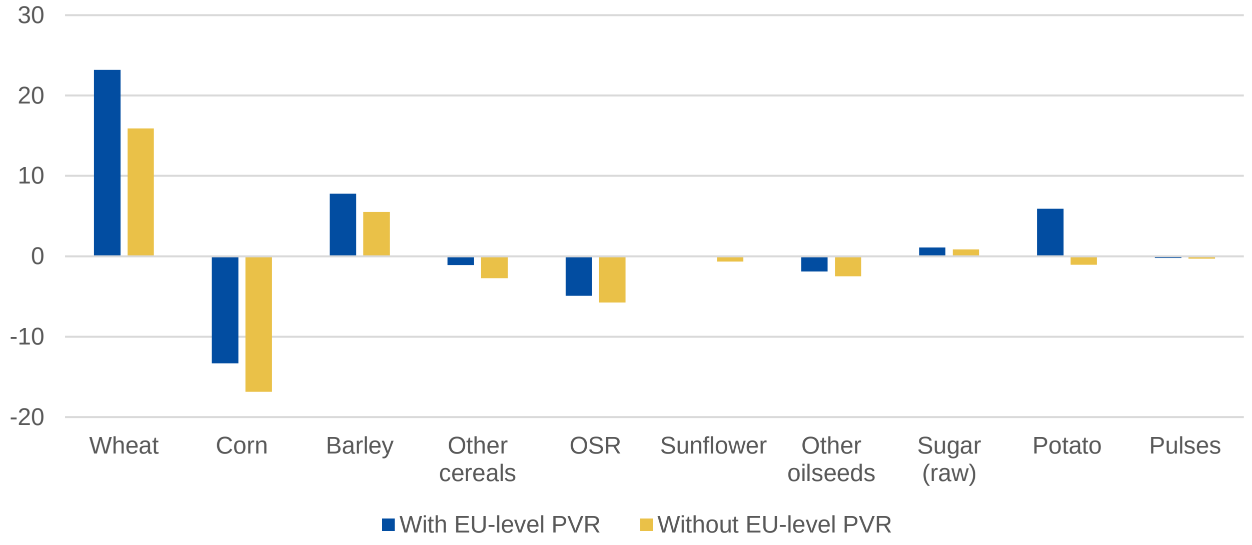


Figure 4.4. Net EU trade volumes for arable crops in 2020 with and without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Therefore, plant breeding progress in the past 25 years, in varieties with an EU-level PVR, allows the EU to remain an exporter of major arable crops, such as wheat, barley, raw sugar, and potato. All other commodities already have a net import balance in agricultural commodity trade.

Without EU-level PVR-related progress in crop genetics in the past 25 years, the EU would currently be in a much worse agricultural trade situation. It would be a net importer of potato, for instance. Apart from this, EU agricultural trade would have deteriorated considerably without progress by European plant breeders in varieties with an EU-level PVR. In the cases of wheat and barley, for instance, net exports would have shrunk by approximately 30 %. Net imports would also have considerably increased in the cases of corn (27 %), other cereals (146 %), and OSR (17 %).

These developments would be caused by changes in exports and imports due to the missing market supply as well as changes in demand (triggered by price changes; see Subsection 4.1.3). Table 4.7 shows these crop-specific net trade changes, which are slightly lower than the market supply changes above due to a price-driven decrease in demand for the relevant arable crops.

CROP	∆ NET TRADE	CROP	∆ NET TRADE	CROP	∆ NET TRADE
Wheat	-7.28	OSR	-0.85	Potato	-6.95
Corn	-3.55	Sunflower	-0.66	Pulses	-0.09
Barley	-2.26	Other oilseeds	-0.59	Green maize	n. a.
Other cereals	-1.61	Sugar (raw)	-0.25	Ryegrass	n. a.

Table 4.7. Net trade changes for arable crops in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Fruit

Similarly, Figure 4.5 displays the change in net EU trade volumes for fruit in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR. The net trade balance for typical fruit grown in the EU would deteriorate while remaining positive. In the cases of peach and strawberry, for instance, the balance would be almost zero, while net exports of apple would decrease by almost 15 %. In addition, already negative net trade balances would become even more substantial. For example, net imports of wine/grape and plum would more than double in the absence of plant breeding progress between 1995 and 2019 in grape and plum varieties with an EU-level PVR.

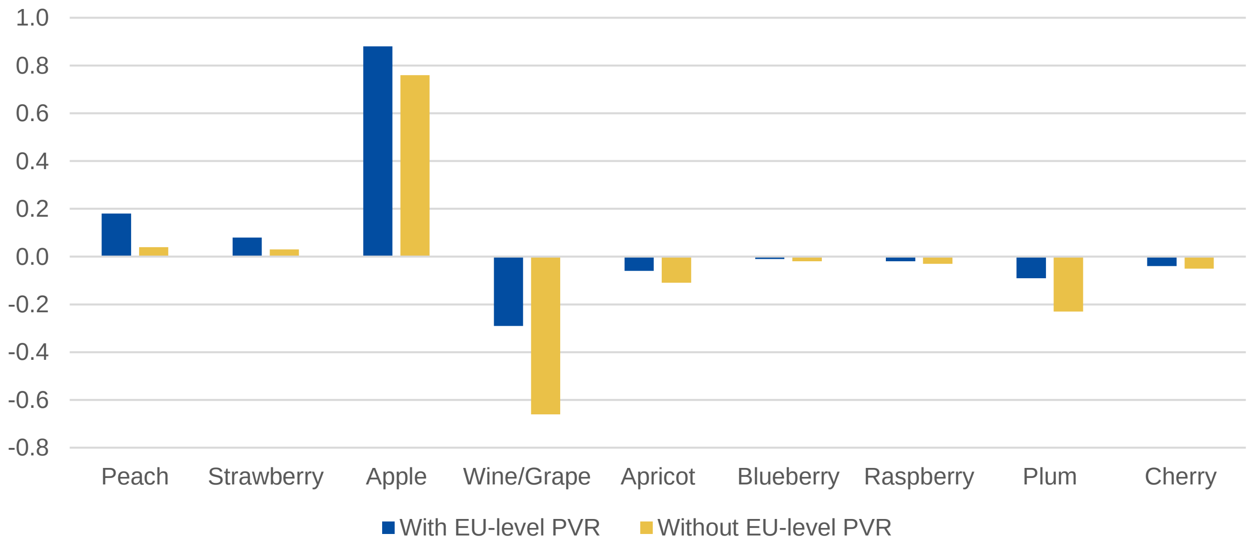


Figure 4.5. Net EU trade volumes for fruit in 2020 with and without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Again, these developments would be caused by changes in exports and imports due to the missing market supply, as well as changes in demand due to market price changes. Like Table 4.7 for arable crops, Table 4.8 shows these crop-specific net trade changes for fruit, which are again all negative.

CROP	∆ NET TRADE	CROP	∆ NET TRADE	CROP	∆ NET TRADE
Peach	-0.14	Wine/Grape	-0.37	Raspberry	-0.01
Strawberry	-0.05	Apricot	-0.05	Plum	-0.14
Apple	-0.12	Blueberry	-0.01	Cherry	-0.01

Table 4.8. Net trade changes for fruit in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

Vegetables

The above arguments can be repeated for vegetables, as Figure 4.6 and Table 4.9 show. Positive net trade balances would deteriorate, while negative net trade balances would become even more substantial.

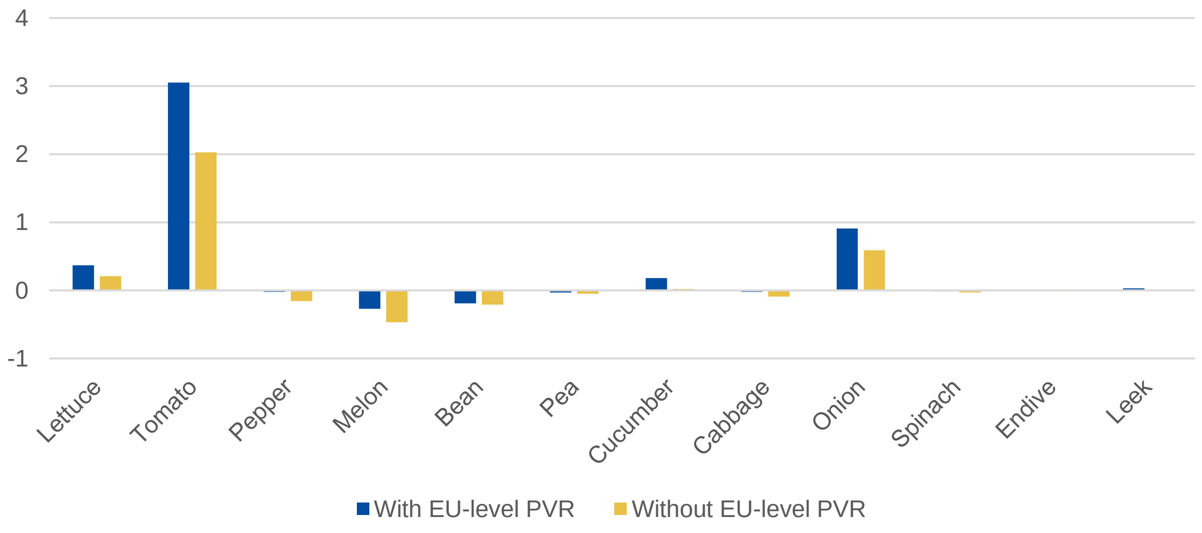


Figure 4.6. Net EU trade volumes for vegetables in 2020 with and without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

CROP	∆ NET TRADE	CROP	∆ NET TRADE	CROP	∆ NET TRADE
Lettuce	-0.16	Bean	-0.02	Onion	-0.32
Tomato	-1.02	Pea	-0.02	Spinach	-0.02
Pepper	-0.14	Cucumber	-0.16	Endive	-0.01
Melon	-0.20	Cabbage	-0.07	Leek	-0.02

Table 4.9. Net trade changes for vegetables in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)

This can be illustrated by the following two examples. First, the case of tomatos shows that, without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, the positive net trade balance would shrink by approximately one third, since more than 1.0 million tons could no longer be exported. Second, the case of melons shows that an additional import of around 200 000 tons due to missing European produce would almost double crop-specific net imports.

Ornamentals

In the case of ornamentals, a substantial part of the loss to domestic market supply would be compensated by international trade activities. For this group of crops, the positive net trade balance would disappear. Currently, the net EU export of ornamentals totals over EUR 1.8 billion (Eurostat 2022b). Without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, quantities worth almost EUR 1.9 billion would need to be imported today. Consequently, the EU would slide into a net import situation, albeit a very small one, for ornamentals as a whole.

4.1.3 Market prices

Arable crops

A comparatively large market supply volume based on varieties with an EU-level PVR not only creates a benefit in terms of the net trade balance as mentioned above: it also enables consumers in the EU and around the globe to buy food and agricultural raw materials at affordable prices (98). Table 4.10 depicts the market price effect of plant breeding progress since 1995 in varieties with an EU-level PVR.

It turns out that prices on internationally linked agricultural commodity markets would be 3 % higher or more today without this progress. Except for green maize and ryegrass, which are not traded (99), the global market price increase is highest (3.6 %) for barley, which is a rather narrow world market in which the EU is a major player. Other oilseeds (mainly soybeans) have the lowest increase (0.1 %). This market is huge in terms of globally traded volumes, with comparably little affected supply coming from the EU.

CROP	PRICE CHANGE	CROP	PRICE CHANGE	CROP	PRICE CHANGE
Wheat	2.98	OSR	2.76	Potato	2.87
Corn	0.59	Sunflower	2.82	Pulses	0.11
Barley	3.56	Other oilseeds	0.10	Green maize	7.56
Other cereals	0.26	Sugar (raw)	0.19	Ryegrass	4.71

Table 4.10. Arable crop price changes by 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (per cent)

---

(98) Apart from this basic price-decreasing effect of genetic improvements, plant breeding progress in varieties with an EU-level PVR also contributes to price stabilisation. Larger tradeable volumes due to plant breeding-related efforts in the EU tend to lower market volatility. Agricultural commodity prices are volatile for several reasons, such as inelastic markets, weather and climate change phenomena, emerging plant diseases, ad hoc policy decisions such as export stops and import bans, input use restrictions, etc. Genetic improvements, and the resulting higher marketable volumes, help keep price volatility low in this rather unfavourable environment (e.g., Santeramo and Lamonaca, 2019).

(99) Since there is neither an EU-wide nor a broader international market for green fodder such as green maize and ryegrass, modelling monetary impacts (e.g. prices and income effects) for these crops is a challenge. The challenge is even greater since green maize and ryegrass are often used internally within a farm, and opportunity costs must be taken into consideration. In accordance with Karoshi (2021), a ‘value price’ of EUR 33.50 per ton (fresh matter) is assumed for the purpose of this study.

Fruit

In the case of fruit, plant breeding progress since 1995 in varieties with an EU-level PVR has also contributed to comparatively low market prices. The corresponding fruit price increases are shown in Table 4.11, and range between 0.5 % and 4.0 %.

CROP	PRICE CHANGE	CROP	PRICE CHANGE	CROP	PRICE CHANGE
Peach	2.03	Wine/Grape	1.05	Raspberry	1.54
Strawberry	3.05	Apricot	3.96	Plum	3.83
Apple	0.50	Blueberry	3.77	Cherry	0.62

Table 4.11. Fruit price changes by 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (per cent)

Vegetables

Slightly larger, but on the same scale, is the range of price increases for vegetables. Without plant breeding progress since 1995 in varieties with an EU-level PVR, the current market prices for vegetables would be between 0.38 and more than 5.7 % higher, as shown in Table 4.12.

CROP	PRICE CHANGE	CROP	PRICE CHANGE	CROP	PRICE CHANGE
Lettuce	4.03	Bean	0.42	Onion	1.55
Tomato	2.63	Pea	0.49	Spinach	0.38
Pepper	1.22	Cucumber	1.18	Endive	2.74
Melon	0.96	Cabbage	0.69	Leek	5.72

Table 4.12. Vegetable price changes by 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (per cent)

Ornamentals

Market shortages would also tend to increase the prices of ornamentals. The average price increase would be 10.5 %, higher than those for many arable crops, fruit, and vegetables. This comparatively high potential price increase is due to (a) the comparably high production shock and (b) the major importance of the EU on the global ornamental market.

4.1.4 Sectoral income

Arable crops

Changing market volumes and market prices affect the income of the market participants who determine supply and demand. From an analytical perspective, changes in so-called societal welfare ([100]) may serve as a proxy for changes in these market-borne, or rather sector-borne, income effects. The current social welfare effect – from an analytical and modelling perspective, the sum of so-called producer surpluses (producer income) and consumer surpluses (consumer savings) ([101]) – of plant breeding progress in the EU between 1995 and 2019 in varieties with an EU-level PVR for arable crops is listed in Table 4.13 and visualised in Figure 4.7.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Wheat	-1,093	OSR	-354	Potato	-1,316
Corn	-466	Sunflower	-185	Pulses	-16
Barley	-373	Other oilseeds	-216	Green maize	-402
Other cereals	-204	Sugar (raw)	-47	Ryegrass	-97

Table 4.13. Arable crop sectoral income changes in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

([100]) This methodological concept is standard in agricultural economics (e.g. Houck, 1986; Jechlitschka et al., 2007) and has often been successfully applied (e.g., Saunders and Driver, 2016; Blandford, 2015).

([101]) The present discussion focuses on the market for agricultural raw materials. Consumers in this context are largely farmers, who also use the crop output as an input for feeding animals and/or bioenergy facilities. In this case especially, it makes sense to include consumer savings in what will be considered a sectoral income effect of plant breeding progress in varieties with an EU-level PVR.

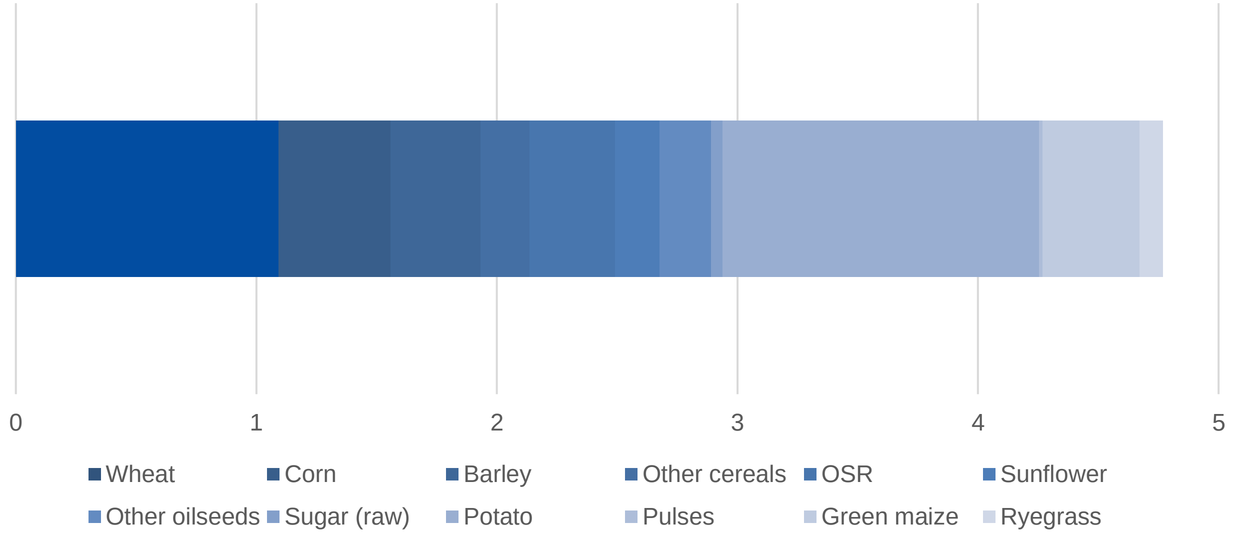


Figure 4.7. Additional arable crop sector income in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (billion EUR)

The total social welfare gains of plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR for arable crops in the EU amount to more than EUR 4.8 billion in 2020.

Fruit

For fruit, an additional sector income of almost EUR 1.0 billion is currently created due to plant breeding progress since 1995 in varieties with an EU-level PVR, as Table 4.14 and Figure 4.8 suggest. 36 % of this may be attributed to the wine/grape subsector alone, while another 41 % can be attributed to the five listed pome fruits.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Peach	-116	Wine/Grape	-339	Raspberry	-33
Strawberry	-144	Apricot	-73	Plum	-119
Apple	-67	Blueberry	-44	Cherry	-16

Table 4.14. Fruit sectoral income changes in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

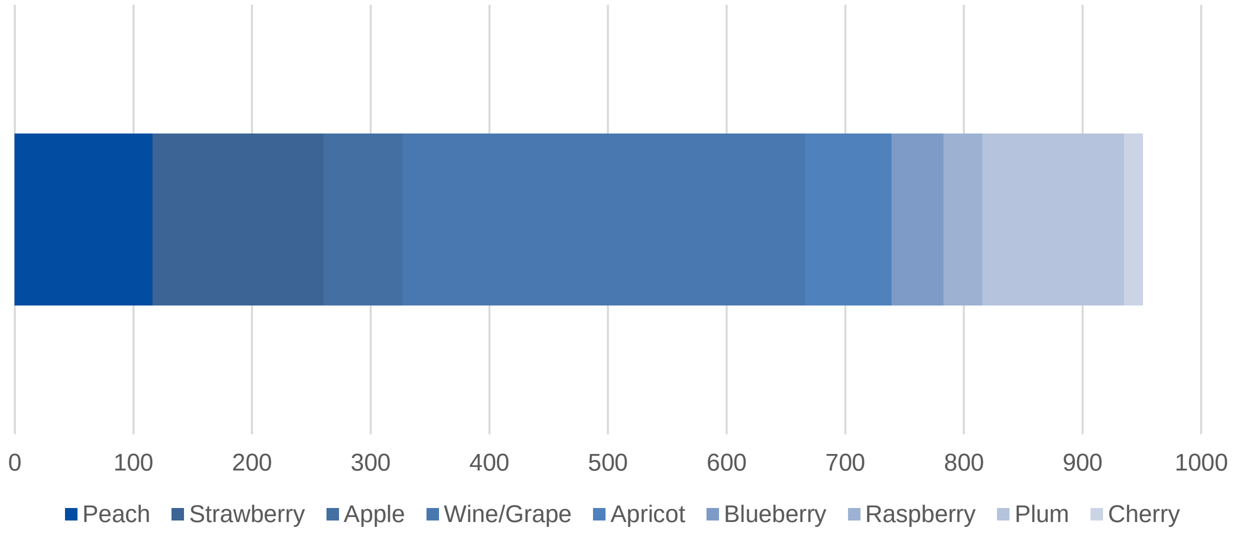


Figure 4.8. **Additional fruit sector income in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)**

Vegetables

For vegetables, an additional sector income of more than EUR 1.8 billion is currently generated due to plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR for the 12 analysed crops. The details per crop are given in Table 4.15 and visualised in Figure 4.9. More than half of the additional sub-sectoral income may be attributed to tomato. The remaining 11 crops, therefore, account for no more than 46 % of the additional income generation.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Lettuce	-186	Bean	-25	Onion	-239
Tomato	-987	Pea	-22	Spinach	-17
Pepper	-110	Cucumber	-101	Endive	-22
Melon	-58	Cabbage	-26	Leek	-26

Table 4.15. **Vegetable sectoral income changes in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)**

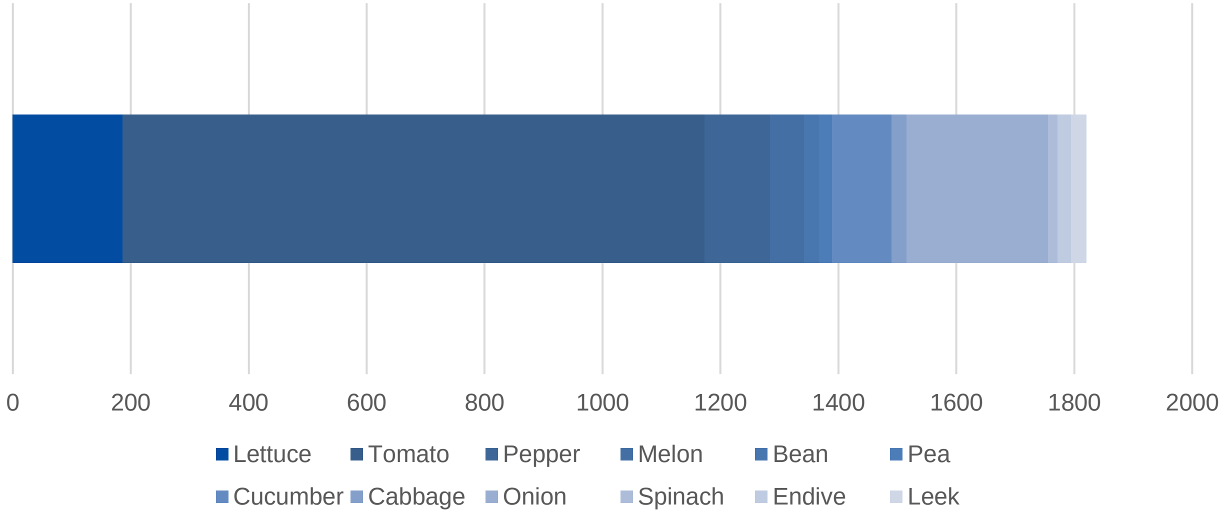


Figure 4.9. Additional vegetable sector income in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

Ornamentals

Due to the specific model content for ornamentals – market volumes are already expressed in euro and not in tons – the model fails when calculating sector income effects. However, assuming that yield progress due to plant breeding in varieties with an EU-level PVR, which account for almost all registered varieties, does not come at a large extra cost, it may be argued that almost all of the market loss, valued at EUR 2.5 billion, should also be considered a direct sector income loss.

According to the available information, the current gross value added in the EU agricultural sector (including forestry and fishery) – a statistical proxy for sectoral income – totals approximately EUR 239 billion (Eurostat, 2021c). The implication is that this number, on aggregate for arable crops, fruit, vegetables, and ornamentals, would have been almost 5 % lower without plant breeding progress since 1995 in varieties with an EU-level PVR.

4.1.5 GDP contributions

Arable crops

Obviously, genetic crop improvements in varieties with an EU-level PVR have a strong economic sectoral impact in the EU. The findings of Lenaerts et al. (2016) support the conclusion that investment in plant breeding activities pays off economically. However, these activities are considered to offer very high returns on investment not only from a private but also a societal perspective (Lotze-Campen et al., 2015; Cobb et al., 2019). Against this background, it is worth examining not only the EU PVR system's effects on sectoral income but also its GDP contributions.

Indeed, plant breeding progress in varieties with an EU-level PVR not only benefits the primary agricultural sector but society as a whole. It also creates economic value for (mainly rural) citizens upstream and downstream in the value chain, because the additional agricultural raw material must be transported, processed, traded, retailed, etc. This tends to increase income generation in other sectors. Accordingly, the additional producer surplus generated through varieties with an EU-level PVR (forming a substantial part of the societal welfare effect discussed in the previous subsection) must be linked to GDP multipliers as described in Subsection 3.2.2. Table 4.16 summarises the results of this multiplier analysis for the EU and its arable farming.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Wheat	-1 250	OSR	-377	Potato	-2 639
Corn	-669	Sunflower	-192	Pulses	-36
Barley	-427	Other oilseeds	-309	Green maize	-588
Other cereals	-365	Sugar (raw)	-98	Ryegrass	-142

Table 4.16. GDP changes related to arable crops in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

The overall GDP contribution of plant breeding progress since 1995 in varieties of arable crops with an EU-level PVR amounts to almost EUR 7.1 billion. Figure 4.10 shows this in terms of:

- agricultural GDP of more than EUR 3.4 billion,

- non-agricultural GDP of more than EUR 3.6 billion, due to multiplier effects upstream and downstream in the various agricultural and food value chains.

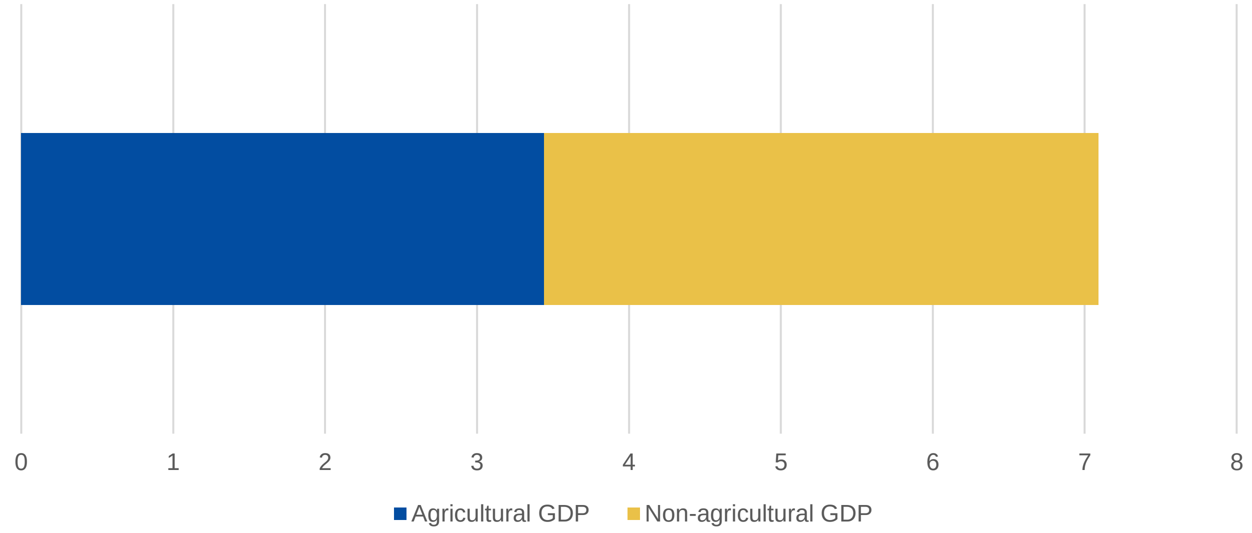


Figure 4.10. GDP surplus related to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (billion EUR)

Fruit

Similarly, Table 4.17 and Figure 4.11 show the current GDP impacts of plant breeding progress between 1995 and 2019 in fruit varieties with an EU-level PVR. It amounts to over EUR 1.1 billion, of which 40 % alone is attributable to wine/grapes, and can furthermore be divided into:

- agricultural GDP of over EUR 700 million,
- non-agricultural GDP worth over EUR 400 million.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Peach	-137	Wine/Grape	-409	Raspberry	-45
Strawberry	-190	Apricot	-76	Plum	-144
Apple	-81	Blueberry	-56	Cherry	-20

Table 4.17. GDP changes related to fruit in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

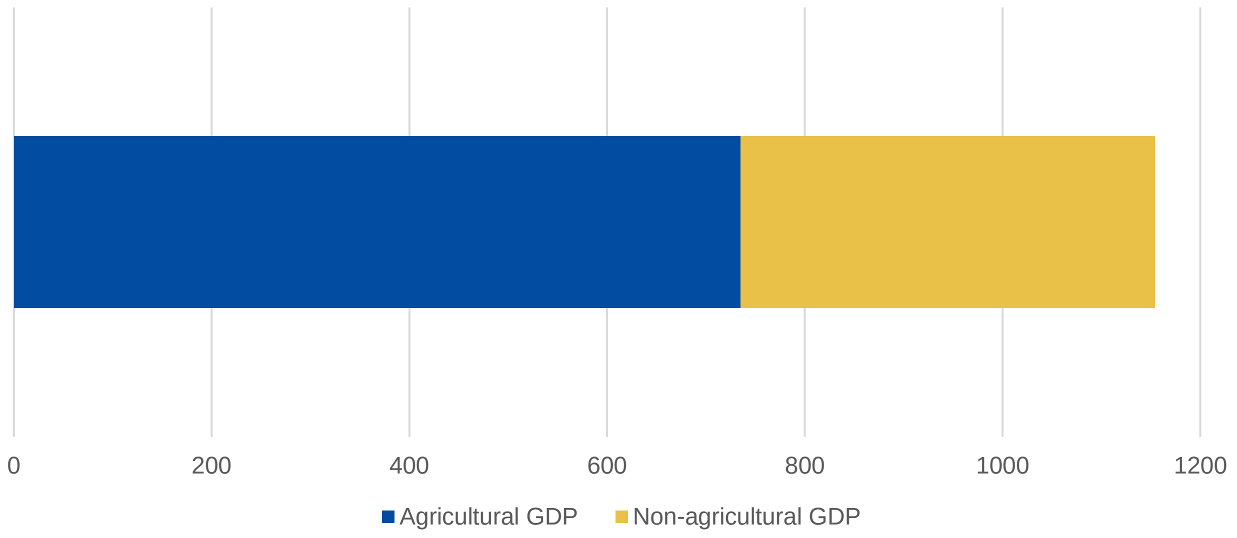


Figure 4.11. GDP surplus related to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

<u>Vegetables</u>

Finally, the accumulated GDP impact of plant breeding since 1995 in vegetable varieties with an EU-level PVR is over EUR 2.2 billion, as depicted in Table 4.18 and Figure 4.12. This can be divided into:

- agricultural GDP of over EUR 1.4 billion,
- non-agricultural GDP of approximately EUR 0.8 billion.

CROP	INCOME CHANGE	CROP	INCOME CHANGE	CROP	INCOME CHANGE
Lettuce	-231	Bean	-36	Onion	-323
Tomato	-1,127	Pea	-31	Spinach	-25
Pepper	-149	Cucumber	-148	Endive	-27
Melon	-83	Cabbage	-35	Leek	-28

Table 4.18. GDP changes related to vegetables in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR).

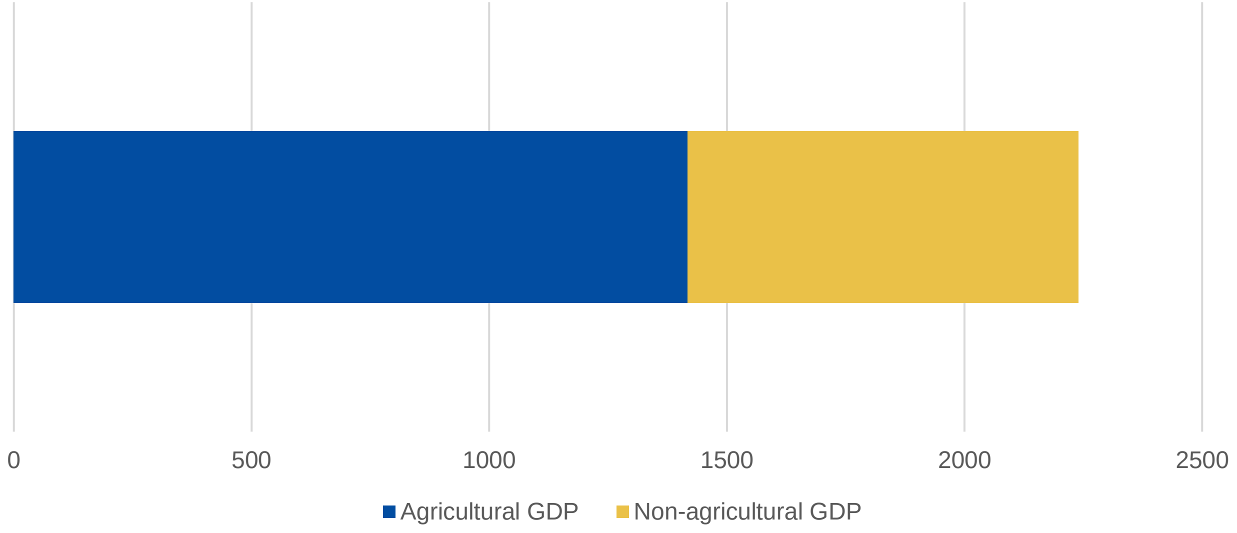


Figure 4.12. GDP surplus related to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million EUR)

Ornamentals

Due to the specific characteristics of the underlying market model (see Section 3.2) and because of a generally weak data background, and particularly unavailable multipliers, this GDP analysis cannot be carried out for ornamentals. However, it is expected that the GDP impact is higher than the already calculated sectoral income effect of EUR 2.5 billion.

On aggregate for arable crops, fruit, vegetables, and ornamentals, therefore, the overall GDP impact of plant breeding progress since 1995 in varieties with an EU-level PVR is around EUR 13.0 billion.

This equals the entire GDP of Malta, and almost half the GDP of EU Member States such as Estonia, Cyprus, and Latvia (Statista, 2022).

4.1.6 Food availability

Arable crops

Plant breeding in varieties with an EU-level PVR increases arable production in the EU. A substantial part of this production via market supply is used as food. Therefore, the EU's PVR system also tends to increase food availability and, by extension, food security. The share of the current increased food availability (or security) that is attributable to plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR will be analysed below. For this purpose, a food basket is imagined, filled with an average amount of food from the 10 relevant arable crop groups (102) that are consumed per capita and per year at (a) the EU level and (b) the global level (103). This is based on food balances for these two regional definitions obtained from the FAO (2021).

Figure 4.13 shows the number of additional people who can be provided with a full food basket of arable crops in 2020 due to plant breeding progress in varieties with an EU-level PVR between 1995 and 2019.

---

(102) Green maize and ryegrass are not used as food and therefore are excluded from the analysis.

(103) The assumption is that food is fully substitutable: wheat can be substituted by corn and vice versa, OSR oil can be substituted by sunflower oil and vice versa, etc.

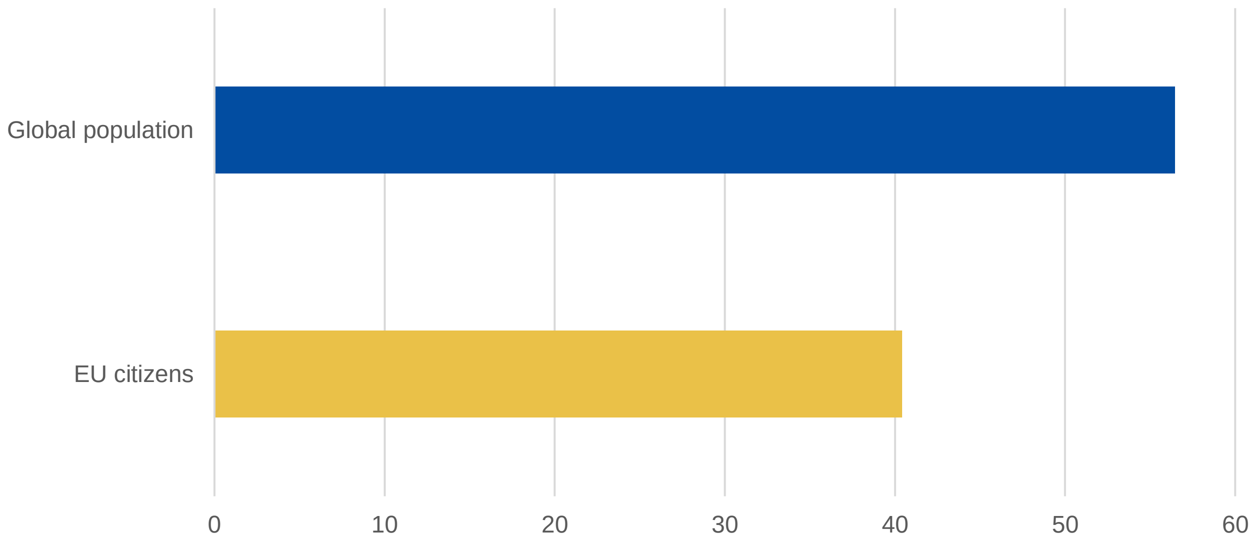


Figure 4.13. Arable crops additionally available as food in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (food for million people)

These plant breeding efforts have dramatically increased the global food availability of grains, oilseeds, root crops, etc. In 2020, food baskets filled with produce from the 10 relevant arable crop groups became available worldwide for almost 57 million more people. In the EU, more than 40 million more citizens were provided with food from arable crops than would otherwise have been the case.

Fruit

The same analytical concept can be applied to fruit. The results of putting the nine relevant fruit crops into one food basket are shown in Figure 4.14. As with arable crops, the current food availability of fruit is also considerably higher due to plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR. Globally, 38 million more food baskets can be filled, while for people living in the EU, the figure is 25 million.

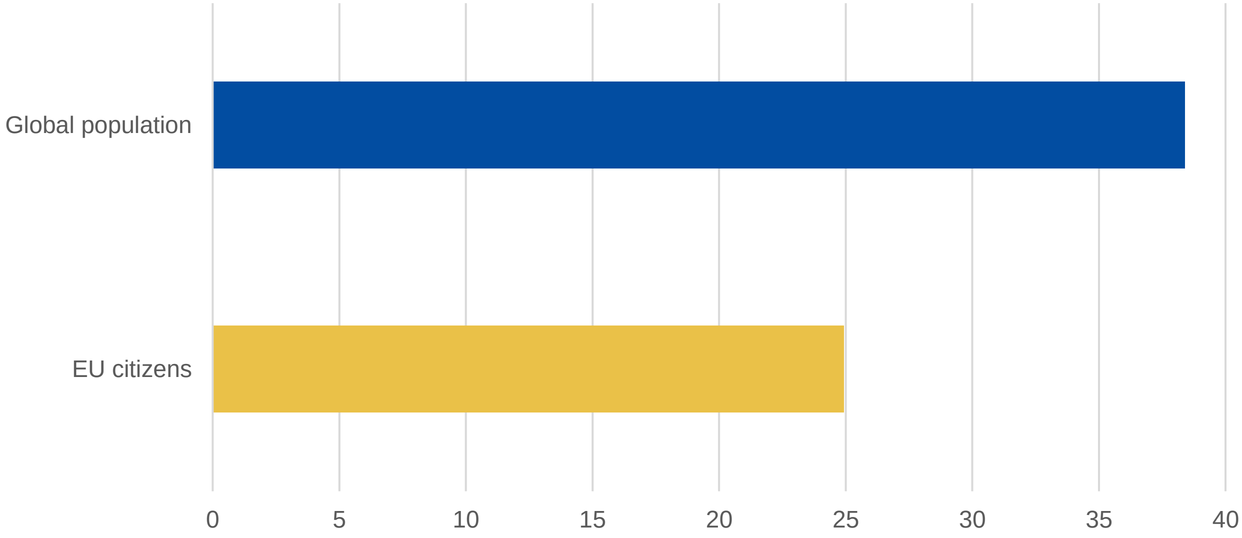


Figure 4.14. Fruit additionally available as food in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (food for million people)

Vegetables

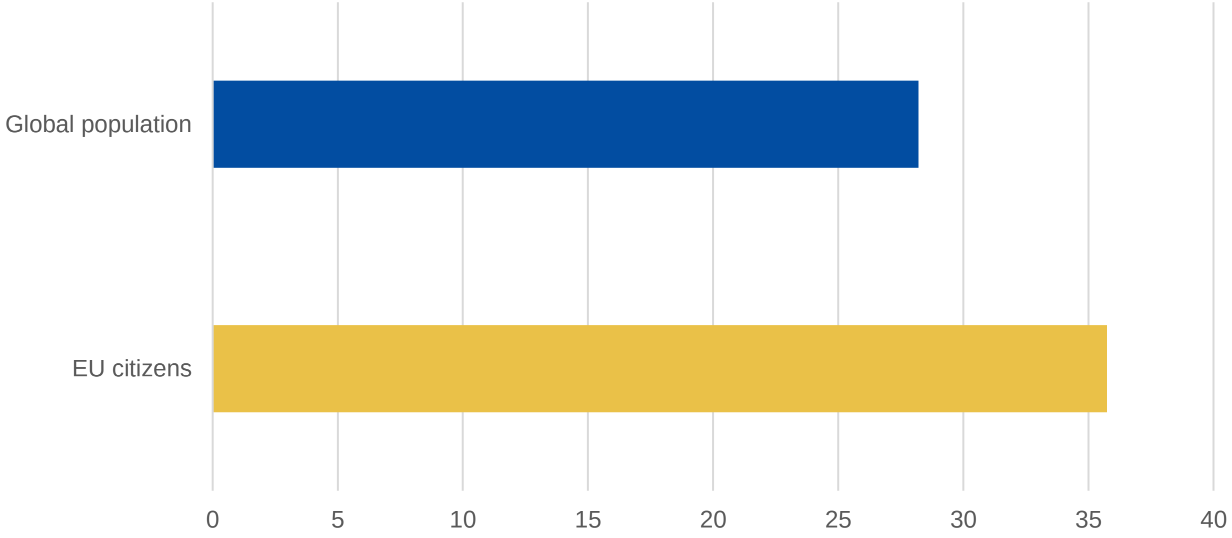


Figure 4.15. Vegetables additionally available as food in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (food for million people)

As shown in Figure 4.15 above, the corresponding figures for vegetables are as follows: plant breeding progress since 1995 in varieties with an EU-level PVR means that food baskets can be filled with the 12 analysed crops for 28 million people consuming at a global scale, or 36 million EU citizens.

Ornamentals

Ornamentals are not relevant to food consumption. Therefore, this analysis is not carried out for this group of crops.

4.1.7 Farm income

Arable crops

Another economic effect to be analysed is the effect on farm income of genetic crop improvements in varieties with an EU-level PVR, in terms of direct arable farming labour and cultivation of the crops under consideration. These crop-specific activities include, for example: tillage, sowing and drilling; applying fertilisers; pest management; harvesting and transport; and other area-related management. Data from the EC (2021b) is used to calculate the effect based on a full-revenue-full-cost approach (see Subsection 3.2.2).

Figure 4.16 shows the results of these calculations for so-called ‘fieldcrop’ farms specialised in the cultivation of arable crops. An annual working unit (AWU) (104) in EU arable farming has most recently generated an income – expressed in terms of farm net value added (FNVA), which is equal to the market revenue plus subsidies and minus taxes, intermediate consumption, and depreciation – of around EUR 22 800. Without the market revenue currently earned due to plant breeding progress since 1995 in varieties with an EU-level PVR, this income would shrink by approximately 12.6 %. In other words, the current income of an AWU engaged in EU arable farming would only have been around EUR 19 900.

---

(104) Here, an AWU is defined as the equivalent of a fully employed worker in arable and horticultural farming who works 1 800 hours per year.

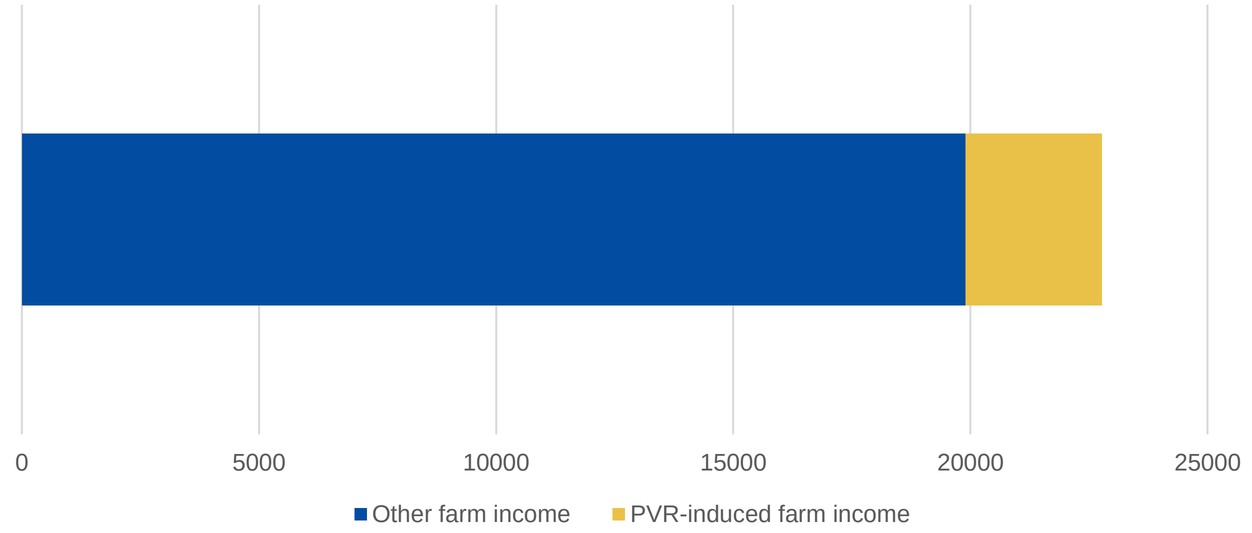


Figure 4.16. Farm income in arable farming in 2020 with and without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (EUR per AWU)

Fruit, vegetables, and ornamentals (105)

The FADN data set allows us also to look at so-called ‘horticulture’ farms specialised in the cultivation of specialty crops. This type of farm is considered the best available proxy to illustrate the current farm income effects of plant breeding progress between 1995 and 2019 in fruit, vegetables, and ornamental varieties with an EU-level PVR as an aggregate. Figure 4.17 shows the results of this analysis.

In this EU farming sector, an AWU has most recently generated an income of around EUR 28 300. Without the market revenue currently earned due to plant breeding progress since 1995 in varieties with an EU-level PVR, this income would shrink by approximately 11.0 %. Therefore, the current income of an AWU engaged in EU horticultural farming would only be around EUR 25 200.

---

(105) Due to the availability of FADN data (EC, 2021b), fruit, vegetables, and ornamentals cannot properly be distinguished. Therefore, the analysis focuses on horticultural farming comprising these three crop groups.

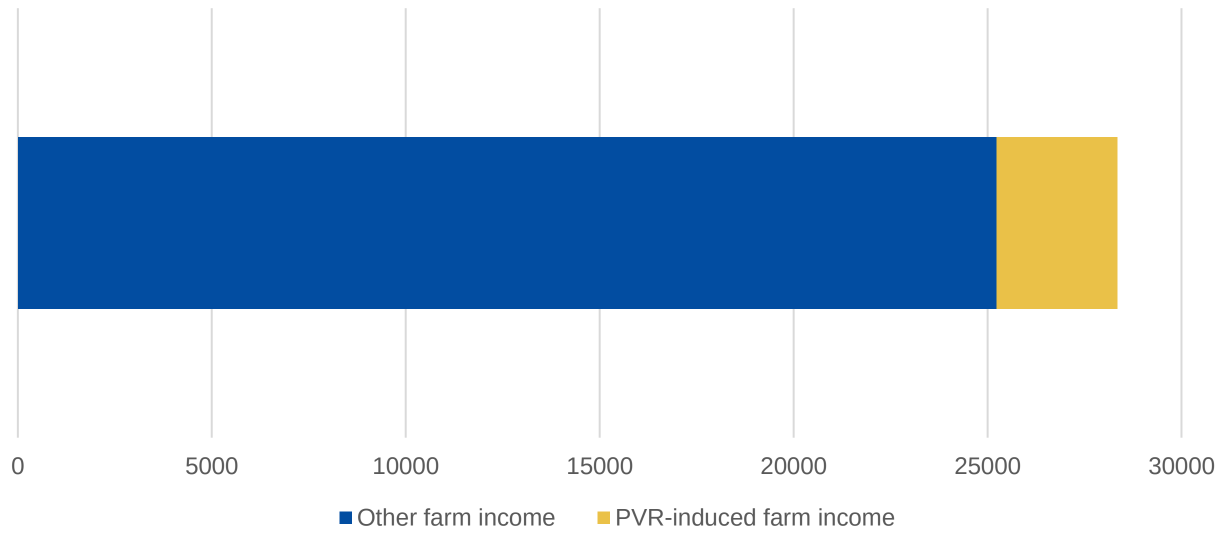


Figure 4.17. **Farm income in horticultural farming in 2020 with and without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (EUR per AWU)**

4.1.8 Farm and other labour

Arable crops

When confronted with a worsening income situation, farmers try to adapt. Some may stop working, while others may partly move to other income-generating options and/or switch to working part-time in arable farming. The underlying reason is that the absence of plant breeding progress in varieties with an EU-level PVR would lead to a smaller workforce requirement in the field and on the farm for cultivating, harvesting, transporting, and storing. The resulting labour effect is calculated using EC (2021b) and KTBL (2021) data. It is shown in Table 4.19 per arable crop.

CROP	LABOUR LOSS	CROP	LABOUR LOSS	CROP	LABOUR LOSS
Wheat	7 790	OSR	2 027	Potato	4 054
Corn	2 940	Sunflower	1 493	Pulses	138
Barley	3 006	Other oilseeds	246	Green maize	638
Other cereals	1 869	Sugar beet	192	Ryegrass	244

Table 4.19. **Labour loss related to arable crops in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (AWU)**

Almost 25 000 AWU would be unnecessary today in EU arable farming if there had not been plant breeding progress in varieties with an EU-level PVR in the last 25 years. The figure is rather high for cereals and potatoes, but comparatively low for the other crops.

Since the absence of the EU's PVR system would result in decreased arable production, this would also lead to reduced input purchases as well as less processing, trading, and retailing of the primary agricultural commodities. Moreover, it would cause labour market turbulence upstream and downstream in the agricultural value chain. Sophisticated multiplier analysis (see Subsection 3.2.2) allows the overall labour effect to be calculated. This leads to the conclusion that, in the EU, at least 504 000 jobs in storing, processing, packaging, international trading and retailing would partly be endangered without plant breeding progress since 1995 in varieties with an EU-level PVR. 'Partly endangered' in this context means that workers would currently suffer from at least some income loss or even unemployment.

Fruit

Applying the same analytical concept to fruit (and later to vegetables) using BMEL (2021) and KTBL (2010) data leads to the crop-specific results shown in Table 4.20.

CROP	LABOUR LOSS	CROP	LABOUR LOSS	CROP	LABOUR LOSS
Peach	635	Wine/Grape	6 623	Raspberry	114
Strawberry	194	Apricot	288	Plum	824
Apple	294	Blueberry	125	Cherry	78

Table 4.20. Fruit-related labour loss in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (AWU)

In this EU horticultural farming sector, more than 9 000 AWU would not be engaged if plant breeding progress since 1995 in varieties with an EU-level PVR had not occurred. Most of these, however, relate to wine/grape production, which is the most labour-intensive subsector. Including the linked upstream and downstream segments of the value chains, almost 160 000 workers would suffer from either income loss or unemployment.

Vegetables

Finally, the vegetable subsector would experience a loss of more than 10 500 AWU if the plant breeding progress of the past 25 years in varieties with an EU-level PVR had not occurred, as shown in Table 4.21. Including the consequent challenges upstream and downstream in the value chains, a total of 243 000 jobs would be endangered as workers would face income loss or, in the worst case, unemployment.

CROP	LABOUR LOSS	CROP	LABOUR LOSS	CROP	LABOUR LOSS
Lettuce	214	Bean	19	Onion	171
Tomato	5 628	Pea	29	Spinach	14
Pepper	704	Cucumber	2 843	Endive	21
Melon	817	Cabbage	25	Leek	29

Table 4.21. Vegetable-related labour loss in 2020 without plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (AWU)

Ornamentals

Due to the weak data background, this labour force analysis cannot be carried out for ornamentals.

On aggregate for arable crops, fruit, and vegetables, the overall labour force impact of plant breeding progress since 1995 in varieties with an EU-level PVR can be calculated at an additional 45 000 AWU engaged in EU crop farming. As a whole, that is to say, along the various segments of agricultural value chains, almost 1.0 million jobs are supported in this way.

4.2 Environmental impacts

The methodology used in this section covers arable crops, fruit and vegetables, but not ornamentals, due to data constraints. It particularly relies on the models and tools of environmental economics described in Subsection 3.2.3. Changing framework conditions affect production and trade, as well as the broader environment. These environmental effects can be described as follows.

- Decreasing yields and production – here due to the absence of plant breeding progress since 1995 in varieties with an EU-level PVR – imply a lower market supply of agricultural commodities today, while market demand remains largely unaffected.

- The resulting market disequilibrium can and will be tackled by using more natural resources, in this case, land. This can happen domestically or abroad. Agricultural land in the EU, however, is already a limited resource, and is becoming even more scarce.

- In this context, the cultivation of additional land for arable and horticultural purposes within the EU is considered impossible (106). In such a situation, changing exports and imports compensate for yield losses.

- This leads to resource-based and, therefore, environmental impacts, such as global changes in land use and GHG emissions, as well as global effects on biodiversity and water use (107).

---

(106) The maintenance of grassland and thus its non-conversion for arable and horticultural purposes is one of the current good agricultural practices defined by EU regulations (EC, 2015; UBA, 2021).

(107) In this part of the analysis, the models described in Subsection 3.2.3 force the EU to interact with other world regions via international trade and define the EU as a single market. Trade interactions within the EU are internally compensated, and resulting volume changes in intra-EU trade are shifted towards the EU border. The following therefore essentially refers to extra-EU trade effects. In this context, green maize and ryegrass are defined as non-tradeable goods. The land pressure and consequent land use effects resulting from market shortcomings in green maize and ryegrass (and the other environmental impacts) will be transferred to additional land-use changes for other crops if the relative share of arable land use per remaining arable crop in the EU remains unchanged due to this green maize and ryegrass transfer effect.

4.2.1 Global land use

Arable crops

The obvious reductions in extra-EU exports and the apparent increases in extra-EU imports that would be caused by the absence of plant breeding progress since 1995 in varieties with an EU-level PVR – depicted as net trade changes in Figure 4.4 – would change the balance of EU net imports of virtual agricultural land. The avoided net virtual land trade in 2020 that can be attributed to the effect of the EU PVR system on EU arable farming is shown in Table 4.22.

CROP	∆ LAND TRADE	CROP	∆ LAND TRADE	CROP	∆ LAND TRADE
Wheat	2.840	OSR	0.974	Potato	0.109
Corn	0.602	Sunflower	0.356	Pulses	0.046
Barley	0.975	Other oilseeds	0.015	Green maize	n. a.
Other cereals	0.650	Sugar beet	0.018	Ryegrass	n. a.

Table 4.22. Avoided net virtual land imports attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million hectares)

If all factors other than land remained unchanged (e.g. yields in the other world regions), more than 6.5 million hectares of land would have been required globally, in addition to the area already in use in 2020, without plant breeding progress in varieties with an EU-level PVR. This would have led to an increased land requirement almost as large as the entire territory of Ireland (Worldometer, 2020). Wheat (2.8 million hectares), barley (1.0 million hectares), and OSR (1.0 million hectares) cause the bulk of the potential growth in virtual EU net land imports.

Even more interesting is the question of where this natural or nature-like land would have been taken from. The regional distribution of avoided virtual EU net agricultural land imports due to plant breeding progress in varieties with an EU-level PVR around the globe is shown in Figure 4.18. The following conclusions can be drawn:

- more than 1.4 million hectares would come from the CIS;

- the MENA region would contribute more than 1.2 million hectares;
- almost 0.9 million additional hectares would need to be occupied in Asia and Oceania, while around 0.7 million hectares would be located in North America and Sub-Saharan Africa, respectively.
- South America would contribute more than 0.5 million additional hectares, and RoW more than 0.1 million hectares.

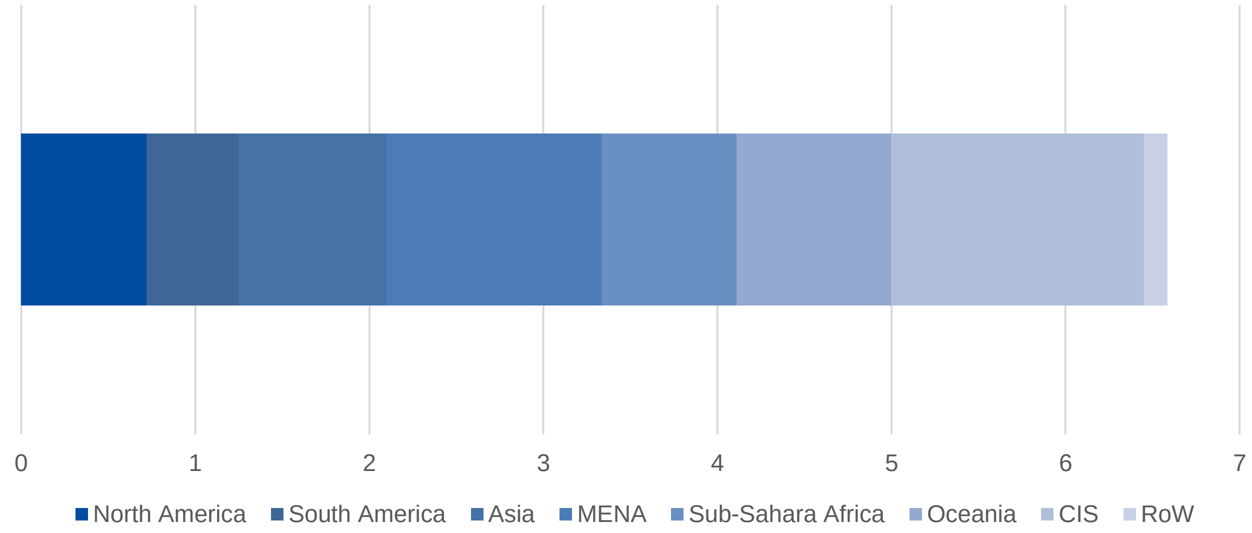


Figure 4.18. Avoided net virtual land imports attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR by region (million hectares)

<u>Fruit</u>

Applying the same analytical concept to fruit (and later to vegetables) is challenging, because trade data for some types of fruit and fruit products are not documented in as much detail as they are for arable crops. This particularly hinders geographic differentiation. Nevertheless, a global analysis can still be carried out.

Table 4.23 displays the avoided net virtual land imports attributable to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR. In total, almost

110 000 additional hectares worldwide (i.e. in countries trading the relevant fruit with the EU) would be needed today without the PVR-based plant breeding progress of the past 25 years. This is considerably lower than the additional land use for arable crops but is not negligible, as the area amounts to more than 1 000 km^2. This is half as large as the Ijsselmeer in the Netherlands, and twice as large as Lake Constance at the borders of Germany, Austria, and Switzerland (EEA, 2018).

CROP	∆ LAND TRADE	CROP	∆ LAND TRADE	CROP	∆ LAND TRADE
Peach	10 400	Wine/Grape	41 455	Raspberry	1 362
Strawberry	2 680	Apricot	8 538	Plum	34 041
Apple	7 538	Blueberry	1 543	Cherry	1 665

Table 4.23: Avoided net virtual land imports attributable to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (hectares)

Vegetables

Similarly, more than 90 000 hectares would be needed globally in addition to the land already used to cultivate vegetables, as listed in Table 4.24.

CROP	∆ LAND TRADE	CROP	∆ LAND TRADE	CROP	∆ LAND TRADE
Lettuce	8 982	Bean	1 348	Onion	18 349
Tomato	32 846	Pea	2 556	Spinach	615
Pepper	8 366	Cucumber	4 016	Endive	898
Melon	7 932	Cabbage	2 747	Leek	2 985

Table 4.24: Avoided net virtual land imports attributable to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (hectares)

The virtual net trade of land would have increased until today by this amount if plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR had not occurred. Again, these almost 1 000 km^2 are a remarkably large area, albeit not as larger as in the case of arable crops.

4.2.2 Global GHG emissions

Arable crops

Figures for the additional global arable land that would currently be needed without plant breeding progress in varieties with an EU-level PVR since 1995 are not available. Recent trends suggest global acreage will expand by 21 million hectares per year (FAO, 2021). Therefore, this land must principally be converted from grassland or natural habitats. However, all this land sequesters carbon both above and below ground. If this land were used for arable farming, a tremendous part of this carbon would be released into the atmosphere, mainly in the form of CO_2. The amount of GHG that would be emitted in such a situation, and currently avoided due to lasting genetic crop improvements through the EU PVR system, can be calculated using the approach described in Subsection 3.2.3 and yields the numbers shown in Figure 4.19.

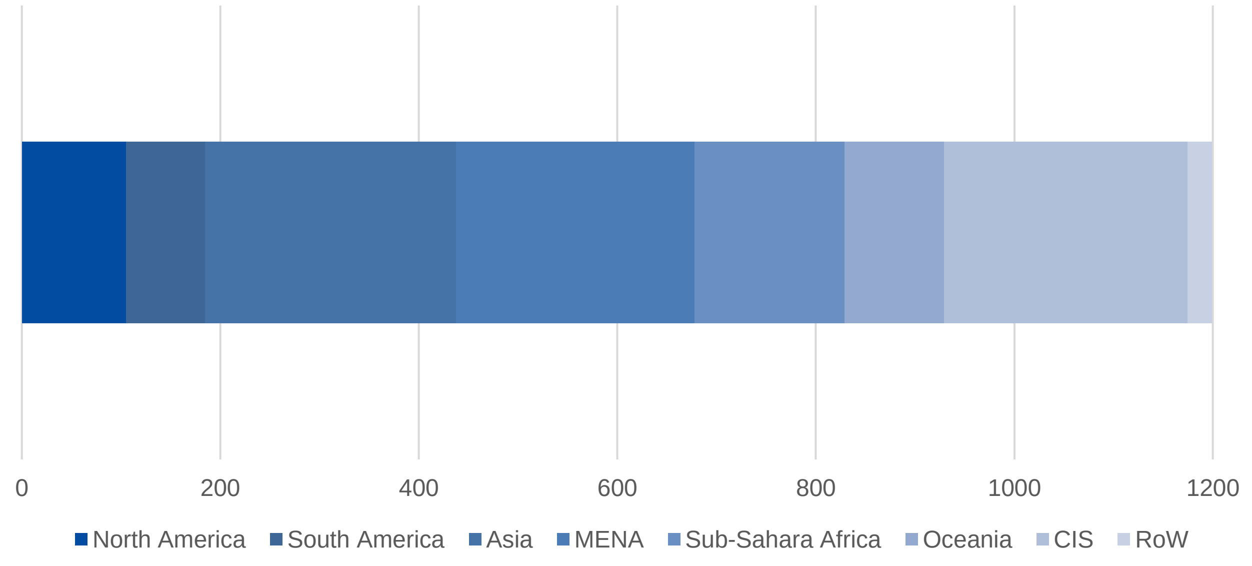


Figure 4.19. Avoided global GHG emissions attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR by region (million tons)

The figure shows that plant breeding successes in the EU since 1995 in varieties with an EU-level PVR have prevented GHG emissions of almost 1.2 billion tons as of 2020. This is more than twice the entire annual GHG emissions of Germany (EEA, 2020). However, this is a one-off effect, and putting these savings into perspective is challenging.

Such non-recurring emissions are typically annualised by dividing total emissions by 20 (years). Therefore, the avoided ‘annualised’ GHG emissions due to plant breeding progress since 1995 in varieties with an EU-level PVR would amount to approximately 60 million tons. This is as much as the total annual GHG emissions in EU Member States such as Ireland, Hungary and Portugal (EEA, 2021). It implies that noteworthy and long-lasting efforts to reduce GHG emissions in the EU would be counteracted in a short period of time without the impacts under consideration here for arable crops.

Fruit and vegetables

The additional global land potentially used today to cultivate fruit and vegetables without plant breeding progress between 1995 and 2019 cannot further be distinguished for specific world regions due to data constraints (see above.) Therefore, similar figures regarding GHG emissions cannot be calculated as they were for arable crops. Nevertheless, the potential GHG emissions due to additional land use can be estimated using an average GHG emission factor.

The results for fruit and vegetables are displayed in Figure 4.20. It turns out that over 35 million tons of GHG had not been emitted by 2020 due to plant breeding progress since 1995 in fruit and vegetable varieties with an EU-level PVR. This one-off effect may not sound particularly large, but is equal to the annual GHG emissions of EU Member States such as Slovakia (EEA, 2021).

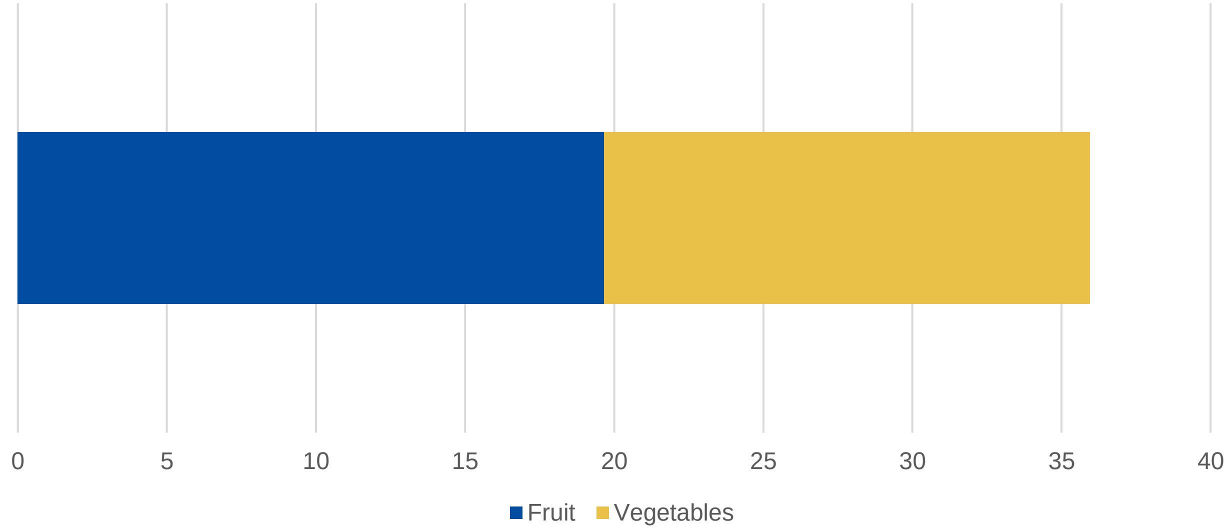


Figure 4.20. **Avoided global GHG emissions attributable to fruit and vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million tons)**

4.2.3 Global biodiversity changes

Arable crops

As mentioned above, plant breeding efforts since 1995 in varieties with an EU-level PVR have prevented the conversion of approximately 6.5 million hectares of grassland and natural habitats in various world regions (Figure 4.18). It is also worth quantifying the associated 'biodiversity-preserving' effect of the underlying genetic crop improvements. As outlined in Subsection 3.2.3, two methods for capturing this effect are employed: first, the GEF-BIO approach; and second, the NBI concept. The global biodiversity loss results from the two separate analyses for the EU are depicted in Figure 4.21.

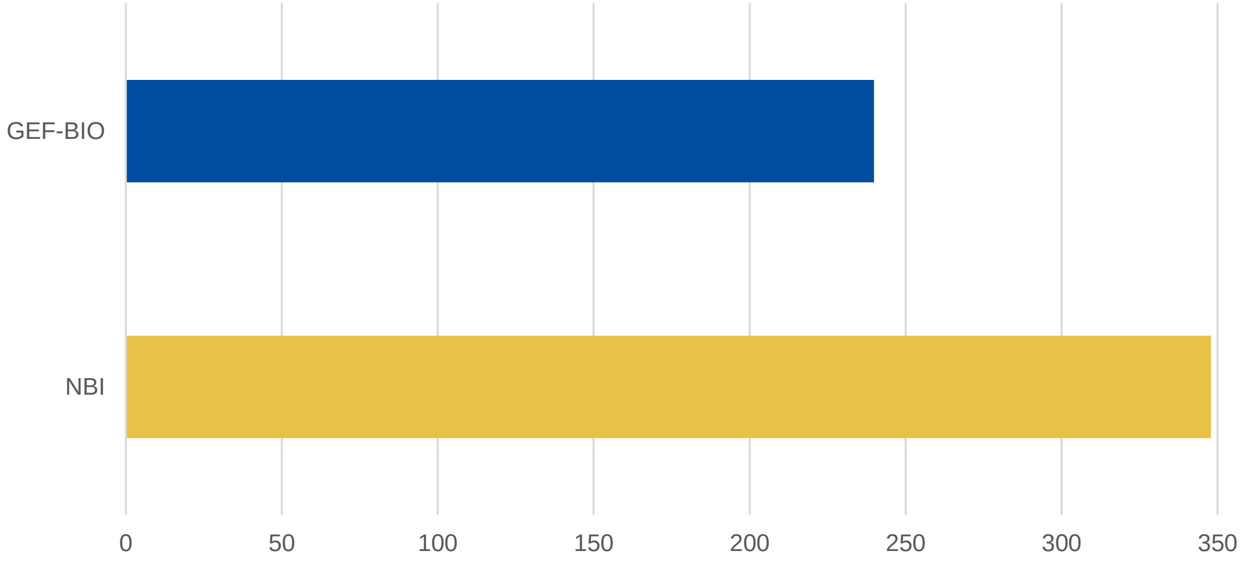


Figure 4.21. Avoided global biodiversity loss attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million points)

The following concept-specific findings concerning avoided biodiversity losses may be highlighted:

- Based on the GEF-BIO, approximately 240 million biodiversity points would have been lost to date by neglecting plant breeding in the EU since the turn of the millennium, on top of the global species richness that has already been lost. This is equivalent to the biodiversity found on 2.4 million hectares of rainforest and savannahs in Brazil, the country to which the GEF-BIO approach allocates 100 points per hectare. Assuming a current cutting rate in the Brazilian Amazon rainforest of 0.75 million hectares per year (Butler, 2020), this implies that plant breeding progress since 1995 in varieties with an EU-level PVR for major arable crops has compensated for more than three years of deforestation and/or slash-and-burn clearance in the Amazon region at its current pace.

- However, the NBI suggests an even larger loss of global biodiversity: it would have declined by almost another 350 million biodiversity points without genetic crop improvements through the EU PVR system in the past 25 years. The latest available figures for Indonesia, the country to which the NBI allocates 100 points per hectare, indicate a current annual loss of approximately 0.45 million hectares of rainforest (Wijaya et al., 2019). If plant breeders in the EU had given up their jobs a quarter of a century ago and had not protected the new varieties with EU-level PVRs, global biodiversity would have reduced by an equivalent of species richness on an additional 3.5 million hectares of Indonesian natural habitats to date, that is to say, the same amount of biodiversity loss that can be attributed to almost 8 years of rainforest clearance in Indonesia at its current rate.

Fruit and vegetables

Aggregating fruit and vegetables, and applying a similar methodological concept (using global averages instead of region-specific GEF-BIO and NBI values, as in the case of GHG emissions), leads to the results displayed in Figure 4.22:

- using the GEF-BIO approach, it must be concluded that without the plant breeding progress over the past 25 years in varieties with an EU-level PVR, the world would currently face a biodiversity loss equal to the number of species found in approximately 70 000 hectares of rainforest and savannahs in Brazil;
- applying the NBI concept, however, leads to the conclusion that global biodiversity similar to that found on more than 105 000 hectares of Indonesian natural habitats would have been lost today without the plant breeding progress over the last 25 years in varieties with an EU-level PVR.

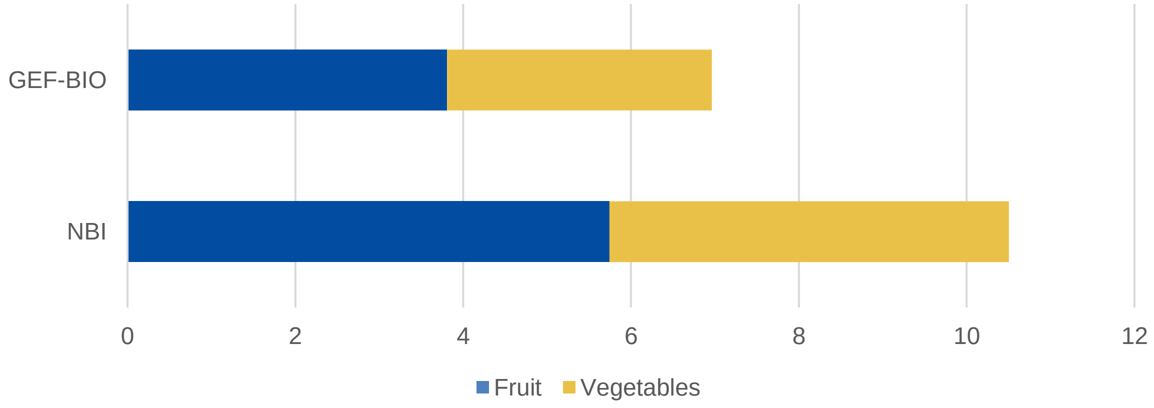


Figure 4.22. Avoided global biodiversity loss attributable to fruit and vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million points)

4.2.4 Global water use

Arable crops

Analysing the impact of plant breeding progress in varieties with an EU-level PVR on global water demand requires a twofold approach. First, one must discuss how water use in domestic production is stimulated, and second, how virtual water trade (via the trade of agricultural commodities and products) is affected.

The production of agricultural commodities requires water. The more tons of a crop produced, the more water is required. The EU PVR system increases domestic production of arable crops (see Subsection 4.1.1), which leads to higher domestic water consumption. However, due to the higher EU exports and/or lower imports (i.e. a better net trade balance; see Subsection 4.1.2) that are caused by this system, water use abroad is also affected. In the case of higher (or lower) water productivity in the EU and its Member States in comparison to other countries, the resulting avoided water use abroad must consequently be higher (or lower) than the additional water used in the EU.

The net effects of both developments, namely the additional water used in the EU (due to higher domestic production) and the water savings abroad (due to higher imports from and/or lower exports to the EU) per arable crop are displayed in Table 4.25.

CROP	∆ WATER USE	CROP	∆ WATER USE	CROP	∆ WATER USE
Wheat	4.975	OSR	0.822	Potato	1.852
Corn	3.650	Sunflower	0.369	Pulses	0.282
Barley	2.670	Other oilseeds	0.303	Green maize	-2.201
Other cereals	1.525	Sugar beet	0.132	Ryegrass	-0.478

Table 4.25. Avoided global water use attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (billion m^3)

In all cases, except for green maize and ryegrass, which are not traded, the balance is positive. This means that plant breeding progress since 1995 in varieties with an EU-level PVR reduces global water use. This is because the additional water needed here in the EU is lower than the water use that can be avoided abroad, since the EU is either exporting more or importing less due to higher domestic arable crop production. The two underlying gross effects and the resulting net effect on regional water use for arable crops with plant breeding based on the EU PVR system since 1995 are displayed in Figure 4.23.

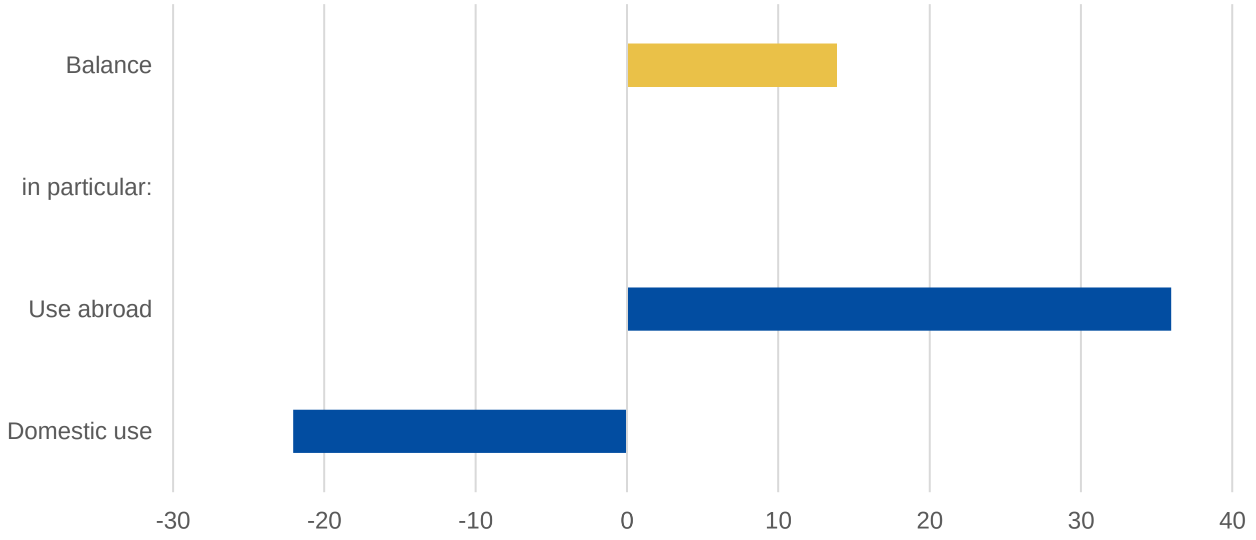


Figure 4.23. Avoided global water use attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, balance (billion m^3)

The following three details must be highlighted. First, due to plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, EU arable crop production in 2020 is higher than it would be without relevant genetic crop improvements. Therefore, the additional demand for domestic water amounts to over 22.0 billion m^3. Second, increased crop production in the EU allows it to export more and/or import less. Consequently, production incentives in foreign countries shrink, and water is currently saved abroad due to plant breeding activities under the EU PVR system in the past 25 years. In total, almost 36.0 billion m^3 of water are saved this way. Third, there is a net water saving of almost 14.0 billion m^3 the effect of the two points just mentioned. This is approximately one third of the amount of water in Lake Constance.

However, these numbers must be set in perspective, since the calculated water volumes consist of three types of water: green water, which naturally vaporises or helps plants to grow through precipitation; blue water, mainly used to irrigate crops; and grey water, which is used to dilute contaminated water. Therefore, anthropogenically used water is blue (used on top of naturally occurring precipitation to grow crops) or grey (used to clear polluted water) (e.g., Mubako, 2018).

Within the balance shown in Figure 4.23, the amounts and shares of green, blue, and grey water use avoided in 2020 due to plant breeding progress in varieties with an EU-level PVR can be calculated, as in Table 4.26.

	Green water	Blue water	Grey water
Volume (in billion m³)	9.935	3.111	0.856
Share of total amount (in %)	71.5	22.4	6.2

Table 4.26. Avoided global green, blue and grey water use attributable to arable crops in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR

A considerable share, almost 30 % (or almost 4.0 billion m³) of globally avoided water use is related to direct human agricultural water-employing activities. Among these, water used for irrigation plays a special role.

Fruit

The same analysis can also be applied to fruit. In this respect, Table 4.27 displays the current net effect per fruit crop of both developments, namely the additional domestic water used in the EU and the water savings abroad due to plant breeding progress since 1995 in varieties with an EU-level PVR.

CROP	∆ WATER USE	CROP	∆ WATER USE	CROP	∆ WATER USE
Peach	-25	Wine/Grape	-24	Raspberry	0
Strawberry	-6	Apricot	-14	Plum	201
Apple	57	Blueberry	6	Cherry	2

Table 4.27. Avoided global water use attributable to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million m³)

The net balance is very crop-specific. There are types of fruit with a positive balance, that is to say, water savings due to plant breeding progress since 1995 in varieties with an EU-level PVR (e.g.

plum and apple), but also those with negative balances (e.g. peach, apricot, and grape). However, the total net balance is positive, as visualised in Figure 4.24. On aggregate, almost 200 million m^3 of agricultural water use is avoided today due to plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR.

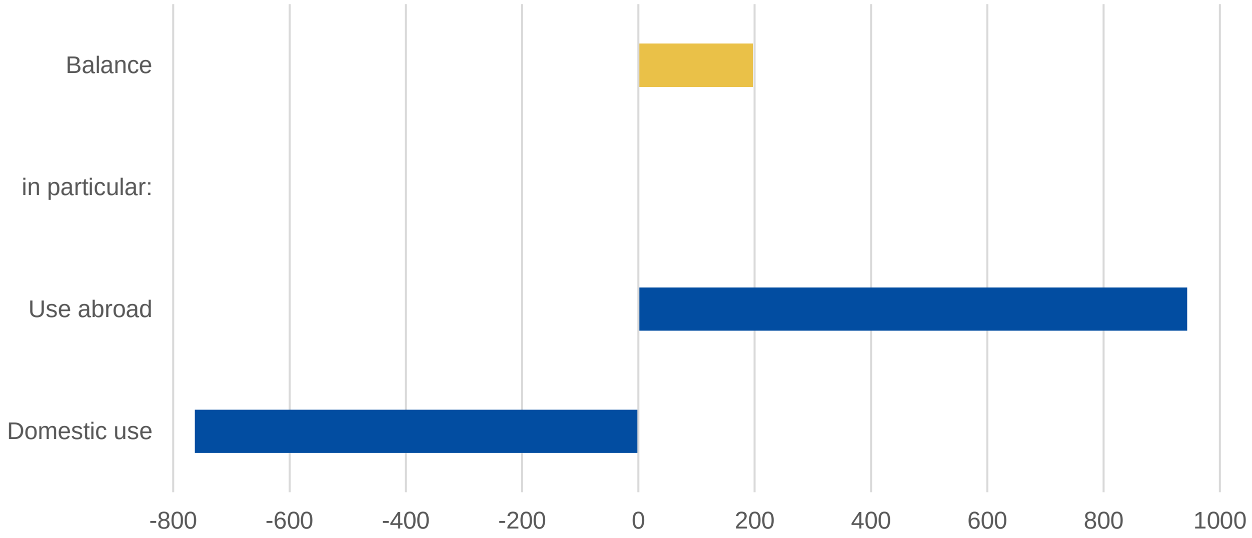


Figure 4.24. Avoided global water use attributable to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, balance (million m^3)

For fruit, the importance of green, blue, and grey water in balancing agricultural water use can be established. Table 4.28 supports the conclusion that human activity-related water use in particular is globally much better off with plant breeding and EU-level PVR.

	Green water	Blue water	Grey water
Volume (in million m^3)	30	89	78
Share of total amount (in %)	15.5	45.1	39.5

Table 4.28. Avoided global green, blue and grey water use attributable to fruit in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR

Vegetables

Finally, the net water use balance for vegetables grown in the EU and impacted by plant breeding progress since 1995 in varieties with an EU-level PVR is analysed in Table 4.29, which shows the crop-specific balances of domestic water use and virtually traded water in vegetables from abroad.

CROP	∆ WATER USE	CROP	∆ WATER USE	CROP	∆ WATER USE
Lettuce	4	Bean	5	Onion	53
Tomato	110	Pea	1	Spinach	2
Pepper	30	Cucumber	36	Endive	0
Melon	11	Cabbage	9	Leek	2

Table 4.29: Avoided global water use attributable to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR (million m^3)

All types of vegetables show a positive balance, that is to say, the avoided water use in other world regions due to lower imports into and higher exports from the EU is higher than the additional water use within the EU due to genetic plant improvements in all 12 cases. Tomato and onion account for most of this avoided water use.

This current positive net water use balance can also be seen in Figure 4.25. In total, 264 million m^3 of water are not used at global scale. This is the result of an additional domestic water use of 387 million m^3, because higher yields are an effect of plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR on the one hand, and 651 million m^3 less virtually traded water on the other.

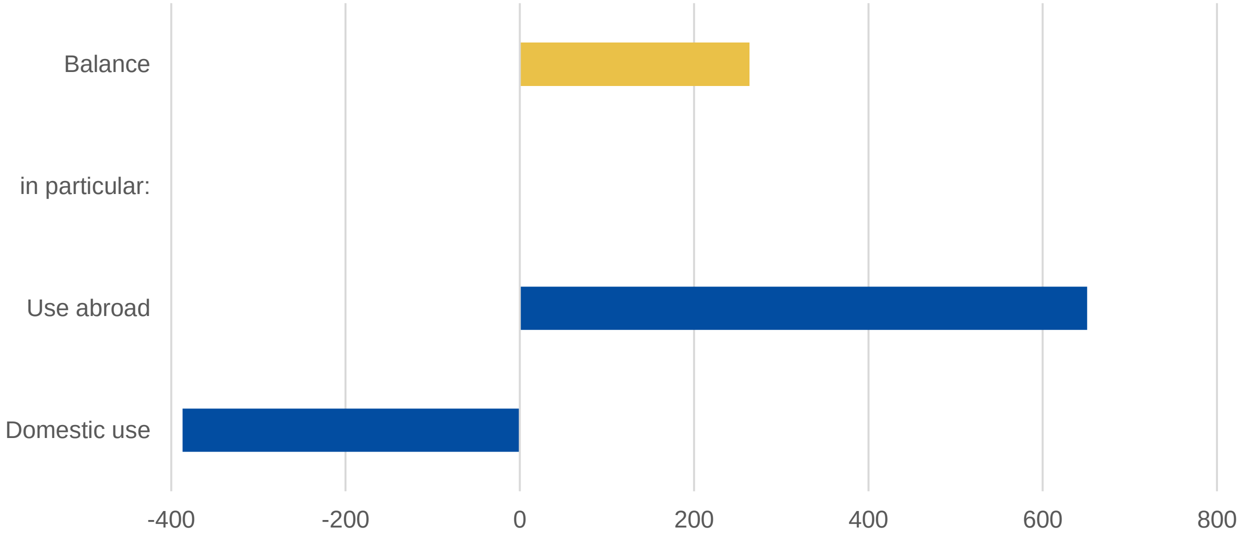


Figure 4.25: **Avoided global water use attributable to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR, balance (million m^3)**

In terms of green, blue, and grey water, the situation is similar to that of fruit. The vast majority of the avoided net water use at global scale may be related to direct human activities, namely irrigation and water pollution. Table 4.30 shows the details. Blue and grey water account for three quarters of the avoided water use attributable to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR.

	Green water	Blue water	Grey water
Volume (in million m^3)	70	88	106
Share of total amount (in %)	26.4	33.2	40.3

Table 4.30: **Avoided global green, blue and grey water use attributable to vegetables in 2020 with plant breeding progress between 1995 and 2019 in varieties with an EU-level PVR**

4.3 Further qualitative arguments

As stated in the literature review, the driving forces behind plant breeding innovations are numerous and complex. Changing environmental conditions and consumption patterns, as well as demand for agricultural and bio-based production chains, lead to new challenges for plant breeders and higher expectations from society in general as well as the agriculture and horticulture industries. These expectations and demands are also expressed in the relevant criteria for variety registration (van Elsen et al., 2013).

- For a long time, the EU regulatory framework for plant breeding has focused on food security and increased agricultural production. Relevant variety registration criteria have focused on yield and crop productivity.

- Around the turn of the millennium, however, authorities began to slightly modify the criteria, especially for variety registration, in order to respond to new agricultural challenges, namely food safety and environmental issues. Therefore, higher yields are no longer the only important trait. Increased disease resistance, product composition, and/or advantageous nutrient profiles, to cite a few examples, are becoming increasingly relevant, thereby influencing plant variety composition on the market.

The close links and reciprocal influence (see Chapter 2) between EU seed legislation as a legal regime and the EU PVP system, mainly for arable crops, make it challenging to analyse the impact of plant breeding progress in varieties with an EU-level PVP on criteria other than yield. The rather recent shift in public and therefore scientific attention towards these other impacts has resulted in only a few academic findings on the importance of an EU-level PVR in, for example, combating biotic and abiotic stressors (see Chapter 2).

For major crops, currently available plant breeding methods often need 10 to 12 years to generate a new variety that can be released and subsequently used on the field (Boldt, 2020; Chen et al., 2019; Kaiser et al., 2020; Zaidi et al., 2020). This is because genetic mutations occur randomly (albeit through deliberate induction) in conventional plant breeding and must be selected through backcrossing over several generations, which takes years. Trait mapping and early generation selection are particularly time-consuming (Noleppa and Cartsburg, 2021).

In other words, the abovementioned partial shift in variety registration criteria and in public attention is not durable enough to result in sufficient new varieties for proper scientific impact analyses. Moreover, the EU PVP system and its impacts on innovation and its outcomes are part of an even wider and more complex protection system in the EU (see Chapter 2). These two factors restrict quantitative analyses of parameters other than yield.

Nevertheless, some additional and largely qualitative arguments can be added. Yield is influenced by numerous variables. These variables can be grouped into three categories: technology, biology, and environment (Tandzi and Mutengwa, 2020). If plant breeding is considered a yield-enhancing technology, resistance to diseases, insects, and weeds may be considered a biological determinant of yield, whereas the ability to cope with climatic conditions, soil fertility challenges, topographic particularities, water issues, etc. may be seen as an environmental yield constraint (Tandzi and Mutengwa, 2020). Therefore, new crop varieties that are more resistant to, for example, specific biotic and/or abiotic stress factors more or less guarantee that potential yields – to which plant breeding also contributes – are realised on the field. In this sense, plant breeding progress in producing resistant crops in varieties with an EU-level PVR is already part of the analysis above (108). However, the effect of yield-ensuring plant breeding cannot be separated from that of yield-enhancing plant breeding.

Voss-Fels et al. (2019a; 2019b) highlight this link. The authors clearly show that higher yields (generated by plant breeding for winter wheat in Germany over the past decades) are highly correlated with other wheat cultivar characteristics. Higher wheat yields are accompanied by better resistance to powdery mildew and stripe rust, and exhibit not only increased radiation use efficiency, but also, among other things, greater nitrogen use efficiency, lower PPP use and better nutrition. This all applies to a rather broad geographic range and, therefore, different weather situations, as well as other abiotic circumstances. Obviously, environmental and other aspects are also positively influenced by plant breeding focused on increasing yield.

In this respect, again, not only enhancing and/or ensuring yields, but also shifting societal demands are important in plant breeding (see Chapter 2). This is obvious from the SDGs and objectives of the EU's Green Deal.

---

(108) In fact, plant breeding has often aimed also to increase durable resistance to specific biotic and abiotic stresses (Tandzi and Mutengwa, 2020).

SDG 2.5 clearly formulates objectives relevant to plant breeding, but also describes in detail how it could contribute to achieving relevant SDGs (see Chapter 2). The following additional arguments refer to specific findings of the economic and environmental analysis regarding impacts of plant breeding progress since 1995 in varieties with an EU-level PVR.

- There are at least two impacts on SDG 1 (no poverty). First, the income contribution of varieties with an EU-level PVR increases the income of EU farmers, who face considerable income disparity (109) (see Subsection 4.1.7). Second, the use of varieties with an EU-level PVR tends to decrease market prices. This allows more people around the world to buy food and other agricultural raw materials at affordable prices, increasing budget options for the poor (see Subsection 4.1.3).

- Varieties with an EU-level PVR are also relevant to SDG 2 (zero hunger). The impact analysis clearly shows that more food is available at the EU as well as the global scale (see Subsection 4.1.6).

- These varieties make two contributions to SDG 8 (decent work and economic growth) and SDG 15 (life on land). The first relates to jobs. It was shown above that the use of these varieties helps maintain jobs in agriculture and horticulture as well as in rural areas, where many work activities upstream and downstream in the value chain are located (see Subsection 4.1.8). In addition, they affect agricultural value added and GDP. Obviously, varieties with an EU-level PVR contribute notably to overall economic performance and growth in the agricultural sector as well as upstream and downstream in the value chain (see Subsections 4.1.4 and 4.1.5).

- These varieties also make numerous contributions to SDG 12 (responsible consumption and production), defined as sustainable consumption and production. The points above mention contributions to economic and social sustainability. Environmental sustainability is also

---

(109) Matthews (2021) states that, in general, farm household income in the EU is much lower than that earned by non-farm households in the Community. More precisely, it is less than half that earned by non-farm self-employed households. Therefore, farm households have achieved nowhere near the same standard of living as non-farm households in the EU and are more prone to restrictions arising from poverty.

supported because these varieties lower the input of natural resources at the global scale. This mainly concerns land (see Subsection 4.2.1) and water (see Subsection 4.2.2). Consequently, biodiversity is protected (see Subsection 4.2.3) and climate change is mitigated (see Subsection 4.2.2).

- The latter point shows that SDG 13 (climate action) is also supported by varieties with an EU-level PVR. The availability and use of these varieties limit GHG emissions at global scale and thereby support climate action plans in the EU and elsewhere.

The Green Deal is considered an integral part of the EC’s strategy to implement and fulfil the SDGs at the EU level (EC, 2019). The F2F and Biodiversity strategies formulate specific objectives in this regard, principally the following four implementation objectives:

1. the inclusion of non-productive land: 10 % of all agricultural land by 2030;
2. an increase of the area under organic farming: 25 % of all agricultural land by 2030;
3. a reduction in the use of chemical PPP and risks arising from these: a 50 % reduction by 2030;
4. a reduction in the use of nitrogen fertilisers: a 20 % reduction by 2030.

Whether substantial adjustments to the two strategies are likely remains to be seen. Given the various, and still unclear, policy decisions to be made, and the vague framework conditions for the two strategies entering into force, any early quantification of the two strategies’ consequences is challenging. Nevertheless, first-impact assessments of the two strategies are already available. The various analyses lead to the following conclusions regarding impacts on crop production if some or all of the abovementioned four objectives are successfully implemented in the EU by 2030 (110).

- Beckmann et al. (2020) analyse objectives 1, 3 and 4 and argue that the production of crop-based raw materials in the EU would shrink, on average, by about one third. Rather sharp

---

(110) This part of our analysis only looks at the partial production and not consumption impacts of the two strategies, because this supply side is also the target of plant breeding activities and the EU PVP system.

decreases are expected in oilseeds (minus 61 %) and wheat (minus 49 %), while the production of coarse grains and sugar crops (-20 % each) as well as fruit and vegetables (-5 %) would be less severely affected.

- Kühl et al. (2021) look at objectives 2, 3 and 4. Although they do not explicitly quantify production effects, it may be concluded that these are about one sixth for crops.

- Barriero-Hurle et al. (2021) consider all four implementation objectives of the two strategies and state that cereal production would drop by approximately 13 % and oilseed production by about 12 %, while fruit and vegetable production would only shrink by about 7.5 %.

- Henning et al. (2021) also argue that considerable production decreases could be expected. Referring to all four implementation objectives, the decreases in output would be as follows: approximately 22 % in cereals, around 20 % in oilseeds, about 13 % in fruits and vegetables, and over 30 % in fodder crops.

- Most recently, Bremmer et al. (2022) have considered implementation objectives 1, 3 and 4 and conclude that production declines of around 10% to 20 % could be expected.

As all these impact assessments use different methodologies and scenario definitions, it is hard to arrive at a universal conclusion. However, a best guess is that an average drop in EU crop production of almost 20 % could be expected as a consequence of a partial implementation of the EU's two Green Deal strategies. This corresponds to the findings in Noleppa and Cartsburg (2021). Although they used only an indicative estimation approach, before any impact assessment was available, they concluded that arable crop production would decrease by slightly over 20 % if all four implementation objectives of the two strategies were successfully achieved by 2030.

In this regard, plant breeding in general, and particularly that in varieties with an EU-level PVR, should be considered congenial partners of the EU's Green Deal (Noleppa and Cartsburg, 2021). Plant breeding can positively contribute to many objectives set out in the two strategies. In particular, plant breeding and the EU PVP system help to compensate for negative externalities that may arise from a production decline due to the two strategies' implementation. In other words, without accelerating plant breeding in the EU and ensuring the meaningful protection of innovative varieties in the future, the objectives of the F2F and the Biodiversity strategies, and therefore the EU’s Green Deal as a whole, are scarcely achievable.

5 Quantitative results: breeders

The previous chapter considered the impact of the CPVR system on the farmers and growers, that is, the users of the plant varieties developed by breeders and protected by a CPVR. This chapter presents descriptive statistics on those breeders and their use of the CPRV system to protect their innovations.

The analysis in this chapter is based on two main data sources: the data on CPVR owners from the CPVO register, and demographic data on companies in the EU in the ORBIS database. This data is in turn collected from chambers of commerce and similar authorities in the Member States that receive basic information on employment, turnover and other data from companies. The two data sets were subsequently matched to arrive at a listing of firms that own CVPRs and for which employment and financial information was available ([111]).

5.1 CPVRs stock by country

At the end of 2021, there were 28,514 active CPVRs (granted status). Table 5.1 shows the top 10 countries of origin, each with at least 600 active CPVRs. The 10 countries in the table are the origin of the 91.3% of the active rights, with the Netherlands for more than one third of all CPVRs. The EU Member States account for 77% of CPVRs. The largest non-EU filing countries are the USA, Switzerland and the UK.

	Country	% CPVR	number CPVR
NL	**Netherlands**	**34.8**	**9,919**
FR	**France**	**17.0**	**4,837**
DE	**Germany**	**14.0**	**3,985**
US	United States	6.7	1,911
CH	Switzerland	5.3	1,523
DK	**Denmark**	**3.2**	**906**
UK	United Kingdom	3.1	872

---

(111) The matching methodology is described in EUIPO-EPO (2019), section 5.2.

	Country	% CPVR	number CPVR
IT	**Italy**	**2.7**	**783**
ES	**Spain**	**2.4**	**681**
BE	**Belgium**	**2.2**	**615**
EU27	**European Union**	**76.9**	**22,669**
	Third countries	**23.1**	5,845
	TOTAL		28,514

Table 5.1: Registered CPVRs by country of owner, top 10 countries (end 2021)

Other significant filing countries, each with at least 100 CPVRs in force, include Australia, Austria, the Czech Republic, Israel, New Zealand, Poland, Sweden and Thailand. These 8 countries are the origin of another 5.2% of the CPVRs in force. The complete table with the 57 countries with active rights is shown in Annex C.

5.2 CPVR stock by region in the European Union

Within countries, CPVRs are quite geographically specific compared to other IPRs. For many countries, the capital regions have little relevance in the CPVO register. With the notable exception of Italy, the stock of CPVRs is concentrated in a few regions with specialisation in specific activities.

It was possible to identify the region of origin (NUTS 3 (112)) of 18 903 CPVRs, or 83% of the total held by EU-based entities. Table 5.2 shows the regions in the EU with more than 200 CPVRs. These 19 regions (out of 1 166) account for 63.3% of the identified rights.

The dominance of the Dutch regions is apparent in ornamental CPVRs, with *Delft en Westland* in the lead. In the case of arable crops, the French regions stand out, with *Aveyron* at the head, and in the case of vegetable crops, both Dutch and French regions are important, with *Kop van Noord-*

---

(112) The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the territory of the EU for statistical purposes. NUTS 3 level, containing 1 166 regions, was used here.

Holland and *Maine-et-Loire* standing out. In the case of fruit varieties, French are also prominent with the *Pyrénées-Orientales* the region with the most fruit CPVRs followed by *Drôme* (in the table).

The complete table of NUTS3 regions is shown in Annex D.

	region	Number	%	Arable	Orn.	Veg.	Fruit
NL	Delft en Westland	2 198	11.6	7	1 349	831	23
NL	Kop van Noord-Holland	1 324	7.0	53	414	870	49
NL	Groot-Rijnmond	1 224	6.5	40	659	497	57
NL	Groot-Amsterdam	1 014	5.4	18	992	4	10
FR	Aveyron	699	3.7	699	15	35	0
FR	Puy-de-Dôme	698	3.7	698	0	24	0
NL	Agglomeratie Leiden en Bollenstreek	561	3.0	4	561	0	0
DE	Pinneberg	512	2.7	2	508	0	8
NL	Midden-Limburg	504	2.7	21	1	454	50
FR	Pyrénées-Atlantiques	409	2.2	409	0	0	0
FR	Maine-et-Loire	378	2.0	70	86	287	5
NL	Oost-Zuid-Holland	375	2.0	3	373	0	3
DK	Nordsjælland	356	1.9	0	356	0	0
DE	Soest	329	1.7	326	12	2	0
NL	Veluwe	325	1.7	40	195	107	3
DE	Stuttgart, Stadtkreis	299	1.6	0	299	0	0
FR	Drôme	277	1.5	15	2	153	124
FR	Nord	265	1.4	263	0	25	0
BE	Arr. Roeselare	215	1.1	0	215	0	0

Table 5.2: Registered CPVRs by region of owner, regions with at least 200 CPVRs (end of 2021)

5.3 CPVR stock by crop

Table 5.3 shows the distribution of rights by crop (113). For each country, the percentage of that country's CPVRs related to each crop type is shown. Percentages above 30% are highlighted.

country	Agricultural	Ornamental	Fruit	Vegetable	Forest
Netherlands	7.17	62.83	2.98	29.72	0.35
France	62.68	15.60	11.76	15.34	0.48
Germany	53.02	44.18	3.39	3.41	0.33
United States	56.15	29.71	13.86	10.43	0.24
Switzerland	35.84	25.62	5.51	40.22	0.27
Denmark	37.12	64.21	0.00	1.56	0.00
United Kingdom	25.48	64.97	10.57	6.75	0.38
Italy	41.70	28.40	30.45	10.43	3.16
Spain	18.67	32.41	50.46	10.49	0.31
Belgium	9.70	84.05	5.10	2.63	1.81

Table 5.3: Registered CPVRs by crop and country, top 10 countries (end 2021)

The specialisation of some countries in particular crops is readily apparent. The Netherlands, Denmark, the United Kingdom and Belgium specialise in ornamentals, with this crop type accounting for between 63% and 84% of CPVRs originating in those countries. In the case of agricultural crops, they are especially important in France, Germany and the United States, with their shares of those countries' CPVRs between 53% and 63%. Fruit rights are particularly important in Italy and Spain although their shares are lower, between 30% and 50%. Netherlands and Switzerland have the highest shares of vegetable rights in their CPVRs. Some countries, especially Italy and Switzerland, present a more balanced picture, with their CPVRs distributed more evenly among the crops.

---

(113) The crop percentages for each country add up to more than 100% because a CPVR can be registered for multiple crops.

5.4 CPVR stock by firm size in the European Union

By matching the CPVO register with the ORBIS database, it was possible to identify the size of 1 227 firms in the EU (representing 78.2% of the total EU-based CPVR owners) that registered 18 931 CPVRs (83.4% of the EU total).

In this sample, large firms own 40% of the stock of CVPRs, with the remaining 60% registered by SMEs (114) or physical persons (115). The average number of CPVRs per firm is also shown in the table. Unsurprisingly, physical persons own the smallest number of CPVRs on average, at 3.3. For firms, the number of CPVRs per firm ranges from 10 for the smallest companies to 95 for large companies. size, gradually going from 3.3 for each natural person to almost 95 for each large firm.

size	%CPVR	Number of CPVR	% firms	Number of firms	CPVRs per firm
physical	8.0	1 510	36.8	451	3.3
micro	21.7	4 116	32.8	402	10.2
small	11.5	2 171	15.5	190	11.4
medium	18.8	3 554	8.5	104	34.2
large	40.0	7 580	6.5	80	94.8
SME + physical	60.0	11 351	93.5	1 147	9.9

Table 5.4: Registered CPVRs by size of owner (end 2021)

---

(114) SMEs are companies with fewer than 250 employees and annual turnover of less than 50 million EUR. Within that category, “micro” companies have 10 employees or fewer; “small” companies have 10-50 employees, and “medium” companies have 50-250 employees.

(115) In reality, this number must be somewhat higher, since the procedure used to identify firms is more successful for large firms. Since all the large firms were manually searched in ORBIS, it is likely that the true percentage of rights registered by SME is higher than the 60% shown in the table. This assumption is reinforced by the fact that the average number of rights per SME is 9.9 and 9.4 for firms whose size could not be determined.

As shown in Table 5.5, the percentage of CPVRs held by SMEs varies among the Member States. In Italy more than 93% of CPVRs is in the hands of SMEs that register on average just 5.4 PVR per SME (compared to almost 10 for the EU). The Netherlands, with almost 60% of CPVRs in the hands of SMEs, is at the EU average, while Germany is above the average at 68.4% and France is below, with 40% of French CPVRs owned by SMEs.

country	% of CPVR	% of firms	Avg. number of CPVRs
Italy	93.4	89.0	5.4
Belgium	92.5	96.1	10.1
Spain	77.7	84.8	6.9
Denmark	73.9	87.8	17.5
Germany	68.4	93.8	14.5
Netherlands	59.6	97.6	8.3
Poland	56.8	87.9	4.0
France	40.0	88.5	15.4
Hungary	39.4	76.5	2.0

% of CPVR is the percentage of CPVRs owned by SMEs or physical persons.
% of firms is the percentage of SMEs or physical persons among all PVR applicants.
Avg. number of PVRs is the average number of CPVRs per SME/physical person.

Table 5.5: Registered CPVRs by SMEs and physical persons (end 2021)

Thus, SMEs play an important role in plant variety innovation in the EU. The constitute by far the majority of CPVR applicants, and they account for close to two thirds of CPVRs in force.

5.5 CPVR stock by economic sector in the European Union

In a sample of 17 662 CPVRs registered by EU-based entities, representing about 78% of all EU-owned CPVRs, it was possible to identify the primary economic sector (NACE (116)) in which the company was active. Unfortunately, NACE does not distinguish between breeders and growers, so the sectoral breakdown shown in Table 5.6 is only partially indicative of the relative weight of the different sectors.

Nevertheless, one can observe that the agriculture sector dominates, accounting for close to 2/3 of all CPVR applications. This is followed by firms specialising in research and development (15%) and wholesale trade (13%).

---

(116) NACE (“Nomenclature statistique des activités économiques dans la Communauté européenne”) is the standard classification of economic activity used in the EU. It is maintained by Eurostat, the EU’s statistical office, and its use is mandatory in all Member States.

Table 5.6: Registered CPVRs by sector (end of 2021)

NACE	Sector	PVR	%
Agriculture		**11 125**	**63.0**
01.30	Plant propagation	2 851	16.1
01.13	Growing of vegetables and melons, roots and tubers	2 414	13.7
01.19	Growing of other non-perennial crops [including flowers among other]	2 184	12.4
01.11	Growing of cereals (except rice), leguminous crops and oil seeds	2 160	12.2
01.64	Seed processing for propagation	574	3.2
01.61	Support activities for crop production	347	2.0
01.24	Growing of pome fruits and stone fruits	297	1.7
R&D		**2 732**	**15.5**
72.19	Other research and experimental development on natural sciences and engineering [including R&D in agricultural sciences, among other]	1 603	9.1
72.11	Research and experimental development on biotechnology	1 095	6.2
72.10	Research and experimental development on natural sciences and engineering [including research in agricultural sciences]	33	0.2
Wholesale		**2 297**	**13.0**
46.21	Wholesale of grain, unmanufactured tobacco, seeds and animal feeds	1 642	9.3
46.22	Wholesale of flowers and plants	474	2.7
46.31	Wholesale of fruit and vegetables	127	0.7
Royalties		**832**	**4.7**
77.40	Leasing of intellectual property and similar products, except copyrighted works	827	4.7
Other		**676**	**3.8**

Table 5.6: Registered CPVRs by sector (end of 2021)

5.6 Employment and turnover of CPVR owners in the EU

For a subset of the CPVR owners in the EU (1 089 firms) data on their turnover and employment is available. In Table 5.7, the combined employment and turnover in those firms is shown. For a small number of mostly large firms plant breeding is only a minor proportion of their activities, and those firms (the 138 firms labelled as "other firms" in the table) have been excluded from the analysis (117).

sector	firms	employees	turnover (million €)
Agriculture (seed growing)	603	35,045	17,780
R&D (agricultural & biotechnology)	128	7,970	2,364
Royalties (PVR)	47	119	722
Wholesale (seeds)	173	27,590	14,552
Total	**951**	**70,725**	**35,418**
Other firms	*138*	*217,223*	*95,457*

Table 5.7: Turnover and employment in EU firms that own CPVRs

The 951 EU firms that have active CPVRs in sectors which register such rights more intensively and for which plant breeding is the principal economic activity, employ almost 71 000 people and have an annual turnover over 35 billion EUR. Notwithstanding the limitations of the data, these figures are a credible assessment of the direct contribution of the breeders using CPVR system to the EU economy.

As discussed earlier in this chapter, plant breeding is concentrated in some regions and some Member States, and constitutes an important part of the economy in those regions. Furthermore, as shown in section 5.4, a large part of this economic activity is carried out by SMEs.

---

(117) Examples of such firms include BASF, Carlsberg or Veltins. Several universities are also among CPVR owners.

6 Concluding remarks

This study has examined many aspects of the contribution of the Community Plant Variety Right to Europe’s economy. It finds that the plant breeding sector employs significant numbers of workers and generates significant turnover, concentrated in particular regions. More importantly, the plant breeding innovations protected by CPVRs are used by European farmers and growers to produce food and ornamental plants, thereby generating additional economic output and making a positive contribution to the EU’s trade balance vis a vis the rest of the world.

It is remarkable that thanks to innovations in plant breeding, European farmers have been able to increase food production in the past 25 years while at the same time reducing their use of resources and the consequent damage to the environment. This report documents, employing credible and widely accepted methods from agricultural economics, that plant breeding protected by CPVRs has made a significant contribution to Europe’s food security and to the European Union’s goal of making Europe climate-neutral by 2050. While difficult to quantify, these innovations also have contributed to the UN’s Sustainable Development Goals, for example by reducing water use, loss of biological diversity and providing access to healthy food, not only within the EU but globally.

Solving the challenges of the coming decades—to feed a growing world population while moving towards climate neutrality and a cleaner environment—will continue to require innovations in plant breeding, and those innovations will continue to need protection by Plant Variety Rights, including the Community Plant Variety Rights.

References

Adams, D.; Alig, R.; McCarl, B.; Murray, B. (2005): FASOMGHG conceptual structure, and specification: documentation. Washington, DC: EPA.

Allan, J.A. (1994): Overall perspectives on countries and regions. In: Rogers, P.; Lydon, P. (eds.): Water in the Arab world: Perspectives and prognoses, p. 65-100. Cambridge, MA: Harvard University Press.

Allan, J.A. (1993): Fortunately, there are substitutes for water: otherwise, our hydro-political futures would be impossible. In: Priorities for Water Resources Allocation and Management 1993: 13-26.

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

Baldock, D.; Hart, K. (2021): Pathways towards a legislative framework for sustainable food systems in the EU. Brussels: Institute for European Environmental Policy.

Barath, L.; Fertö, I. (2017): Productivity and convergence in European agriculture. In Journal of Agricultural Economics (68): 228-248

Barreiro-Hurle, J.; Bogonos, M.; Himics, M.; Hristov, J.; Pérez-Domínguez, I.; Sahoo, A.; Salputra, G.; Weiss, F.; Baldoni, E.; Elleby, C. (2021): Modelling environmental and climate ambition in the agricultural sector with the CAPRI model: exploring the potential effects of selected Farm to Fork and Biodiversity strategies targets in the framework of the 2030 climate targets and the post 2020 Common Agricultural Policy. Seville: JRC.

Beach, H.; Adams, D.; Alig, R.; Baker, J.; Latta, G.; McCarl, B.; Murray, B.; Rose, S.; White, E. (2010): Model documentation for the forest and agricultural sector optimization model with greenhouse gases (FASOMGHG). Washington, DC: EPA.

Beckman, J.; Ivanic, M.; Jelliffe, J.L.; Baquedano, F.G.; Scott, S.G. (2020): Economic and food security impacts of agricultural input reduction under the European Union Green Deal's Farm to Fork and Biodiversity strategies. Economic Brief Number 30. Washington, DC: USDA.

Bharadwaj, D.N. (2016): Sustainable agriculture and plant breeding. In: Jameel, M.; Shri, A.K.; Jain, M.; Johnson, D.V. (eds.): Advances in plant breeding strategies: agronomic, abiotic and biotic stress traits. Cham: Springer International Publishing: 3–34.

Bishaw, Z.; van Gastel, A.J.G. (2009): Variety release and policy options. In: Ceccarelli, S.; Guimarães, E.P.; Weltzien, E. (eds.): Plant breeding and farmer participation. Chapter 21. Rome: FAO.

Bjørnstad, A. (2016): 'Do not privatize the giant's shoulders': rethinking patents in plant breeding. In: Trends in Biotechnology (34): 1–9.

Blakeney, M. (2012): Patenting of plant varieties and plant breeding methods. In: Journal of Experimental Botanics (63): 1069–1074.

Blandford, D. (2015): A U.S. perspective on measuring trade effects of domestic agricultural policies in the United States and Canada. London: Routledge.

Boldt, B. (2020): Fusarienresistenzen im Weizengenom orten. In: Bioökonomie.de (05.08.2020).

Bostyn, S.J.R. (2013): Patentability of plants: at the crossroads between monopolizing nature and protecting technological innovation? In: World Intellectual Property (16): 105–149.

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

Bremmer, J.; Gonzalez-Martinez, A.; Jongeneel, R.; Huiting, H.; Stokkers, R.; Ruijs, M. (2022): Impact assessment of EC 2030 Green Deal targets for sustainable crop production. Wageningen: Wageningen Economic Research.

Brown, J. (2008): An introduction to plant breeding. Oxford: Blackwell Publishers.

Butler, R.A. (2020): Brazil revises deforestation data: Amazon rainforest loss topped 10,000 square km in 2019. In: Mongabay Series: Amazon Conservation, Global Forest, 10 June 2020.

Cabrera Medaglia, J.; Oguamanam, C.; Rukundo, O.; Perron-Welch, F. (2019): Comparative study of the Nagoya Protocol, the Plant Treaty and the UPOV Convention: the interface of access and benefit sharing and plant variety protection. Montreal: Centre for International Sustainable Development Law.

Cagatay, S.; Saunders, C.; Wreford, A. (2003): Lincoln Trade and Environment Model (LTEM): linking trade and environment. Agri-business and Economics Research Unit Research Papers No. 263. Lincoln: Lincoln University.

Cammalleri, C.; Naumann, G.; Mentaschi, L.; Formetta, G.; Forzieri, G.; Gosling, S.; Bisselink, B.; De Roo, A.; Feyen, L. (2020): Global warming and drought impacts in the EU. Ispra: JRC.

CBD (Convention on Biological Diversity) (2001): Global biodiversity outlook 1. Montreal: CBD.

CBI (Centre for the Promotion of Imports from Developing Countries) (2017): Which trends offer opportunities on the European cut flowers and foliage market? The Hague: CBI.

Chen, K.; Wang, Y.; Zhang, R.; Zhang, H.; Gao, C. (2019): CRISPR/Cas genome editing and precision plant breeding in agriculture. In: Annual Review of Plant Biology (70): 667-697.

Chiang, A.; Wainwright, K. (2005): Fundamental methods of mathematical economics. 4th ed. Boston, MA: McGraw-Hill.

Cingiz, K.; Gonzalez-Hermoso, H.; Heijman, W.; Wesseler, J.H.H. (2021): A cross-country measurement of the EU bioeconomy: an input-output approach. In: Sustainability (13): 3003.

Clark, J.R.; Brazelton Aust, A.; Jondle, R. (2012): Intellectual property protection and marketing of new fruit cultivars. In: Badenes, M.L.; Byrne, D.H. (eds.): Fruit breeding. Boston, MA: Springer US: 69-96.

Cobb, J.N.; Juma, R.U.; Biswas, P.S.; Arbelaez, J.D.; Rutkoski, J.; Atlin, G.; Hagen, T.; Quinn, M.; Ng, E.H. (2019): Enhancing the rate of genetic gain in public-sector plant breeding programs: lessons from the breeder's equation. In: Theoretical and Applied Genetics (132): 627–645.

Coomes, O.T.; McGuire, S.J.; Garine, E.; Caillon, S.; McKey, D.; Demeulenaere, E. (2015): Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. In: Food Policy (56): 41–50.

Correa, C.M. (2017): Implementing farmers' rights relating to seeds. Research Paper 75. Geneva: South Centre.

Correa, C. M.; Shashikant, S.; Meienberg, F. (2015): Plant variety protection in developing countries: a tool for designing a sui generis plant variety protection system – an alternative to UPOV 1991. Lausanne: Association for Plant Breeding for the Benefit of Society.

CPVO (Community Plant Variety Office) (2022): Statistics. Angers: CPVO.

CPVO (Community Plant Variety Office) (2021): CPVO Variety Finder. Angers: CPVO.

Curtis, F.; Nilsson, M. (2012): Collection systems for royalties in wheat: an international study. Nyon: ISF.

Czyzewski, B.; Matuszczak, A.; Grzelak, A.; Guth, M.; Majchrzak, A. (2020): Environmentally sustainable value in agriculture revisited: how does Common Agricultural Policy contribute to eco-efficiency? In: Sustainability Science (6):137–152.

DEFRA (Department for Environment Food and Rural Affairs) (2020): Total factor productivity of the UK agricultural industry. York: DEFRA.

Deloitte (2016): Study on market-related issues regarding plant variety protection. Final Report. London: Deloitte.

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

DG GROW (Directorate General Internal Market, Industry, Entrepreneurship and SMEs) (2016): Final report of the expert group on the development and implications of patent law in the field of biotechnology and genetic engineering. Brussels: EC.

Eaton, D. (2002): TRIPS and plant varietal protection: economic analysis and policy choices. The Hague: Agricultural Economics Research Institute (LEI).

EC (European Commission) (2021a): EU plant variety database. Brussels: EC.

EC (European Commission) (2021b): FADN database: standard results about the economic situation of EU farms by different groups. Brussels: EC.

EC (European Commission) (2021c): Fruit reproductive material information system. Brussels: EC.

EC (European Commission) (2021d): Market overview by sector. Dashboards. Brussels: EC.

EC (European Commission) (2021e): Study on the Union's options to update the existing legislation on the production and marketing of plant reproductive material. Commission Staff Working Document. Brussels: EC.

EC (European Commission) (2020a): A Farm to Fork strategy for a fair, healthy and environmentally friendly food system. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels: EC.

EC (European Commission) (2020b): EU Biodiversity strategy for 2030: bringing nature back into our lives. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels: EC.

EC (European Commission) (2020c): Horticultural products: flowers and ornamental plants – production statistics 2010 – 2019. Brussels: EC.

EC (European Commission) (2020d): Report on the protection and enforcement of intellectual property rights in third countries. Commission Staff Working Document. Brussels: EC.

EC (European Commission) (2019): Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal. Brussels: EC.

EC (European Commission) (2016): Productivity in EU agriculture – slowly but steadily growing. In: EU Agricultural Markets Briefs (10). Brussels: EC.

EC (European Commission) (2015): Guidance document on the implementation by member states of permanent grassland provisions in the context of the payments for agricultural practices beneficial for the climate and the environment (greening): Claim year 2015. Brussels: EC.

EEA (European Environment Agency) (2021): EEA greenhouse gases – data viewer. Copenhagen: EEA.

EEA (European Environment Agency) (2020): Annual European Union greenhouse gas inventory 1990–2018 and inventory report 2020: submission to the UNFCCC Secretariat. Copenhagen: EEA.

EEA (European Environment Agency) (2018): Large European lakes and reservoirs. Copenhagen: EEA.

Eidman, V.; Hallam, A.; Morehart, M.; Klonsky, K. (2000): Commodity costs and returns estimation handbook. Ames, IA: Iowa State University of Science and Technology.

Esquinas-Alcázar, J. (2005): Protecting crop genetic diversity for food security: political, ethical, and technical challenges. In: Nature Reviews Genetics (6): 946–953.

ETP (European Technology Platform 'Plants for the Future') (2015): Building sustainable innovation: leadership in European agriculture - an innovation action plan to 2020. Brussels: ETP.

EUIPO-EPO (2019): IPR-intensive industries and economic performance in the European Union. Alicante and Munich: EUIPO and EPO.

Eurostat (2022a): Economic accounts for agriculture – values at current prices. Luxembourg: Eurostat.

Eurostat (2022b): EU-Handel nach HS2,4,6 und CN8 seit 1988. Luxemburg: Eurostat.

Eurostat (2021a): Crop production in EU standard humidity. Luxembourg: Eurostat.

Eurostat (2021b): EU-Handel nach SITC seit 1988. Luxembourg: Eurostat.

Eurostat (2021c): Gross value added and income by A*10 industry breakdowns. Luxembourg: Eurostat.

Eurostat (2021d): Statistics in flowers and ornamental plants: number of farms and areas by size of farm (UAA) and size of flower and ornamental plant area. Luxembourg: Eurostat.

Fageria, N.K.; Baligar, V.C.; Li, Y.C. (2008): The role of nutrient efficient plants in improving crop yields in the 21st century. In: Journal of Plant Nutrition (31): 1121–1157.

FAO (Food and Agriculture Organization) (2021): FAOSTAT. Rome: FAO.

FAO (Food and Agriculture Organization) (2012): Technical conversion factors for agricultural commodities. Rome: FAO.

FAO (Food and Agriculture Organization) (2003): Medium-term prospects for agricultural commodities: projections to the year 2010. Rome: FAO.

FAO (Food and Agriculture Organization); OECD (Organisation for Economic Co-operation and Development); UPOV (International Union for the Protection of New Varieties of Plants); ISF (International Seed Federation); ISTA (International Seed Testing Association) (2009): Responding to the challenges of a changing world: the role of new plant varieties and high-quality seed in agriculture. Session 3 “Plant Variety Protection” Rome: Second World Seed Conference.

Fonderflick, J.; Besnard, A.; Chardès, M.C.; Lanuzel, L.; Thill, C.; Pointereau, P. (2020): Impacts of agricultural intensification on arable plants in extensive mixed crop-livestock systems. In: Agriculture, Ecosystems & Environment (290): 106778.

Francois, J.F.; Reinert, K.A. (1997): Applied methods for trade policy analysis. Cambridge: Cambridge University Press.

Fuentes-Saguar, P.D.; Mainar-Causapé, A.J.; Ferrari, E. (2017): The role of bioeconomy sectors and natural resources in EU economies: a social accounting matrix-based analysis approach. In: Sustainability (9): 2383.

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

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

GHK Consulting (2011): Evaluation of the Community Plant Variety Right acquis – Final Report. Frankfurt am Main: GHK Consulting.

Golay, C.; Batur, F. (2021): Practical manual on the right to seeds in Europe: the United Nations declaration on the rights of peasants and other people working in rural areas and the right to seeds in Europe. Geneva: The Geneva Academy of International Humanitarian Law and Human Rights.

Golay, C.; Bessa, A. (2019): The right to seeds in Europe: the United Nations declaration on the rights of peasants and other people working in rural areas and the protection of the right to seeds in Europe. Academy Briefing, No. 15. Geneva: The Geneva Academy of International Humanitarian Law and Human Rights.

Grogan, D. (2012): Origin and yield of European perennial ryegrass (Lolium perenne L.) varieties in Ireland. Dublin: Department of Agriculture, Fisheries and Food.

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

Hakeem, K.R. (2020): The global floriculture industry: shifting directions, new trends, and future prospects. Palm Bay, FL: Apple Academic Press Inc.

Heald, P.J.; Chapman, S. (2011): Veggie tales: pernicious myths about patents, innovation, and crop diversity in the 20th century. Urbana, IL: University of Illinois.

Hehanussa, S.; Ilge, B. (2018): UPOV 91 and trade agreements: compromising farmers' right to save and sell seeds. Both ENDS discussion paper. Utrecht: Both ENDS.

Heiderer, R.; Ramos, F.; Capitani, C.; Koeble, R.; Blujdea, V.; Gomez, O.; Mulligan, D.; Marelli, L. (2010): Biofuels, a new methodology to estimate GHG emissions from global land use change: a methodology involving spatial allocation of agricultural land demand and estimation of CO_2 and N_2O emissions. Luxembourg: Publications Office 174ft he European Union.

Henning, C.; Witzke, P.; Panknin, L.; Grunenberg, M. (2021): Ökonomische und ökologische Auswirkungen des Green Deals in der Agrarwirtschaft: eine Simulationsstudie der Effekte der F2F-Strategie auf Produktion, Handel, Einkommen und Umwelt mit dem CAPRI-Modell. Kiel: CAU

Henry, C.; Stiglitz, J.E. (2010): Intellectual property, dissemination of innovation and sustainable development. In: Global Policy (1): 237–251.

HFFA Research (2016): The economic, social and environmental value of plant breeding in the European Union: an ex-post evaluation and ex-ante assessment. Berlin: HFFA Research GmbH.

Houck, J.P. (1986): Elements of agricultural trade policies. London: Collier Macmillan Publishers.

IndexMundi (2017): IndexMundi data base. Commodity Prices. Agriculture. Charlotte, NC: IndexMundi.

IPCC (Intergovernmental Panel on Climate Change) (2020): Climate change and land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for Policymakers. Geneva: IPCC.

Jechlitschka, K.; Kirschke, D.; Schwarz, G. (2007): Microeconomics using Excel®: integrating economic theory, policy analysis and spreadsheet modelling. London: Routledge.

Jiménez-Donaire, M.D.P.; Vicente Giráldez, J.; Vanwalleghem, T. (2020): Impact of climate change on agricultural droughts in Spain. In: Water (12): 3214.

Lamichhane, J.R.; Arseniuk, E.; Boonekamp, P.; Czembor, J.; Decroocq, V.; Enjalbert, J. (2018): Advocating a need for suitable breeding approaches to boost integrated pest management: a European perspective. In: Pest Management Science (74): 1219–1227.

Ledebur, E.O. (2001): Der Agraraußenhandel der MERCOSUL Länder – Handelsliberalisierung, regionale und überregionale Integration. Kiel: Wissenschaftsverlag Vauk.

Louwaars, N.P. (2018): Plant breeding and diversity: a troubled relationship? In: Euphytica: Netherlands Journal of Plant Breeding (214): 114.

Kaiser, N.; Douches, D.; Dhingra, A.; Glenn, K.C.; Herzig, P.R.; Stowe, E.C.; Swarup, S. (2020): The role of conventional plant breeding in ensuring safe levels of naturally occurring toxins in food crops. In: Trends in Food Science & Technology (100): 51–66.Karoshi, M. (2021): Richtpreise für den Verkauf von Silomais ab Feld 2021. In: lkonline (25.08.2021).

Kazlauskiene, N.; Meyers, W. (2003): Implications of EU accession for trade regimes and trade flows of CEECs. Paper presented at the International Conference “Agricultural Policy Reform and the WTO: Where are we Heading?”. Capri, June 23-26, 2003.

Kazlauskiene, N.; Meyers, W. (1993): Modelling agricultural markets for policy and trade analysis in Lithuania. Baltic Report No. 93-BR13. Vilnius: Lithuanian Institute of Agrarian Economics.

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

KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) (2021): Leistungs-Kostenrechnung Pflanzenbau. Darmstadt: KTBL.

Kühl, R.; Müller, J.; Kruse, J.; Monath, J.; Paul, L.M. (2021): Green Deal – wie und zu welchem Preis können die Ziele von der deutschen Agrar- und Ernährungswirtschaft erreicht werden? Gießen: Justus-Liebig-Universität.

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

Lenaerts, B.; de Mey, Y.; Demont, M. (2018): Global impact of accelerated plant breeding: evidence from a meta-analysis on rice breeding. In: PloS ONE (13, 6): e0199016.

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

Lüttringhaus, S.; Cartsburg, M. (2018): Modelling agricultural markets with the HFFA-Model. Methodological Paper. Berlin: HFFA Research GmbH.

Mamias, S. (2018): The floriculture supply chain: characteristics and prospects. Amsterdam: Union Fleurs.

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

Mariani, S. (2021): Law-driven innovation in cereal varieties: the role of plant variety protection and seed marketing legislation in the European Union. In: Sustainability (13: 8049).

Mariani, S. (2020): Innovation and plant variety protection in the European Union: the case of cereal varieties - an empirical legal study. Macerata: Università degli Studi di Macerata.

Martínez López, A.H. (2021): The interface between trademarks and plant variety denominations: towards clearer coexistence at international and EU level. Angers: CPVO.

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

Matthews, A. (2021): Farm and non-farm income comparisons. In: Cap Reform, February 9, 2021.

McDonagh, J.; O`Donovan, M.; McEvoy, M.; Gilliland, T.J. (2016): Genetic gain in perennial ryegrass (Lolium perenne) varieties 1973 to 2013. In: Euphytica (212): 187-199.

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

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

Mekonnen, M.M.; Hoekstra, A.Y. (2011b): The green, blue, and grey water footprint of crops and derived crop products. In: Hydrology and Earth System Sciences (15): 1577-1600.

Metzger, A.; Zech, H. (2020): A comprehensive approach to plant variety rights and patents in the field of innovative plants. Berlin: Humboldt University Berlin.

Miflin, B. (2000): Crop improvement in the 21st century. In: Journal of Experimental Botanics (51): 1–8.

Moschini, G.; Yerokhin, O. (2007): The economic incentive to innovate in plants: patents and plant breeder's rights. In: Kesan, J.P. (ed.): Agricultural biotechnology and intellectual property: seeds of change. Urbana, IL: University of Illinois

Mubako, S.T. (2018): Blue, green, and grey water quantification approaches: a bibliometric and literature review. El Paso, TX: University of Texas – Center for Environmental and Resource Management.

NIST (National Institute of Standards and Technology) (2012): Engineering statistical handbook. Gaithersburg, MD: NIST.

Noleppa, S.; Cartsburg, M. (2021): The socio-economic and environmental values of plant breeding in the EU and selected EU member states. An ex-post evaluation and ex-ante assessment considering the “Farm to Fork” and “Biodiversity” strategies. HFFA Research Report 2021. Berlin: HFFA Research GmbH.

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

Noleppa, S.; Lütringhaus, S. (2016): Der Einsatz von Epoxiconazol im Getreideanbau: Eine Analyse ökonomischer Auswirkungen und von Umwelteffekten für Deutschland und die Europäische Union unter besonderer Berücksichtigung zunehmender Resistenzen. HFFA Research Report 05/2016. Berlin: HFFA Research GmbH.

OECD (Organisation for Economic Co-operation and Development) (2018): Concentration in seed markets: potential effects and policy responses. Paris: OECD.

Oxfam (2018): The status of patenting plants in the global south. Nairobi: Oxfam.

Oxfam Plantum; Euroseeds (2019): Can the exchange or sale of self-produced seed be allowed under UPOV 1991? Report and recommendations of the project "Options to interpret the notion of private and non-commercial use as included in Article 15.1.i of the UPOV 1991 Convention”. Nairobi: Oxfam.

Peschard, K. (2021): Searching for flexibility: why parties to the 1978 Act of the UPOV Convention have not acceded to the 1991 Act. Lausanne: Association for Plant Breeding for the Benefit of Society.

Pfeiffer, W.H.; McClafferty, B. (2007): HarvestPlus: breeding crops for better nutrition. In: Crop Science (47): 88-105.

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

Pretty, J.; Benton, T.G.; Pervez Bharucha, Z.; Dicks, L.V.; Butler Flora, C.; Godfray, H.C.J.; Goulson, D.; Hartley, S.; Lampkin, N.; Morris, C.; Pierzynski, G.; Prasad, P.V.V.; Reganold, J.; Rockström, J.; Smith, P.; Thorne, P.; Wratten, S. (2018): Global assessment of agricultural system redesign for sustainable intensification. In: Nature Sustainability (1): 441-446.

Redman, G.; Noleppa, S. (2017): Mycotoxins – the hidden danger in food and feed. Melton Mowbray: The Andersons Centre.

Romero, T.; Correa, C. (2021): Patenting of plants and exceptions to exclusive rights: lessons from European law. Geneva: South Centre.

Roningen, V. (2016): VORSIM 2015 model building software and models for Excel 2013 and 2016. Arlington, VA: VORSIM.

Roningen, V. (2004): The economic impact of a Peru Free Trade Agreement (FTA) with the United States on the sugar, cotton, and other sectors in Peru: a partial equilibrium analysis. Washington, DC: USAID.

Roningen, V. (1986): A static world policy simulation (SWOPSIM) Modelling framework. Staff Report AGES 860625, Economic Research Service. Washington, DC: USDA.

Roningen, V.; Sullivan, F.; Dixit, P. (1991): Documentation of the Static World Policy Simulation (SWOPSIM) Modelling framework. ERS Staff Report No. AGES 9151. Washington, DC: USDA.

Royal Flora Holland (2020): Joining Forces. Annual Report 2020. Aalsmeer: Royal Flora Holland.

Royal Flora Holland (2019): The strength of the marketplace: 2019 annual report. Aalsmeer: Royal Flora Holland.

Rutz, H.W. (2008): Study on farm saved seed in the European Union. Brussels: EC.

Sadoulet, E.; de Janvry, A. (1995) : Quantitative development policy analysis. Baltimore, MD: The Johns Hopkins University Press.

Santeramo, F.G.; Lamonaca, E. (2019): On the drivers of global grain price volatility: an empirical investigation. In: Agricultural Economics – Czech (65): 31–34.

Saraswathi, M.S.; Kalaiponmani, K.; Uma, S.; Backiyarani, S. (2018): Chapter 14 – critical evaluation of the benefits and risks of genetically modified horticultural crops. In: Genetic Engineering of Horticultural Crops (2018): 315-351.

Saunders, C.; Wreford, A. (2005): Agricultural trade liberalization and greenhouse gas emissions: modelling the linkages using a partial equilibrium trade model. In: Agricultural and Resource Economics Review (42): 32-41.

Saunders, J.; Driver, T. (2016): International trade implications for consumer attitudes to New Zealand food attributes. Research report / Agribusiness and Economics Research Unit, Lincoln University. Lincoln: Lincoln University.

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

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

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

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

Searchinger, T.; Heimlich, R. (2008): Estimating greenhouse gas emissions from soy-based US biodiesel when factoring in emissions from land use change. In: Outlaw, J. L.; Ernstes, D.P. (eds.): The lifecycle carbon footprint of biofuels: 35–45. Miami Beach, FL: Farm Foundation.

Stamp, P.; Visser, R. (2012): The twenty-first century, the century of plant breeding. In: Euphytica (186): 585–591.

Statista (2022): Gross domestic product at current market prices of selected European countries in 2020 (in million euros). Hamburg: Statista.

Struik, P.C.; Kuyper, T.W. (2017): Sustainable intensification in agriculture: the richer shade of green – a review. In: Agronomy for Sustainable Development (37): 39.

Sullivan, J.; Roningen, V.; Leetmaa, S.; Gray, D. (1992): A 1989 global database for the Static World Policy Simulation (SWOPSIM) modelling framework. Staff Report, Economic Research Service. Washington, DC: USDA

Tandzi, N.L.; Mutengwa, S.C. (2020): Factors affecting yield of crops. In: Amanullha, D. (ed.): Agronomy - Climate Change & Food Security. London: IntechOpen.

Tansey, G.; Rajotte, T. (eds.) (2008): The future control of food: a guide to international negotiations and rules on intellectual property, biodiversity, and food security: Ottawa: International Development Research Centre.

The World Bank (2021): Inflation, consumer prices (annual %) – European Union. Washington, DC: The World Bank.

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

UBA (Umweltbundesamt) (2021): Indicator: grasslands. Dessau-Roßlau: UBA.

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

UN (United Nations) (2009): The right to food: seed policies and the right to food – enhancing agrobiodiversity and encouraging innovation. Report of the Special Rapporteur on the right to food. New York, NY: UN.

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

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

UPOV (International Union for the Protection of New Varieties of Plants) (2005): UPOV report on the impact of plant variety protection. UPOV Publications, 353(E). Geneva: UPOV.

USDA (United States Department of Agriculture) (2021): International agricultural productivity. Data and methods as of October 2021. Washington, DC: USDA.

van Dijk, M.; Morley, T.; Rau, M.L.; Saghai, Y. (2021): A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. In: Nature Food (2): 494-501.

van Elsen, A.; Ayerdi-Gotor, A.; di Vicente, C.; Traon, D.; Gennatas, J.; Amat, L. (2013): Plant breeding for an EU bio-based economy. The potential of public sector and public/private partnership. Brussels: EC.

Villoria, N. (2019): Consequences of total factor productivity growth for the sustainability of global farming: accounting for direct and indirect land use effects. In: Environmental Research Letters (14): 125002.

Von Witzke, H.; Noleppa, S. (2012): The economics of Rumpelstiltskin: Why speculation is not a prime cause of high and volatile international agricultural commodity prices: An economic analysis of the 2007-08 price spike. Berlin: Humboldt Forum for Food and Agriculture (HFFA) e. V.

Voss-Fels, K.P.; Stahl, A.; Wittkop, B.; Lichthardt, C.; Nagler, S.; Rose, T.; Chen, T.W.; Zetzsche, H.; Seddig, S.; Baig, M.M.; Ballvora, A.; Frisch, M.; Ross, E.; Hayes, B.J.; Hayden, M.J.; Ordon, F.; Leon, J.; Kage, H.; Friedt, W.; Stützel, H.; Snowdon, R.J. (2019a): Breeding improves wheat productivity under contrasting agrochemical input levels. In: Nature Plants (706): 706–714.

Voss-Fels, K.P.; Stahl, A.; Wittkop, B.; Lichthardt, C.; Nagler, S.; Rose, T.; Chen, T.W.; Zetzsche, H.; Seddig, S.; Baig, M.M.; Ballvora, A.; Frisch, M.; Ross, E.; Hayes, B.J.; Hayden, M.J.; Ordon, F.; Leon, J.; Kage, H.; Friedt, W.; Stützel, H.; Snowdon, R.J. (2019b): Breeding improves wheat productivity under contrasting agrochemical input levels. In: Nature Plants (706): Supplementary information.

Wang, D.D.; Li, Y.; Bhupathiraju, S.N.; Rosner, B.A.; Sun, Q.; Giovannucci, E.C.; Rimm, E.B.; Manson, J.E.; Willett, W.C.; Stampfer, M.J.; Hu, F.B. (2021): Fruit and vegetable intake and mortality: results from two prospective cohort studies of US men and women and a meta-analysis of 26 cohort studies. In: Circulation (143): 1642-1654.

Wang, X.; Dietrich, J.P.; Lotze-Campen, H.; Biewald, A.; Stevanovíc, M.; Bodirsky, B.L.; Brümmer, B.; Popp, A. (2020): Beyond land-use intensity: assessing future global crop productivity growth under different socioeconomic pathways. In: Technological Forecasting and Social Change (160): 120208.

Wijaya, A.; Nirarta, T.; Samadhi, K.; Juliane, R. (2019): Indonesia is reducing deforestation, but problem areas remain. Washington, DC: WRI.

Winge, T. (2012): A guide to EU legislation on the marketing of seed and plant propagating material in the context of agricultural biodiversity. FNI Report, 11/2012. Lysaker: Fridtjof Nansen Institute.

Worldometer (2020): Largest countries in the world (by area). N.L.: Worldometer.

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

Zaidi, S.S.A.; Mahas, A.; Vanderschuren, H.; Mahfouz, M.M. (2020): Engineering crops of the future: CRISPR approaches to develop climate resiient and disease-resistant plants. In: Genome Biology (21): 289.

Annex A List of references for comparison of annual total factor productivity growth

AgbioInvestor (2018): The challenges facing agriculture and the plant science industry in the EU. Pathhead: AgbioInvestor Agricultural Market Intelligence.

Akande, O.P. (2012): An evaluation of technical efficiency and agricultural productivity growth in EU regions. Wageningen: Wageningen University & Research.

Barath, L.; Fertö, I. (2017): Productivity and convergence in European agriculture. In: Journal of Agricultural Economics (68): 228-248.

Cechura, L.; Grau, A.; Hockmann, H.; Kroupová, Z. (2014): Total factor productivity in European agricultural production. Working Paper, No 9. Halle/Saale: IAMO.

DEFRA (Department for Environment, Food and Rural Affairs) (2020): Total factor productivity for the UK agriculture industry. First estimate for 2019. London: DEFRA.

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

EC (European Commission) (2018): Production, yields and productivity. Brussels: EC.

EC (European Commission) (2016): Productivity in EU agriculture – slowly but steadily growing. EU Agricultural Markets Briefs, No 10. Brussels: EC.

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

Kijek, A.; Kijek, T.; Nowak, A.; Skrzypek, A. (2019): Productivity and its convergence in agriculture in new and old European Union member states. In: Agricultural Economics – Czech (65): 01-09.

Nowak, A.; Kubik, R. (2019): Changes in agricultural productivity in new and old member states of the European Union. In: European Research Studies Journal (4): 101-114.

Piesse, J.; Thirtle, C. (2010): Agricultural productivity in the United Kingdom. In: Alston, J.M.; Babcock, B.A.; Pardey, P.G. (eds.): The shifting patterns of agricultural production and productivity worldwide: Chapter 7. Ames, IA: ISU.

Rusielik, R. (2020): Productivity of European Union agriculture in 2009-2018: measurement and analysis using the aggregated productivity indexes. In: Research Paper of Wroclaw University of Economics and Business (64): 174-186.

USDA (United States Department of Agriculture) (2021): International agricultural productivity. Data and methods as of October 2021. Washington, DC: USDA.

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

Villoria, N. (2019): Consequences of agricultural total factor productivity growth for the sustainability of global farming: accounting for direct and indirect land use effects. In: Environmental Research Letters (14): 125002.

Wang, X.; Dietrich, J.P.; Lotze-Campen, H.; Biewald, A.; Stevanovic, M.; Bodirsky, B.L.; Brümmer, B.; Popp, A. (2020): Beyond land-use intensity: assessing future global crop productivity growth under different socioeconomic pathways. In: Technological Forecasting and Social Change (160): 120208.

Annex B List of references for definition of plant breeding shares in innovation-induced productivity growth

Acreche, M.M.; Briceño-Félix, G.; Sánchez, J.A.M.; Slafer, G.A. (2008): Physiological bases of genetic gains in Mediterranean bread wheat yield in Spain. In: European Journal of Agronomy (28): 162-170.

ADAS UK (2015): Plant breeding. The essential platform for sustainable agriculture. The plant breeding industry is a major contributor to more sustainable agriculture and food production. Kenilworth: British Society of Plant Breeders.

Agroscope (2011): Variétés suisses de blé de printemps: le progrès génétique à la loupe. Nyon: Station de recherche ACW.

Ahlemeyer, J.; Friedt, W. (2011): Entwicklung der Weizenerträge in Deutschland. Welchen Anteil hat der Zuchtfortschritt? 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 19-23. Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Ahlemeyer, J.; Aykut Tonk, F.; Friedt, W.; Ordon, F. (2006): Genetic gain and genetic diversity in German winter barley cultivars. In: Options Méditerranéennes, Series A (81): 43-47.

Ahrends, H.; Eugster, W.; Gaiser, T.; Rueda-Ayala, V.; Hüging, H.; Ewert, F.; Siebert, S. (2018): Genetic yield gains of winter wheat in Germany over more than 100 years (1895-2007) under contrasting fertilizer applications. In: Environmental Research Letters (13): 104003.

Algermissen, C. (2019): Arbeitspapier zu den Züchtungserfolgen bei Körnerleguminosen und zur Notwendigkeit einer lückenlosen Erhebung von Nachbaugebühren für geschützte Sorten. Bonn: BDP.

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

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

Audigeos, D. (2019): Progrès génétique blé dur: la recherche variétale active malgré la conjoncture. In: Perspectives Agricoles (465): 61-63.

Balaguer, G. J. (2017): Aprovechamiento de la diversidad en Solanum L. sección Lycopersicon para la mejora genética de la calidad organoléptica en tomate. Tesis doctoral: Universitat Politècnica de València.

Barrière, Y.; Alber, D.; Dolstra, O.; Catherine, L.; Motto, M.; Ordas, A.; Waes, J.; Vlasminkel, L.; Welcker, C.; Monod, J. P. (2006): Past and prospects of forage maize breeding in Europe. II. History, germplasm evolution and correlative agronomic changes. In: Maydica (51): 259-274.

Barrière, Y. (2001): Le maïs et l'eau: une situation aujourd'hui paradoxale, mais des progrès génétiques à attendre d'un idéotype redéfini. In: Fourrages (168): 477-489.

Beuch, S. (2011): Züchtung auf Ertrag und Qualität bei Hafer (Avena sativa L.) – Entwicklung und Perspektiven. 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 57-63, Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Bingham, I.; Karley, A.; White, P.; Thomas, W.T.B.; Russell, J.R. (2012): Analysis of improvements in nitrogen use efficiency associated with 75 years of barley breeding. In: European Journal of Agronomy (42): 49-58.

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

Bradshaw, J.E. (2009): Potato breeding at the Scottish Plant Breeding Station and the Scottish Crop Research Institute: 1920–2008. Potato Research (52): 141-172.

Brancourt-Hulmel, M.; Doussinault, G.; Lecomte, C.; Bérard, P.; Buanec, B.; Trottet, M. (2003): Genetic improvement of agronomic traits of winter wheat cultivars released in France from 1946 to 1992. In: Crop Science (43): 37-45.

Brisson, N.; Gate, P.; Gouache, D.; Charmet, G.; Oury, F.X.; Huard, F. (2010): Why are wheat yields stagnating in Europe? A comprehensive data analysis for France. In: Field Crops Research (119): 201-212.

BSPB (British Society of Plant Breeders) (2014): Plant breeding matters. The business and science of crop improvement. Ely: BSPB.

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

Bruins, M. (2020): Sugar rush: what it takes to develop a new sugar beet variety. In: European Seed (no date).

Buhinicek, I.; Kaucis, D.; Kozic, Z.; Jukic, M.; Gunjaca, J.; Sarcivic, H.; Stepinac, D.; Simic, D. (2021): Trends in maize grain yields across five maturity groups in a long-term experiment with changing genotypes. In: Agriculture (11): 887.

Button, P. (2014): Anwendung der Wissenschaft: Herausforderungen und Chancen. Sortenschutz und Technologietransfer. Symposium über Pflanzenzüchtung für die Zukunft. Genf: UPOV.

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

Causse, M.; Zhao, J.; Diouf, I.; Wang, J.; Lefebvre, V.; Caromel, B.; Génard, M.; Bertin, N. (2020): Genomic designing for climate-smart tomato. In: Genomic Designing of Climate-Smart Vegetable Crops, Springer: 47-159.

Chairi, F.; Aparicio, N.; Serret, M. D.; Araus, J. L. (2020): Breeding effects on the genotype × environment interaction for yield of durum wheat grown after the Green Revolution: The case of Spain. The Crop Journal (8:4): 623-634.

Chairi, F.; Vergara-Diaz, O.; Vatter, T.; Aparicio, N.; Nieto-Taladriz, M.T.; Kefauver, S.C.; Bort, J.; Serret, M.D.; Araus, J.L. (2018): Post-green revolution genetic advance in durum wheat: the case of Spain. In: Field Crops Research (228): 158-169.

Crosbie, T.M.; Eathington, S.R.; Johnson, G.R. (2006): Plant breeding: past, present, and future. In: Plant Breeding: The Arnel R. Hallauer International Symposium. Hiboken, NJ: Blackwell Publishing.

Debaeke, P.; Bret-Mestries, E.; Aubertot, J.N.; Casadebaig, P.; Champolivier, L.; Dejoux, J.F.; Maury, P.; Seassau, C. (2020): Sunflower agronomy: 10 years of research in partnership within the “Sunflower” Technological Joint Unit (UMT) in Toulouse. In: Oilseeds and Fats, Crops and Lipids (27).

De Santis, M.A.; Giuliani, M.M.; Giuzio, L.; De Vita, P.; Lovegrove, A.; Shewry, P.R.; Flagella, Z. (2017): Differences in gluten protein composition between old and modern durum wheat genotypes in relation to 20th century breeding in Italy. In: European Journal of Agronomy (87): 19-29.

De Vita, P.; Mastrangelo, A.; Matteu, L.; Mazzucotelli, E.; Virzì, N.; Palumbo, M.; Lo Storto, M.; Rizza, F.; Cattivelli, L. (2010): Genetic improvement effects on yield stability in durum wheat genotypes grown in Italy. In: Field Crops Research (119): 68-77.

De Vita, P.; Li Destri Nicosia, O.; Nigro, F.; Platani, C. (2007): Breeding progress in morpho-physiological, agronomical, and qualitative traits of durum wheat cultivars released in Italy during the 20th century. In: European Journal of Agronomy (26): 39-53.

DMK (Deutsches Maiskomitee e.V.) (2019): Überdurchschnittlicher Züchtungsfortschritt bei Mais. Bonn: DMK.

DMK (Deutsches Maiskomitee e.V.) (2016): Jährlicher Züchtungsfortschritt kommt nicht immer in der Praxis an. Bonn: DMK.

DTZ Life Sciences Group (2010): Economic impact of plant breeding in the UK. Final Report. Ely: British Society of Plant Breeders.

Duvick, D. (2005): The contribution of breeding to yield advances in maize (Zea Mays L.). In: Advances in Agronomy (86): 83-145.

Edgerton, M.D. (2009): Increasing crop productivity to meet global needs for feed, food, and fuel. In: Plant Physiology (149): 7-13.

Fischer, R.A.; Connor, D.J. (2018): Issues for cropping and agricultural science in the next 20 years. In: Field Crops Research (222): 121-142.

Fischer, R.A.; Byerlee, D.; Edmeades, G. (2014): Crop yields and global food security: will yield increase continue to feed the world? ACIAR Monograph No. 158. Canberra: Australian Centre for International Agricultural Research.

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

Foolad, M. (2007): Genome Mapping and Molecular Breeding of Tomato. In: International Journal of Plant Genomics (2007): 64358.

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

Friedt, W.; Zetzsche, H. (2019): Zuchtfortschritt bei Weizen: Ergebnis der Optimierung von Kornertrag, Ertragssicherheit und Qualität. In: Schwerpunkt Pflanzenbauwissenschaften (71):11.

Gemeinschaftsfonds Saatgetreide (2011): Ertragsentwicklung auf dem Prüfstand. Studie mit 90 Winterweizen-Sorten belegt positiven Einfluss des Züchtungsfortschritts. In: Saat-Gut! Der Newsletter des Gemeinschaftsfonds Saatgetreide (01/2011).

GIPB (Global Partnership Initiative for Plant Breeding Capacity Building) (2008): Plant breeding impacts and current challenges. Rome: FAO.

Giunta, F.; Motzo, R.; Pruneddu, G. (2007): Trends since 1900 in the yield potential of Italian-bred durum wheat cultivars. In: European Journal of Agronomy (27): 12-24.

Guarda, G.; Padovan, S.; Delogu, G. (2004): Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. In: European Journal of Agronomy (21): 181-192.

Hanse, B.; Tijink, F.G.J.; Maassen, J.; van Swaaij, N. (2018): Closing the yield gap of sugar beet in the Netherlands - a joint effort. In: Frontiers in Plant Science (9): 184.

Hartl, L.; Mohler, V.; Henkelmann, G. (2011): Backqualität und Ertrag im deutschen Weizensortiment. I. Historische Entwicklung. 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 25-28, Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Herz, M. (2011): Züchtungsfortschritt in der Malzqualität von Winterbraugerste. 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 51-55. Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Hoffmann, C.M.; Kenter, C. (2018): Yield potential of sugar beet – have we hit the ceiling? In: Frontiers in Plant Science (9): 289.

Hoffmann, C.; Loel, J. (2015): Bedeutung der Züchtung für den Ertragsanstieg von Zuckerrüben. In: Sugar Industry (140): 48-56.

INRAE (Institut National de la Recherche l’Agronomique, l’Alimentation et l’Environnement) (2020): Maïs et sécheresse: des progrès attendus prochainement. Paris: INRAE.

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

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

Koch, G. (2007): Genetisch-züchterische Grundlagen des Ertragspotentials von Zuckerrüben. In: Sugar Industry (132): 43-49.

Labalette, F; Legros, S. (2013): Forces et faiblesses de l'amélioration variétale d'espèces oléagineuses de diversification, l'exemple pour la France du soja, du lin et du chanvre. In: Oilseeds and Fats, Crops and Lipids (20): 4.

Laidig, F.; Feike, T.; Hadasch, S.; Rentel, D.; Klocke, B.; Miedaner, T.; Peipho, H.P. (2021a): Breeding progress of disease resistance and impact of disease severity under natural infections in winter wheat variety trails. In: Theoretical and Applied Genetics (134): 1281-1302.

Laidig, F.; Feike, T.; Klocke, B.; Macholdt, J.; Miedaner, T.; Rentel, D.; Peipho, H.P. (2021b): Long-term breeding progress of yield, yield-related, and disease resistance traits in five cereals crops of German variety trials. In: Theoretical and Applied Genetics (134): 3805-3827.

Laidig, F.; Piepho, H.P.; Rentel, D. (2017): Breeding progress, environmental variation and correlation of winter wheat yield and quality traits in German official variety trials and on-farm during 1983-2014. In: Theoretical and Applied Genetics (130): 223-245.

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

Lantican, M.; Braun, H.J.; Payne, T.S.; Singh, R.G.; Sonder, K.; Baum, M.; Ginkel, M.; van Erenstein, O. (2016): Impacts of international wheat improvement research: 1994-2014. Mexico: CIMMYT.

Le Buanec, B. (2011): Die Entwicklung der Pflanzenzucht und des Sortenschutzes. Symposium über Pflanzenzüchtung für die Zukunft, 21. Oktober 2011, Genf.

Le Cahier Technique (2018): Comment sont évaluées les variétés? In: Le Betteravier Français (1082), Paris: Institut Technique de la Betteravier.

Lecompte, F.; Causse, M. (2014): Variétés et systèmes de culture de tomate: les apports conjoints de la génétique et de l'agronomie. In: Agronomie, Environnement & Sociétés. (4): 2.

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

Lenaerts, B.; Collard, B.C.Y.; Demont, M. (2019): Improving global food security through accelerated plant breeding. In: Plant Science (287): 110207.

Les culturales 2018 (2018): Progrès génétique en blé dur. Des variétés plus tolérantes aux maladies. In: Expertises et Innovations (no date).

Lillemo, M.; Reitan, L.; Bjørnstad, Å. (2009): Increasing impact of plant breeding on barley yields in central Norway from 1946 to 2008. In: Plant Breeding (129): 484 490.

Loel, J.; Kenter, C.; Märländer, B.; Hoffmann, C. (2014): Assessment of breeding progress in sugar beet by testing old and new varieties under greenhouse and field conditions. In: European Journal of Agronomy (52): 146-156.

Loel, J.; Kenter; C.; Hoffmann, C. (2011): Analyse des Zuchtfortschritts von Zuckerrüben. In: Zuckerindustrie (136): 109-118.

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

Macholdt, J.; Honermeier, B. (2017): Yield stability in winter wheat production: a survey on German farmers’ and advisors’ views. In: Agronomy (7): 45.

Mackay, I.; Horwell, A.; Garner, J.; White, J.; McKee, J.; Philpott, H. (2011): Re-analyses of the historical series of UK variety trials to quantify the contributions of genetic and environmental factors to trends and variability in yield over time. In: Theoretical and Applied Genetics (122): 225-238.

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

Märländer, B.; Hoffmann, C.; Koch, H.J.; Ladewig, E.; Merkes, R.; Petersen, J.; Stockfisch, N. (2003): Environmental situation and yield performance of the sugar beet crop in Germany: heading for sustainable development. In: Journal of Agronomy and Crop Science (189): 201-226.

Malyska, A.; Jacobi, J. (2018): Plant breeding as the cornerstone of a sustainable bioeconomy. In: New Biotechnology (40): 129-132.

McDonagh, J.; O`Donovan, M.; McEvoy, M.; Gilliland, T.J. (2016): Genetic gain in perennial ryegrass (Lolium perenne) varieties 1973 to 2013. In: Euphytica (212): 187-199.

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

Mechtler, K.; Hendler, M. (2011): Ertrags- und Qualitätsentwicklung bei Öl- und Eiweißfrüchten in der Sortenwertprüfung. 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 79-85 Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Meyer, R.; Ratinger, T.; Voss-Fels, K.P. (2013): Technology options for feeding 10 billion people. Plant breeding and innovative agriculture. Science and Technology Options Assessment. Brussels: European Parliament.

Miflin, B. (2000): Crop improvement in the 21st century. In: Journal of Experimental Botany (51): 342.

Millet, E.J.; Kruijer, W.; Coupel-Ledru, A. (2019): Genomic prediction of maize yield across European environmental conditions. In: Nature Genetics (51): 952-956.

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

Nikolla, M.; Kapaj; A.; Lulliri, J.; Harizaj, A. (2012): Measuring the effect of production factors on yield of greenhouse tomato production using multivariate models. In. European Scientific Journal (88): 93-104.

Noleppa, S. (2016): The economic and societal value of plant breeding in the European Union and Germany. An ex-post evaluation and ex-ante assessment. Humboldt Forum for Food and Agriculture (HFFA) e. V. Working Paper 03/2016. Berlin: HFFA e. V.

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

Novoselović, D.; Drezner, G.; Lalić, A. (2000): Contribution of wheat breeding to increased yields in Croatia from 1954 to 1985. In: Cereal Research Communications (28): 95-99.

Oberforster, M.; Werteker, M. (2011): Inverse und nicht inverse Beziehungen von Kornertrag und Qualität im österreichischen Sortenspektrum von Weizen, Gerste und Roggen. 61. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, 23.-25. November 2010: 9-17. Raumberg-Gumpenstein: Lehr- und Forschungszentrum für Landwirtschaft.

Olesen, J.E.; Petersen, J.; Haastrup, M. (2010): Causes of yield stagnation in Danish winter wheat. Plantekongres 2010: 116-117.

Ortiz, R.; Nurminiemi, M.; Madsen, S. (2002): Genetic gains in Nordic spring barley breeding over sixty years. In: Euphytica (126): 283-289.

Oury, F.X.; Godin, C.; Mailliard, A.; Chassin, A.; Gardet, O.; Giraud, A.; Heumez, E.; Morlais, J.Y.; Rolland, B.; Rousset, M.; Trottet, M.; Charmet, G. (2012): A study of genetic progress due to selection reveals a negative effect of climate change on bread wheat yield in France. In: European Journal of Agronomy (40): 28-38.

Parliament of the United Kingdom (2012): Written evidence submitted by the British Society of Plant Breeders. Science and Technology. London: Parliament of the United Kingdom.

Peltonen-Sainio, P.; Jauhiainen, L.; Laurila, I.P. (2009): Cereal yield trends in northern European conditions: changes in yield potential and its realization. In: Field Crops Research (110): 85-90.

Peltonen-Sainio, P.; Jauhiainen, L.; Lehtonen, H. (2016): Land use, yield and quality changes of minor field crops: is there superseded potential to be reinvented in Northern Europe? In: PLoS ONE (11): e0166403.

Perspectives Agricoles (2020): Variétés de blé tendre cultivées en France. Cinquante ans de progrès génétique. Flers: Perspectives Agricoles.

Peters, R. (2019): Kartoffelzüchtung – Bedeutung für die gesamte Landwirtschaft. Visselhövede: Potato Consult UG.

Pierre, J.B.; Braun, P.; Piraux, F. (2010): Blé dur. Quand progrès génétique allie qualité et agronomie. In: Perspectives Agricoles (363): 49-51.

Pinochet, X.; Renard, M. (2012): Progrès génétique en colza et perspectives. In: OCL - Oilseeds and Fats, Crops and Lipids (19): 147-154.

Redaelli, R.; Laganà, P.; Rizza, F.; Nicosia, O.; Cattivelli, L. (2008): Genetic progress of oats in Italy. In: Euphytica (164): 679-687.

Reynolds M.; Foulkes J.; Furbank R.; Griffiths S.; King J.; Murchie E.; Parry M.; Slafer, G. (2012): Achieving yield gains in wheat. In: Plant, Cell & Environment (35): 1799-1823.

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

Royo, C.; Álvaro, F.; Martos, V.; Ramdani, A.; Isidro, J.; Villegas, D.; Garcia del Moral, L.J. (2007): Genetic changes in durum wheat yield components and associated traits in Italian and Spanish varieties during the 20th century. In: Euphytica (155): 259-270.

Sampoux, J.P.; Baudouin, P.; Bayle, B.; Béguier, V.; Bourdon, P.; Chosson, J.F.; Deneufbourg, F.; Galbrun, C.; Ghesquière, M.; Noël, D.; Pietraszek, W.; Tharel, B.; Viguié, A. (2011): Breeding perennial grasses for forage usage: an experimental assessment of trait changes in diploid perennial ryegrass (Lolium perenne L.) cultivars released in the last four decades. In: Field Crops Research (123): 117-129.

Sanchez-Garcia, M.; Royo, C.; Aparicio, N.; Martín-Sánchez, J.; Alvaro, F. (2013): Genetic improvement of bread wheat yield and associated traits in Spain during the 20th century. In: The Journal of Agricultural Science (151): 105-118.

Schils, R.L.M.; Van den Berg, W.; Van der Schoot, J.R.; Groten, J.A.M.; Rijk, B.; Van de Ven, G.W.J.; Van Middelkoop, J C.; Holshof, G.; Van Ittersum, M.K. (2020): Disentangling genetic and non-genetic components of yield trends of Dutch forage crops in the Netherlands. In: Field Crops Research (249), 107755.

Schori, A.; Fossati, D.; Mascher, F.; Fossati, A. (2007): Amélioration génétique du triticale à Agroscope Changins-Wädenswil. Nyon: Station de recherche ACW.

Scott, R.; Jaggard, K. (2000): Impact of weather, agronomy and breeding on yields of sugarbeet grown in the UK since 1970. In: The Journal of Agricultural Science (134): 341-352.

Semences de France (2011): Maïs: Le progrès génétique. La Chapelle-d'Armentières: Semences de France.

Shearman, V.J.; Sylvester-Bradley, R.; Scott, R.K.; Foulkes, M.J. (2005): Physiological processes associated with wheat yield progress in the UK. In: Crop Science (45): 175-185.

Silvey, V. (1995): Plant breeding in improving crop yields and quality in recent decades. In: Acta Horticulturae (35): 19-24.

Steward, A.; Hayes, R. (2011): Ryegrass breeding – balancing trait priorities. In. Irish Journal of Agriculture and Food Research (50): 31-46-

Subira, J.; Álvaro, F.; García del Moral, L.F.; Royo, C. (2015): Breeding effects on the cultivar × environment interaction of durum wheat yield. In: European Journal of Agronomy (68): 78-88.

Tabel, C.; Allerit, R. (2005): Bilan du progrès génétique obtenu pour différents caractères et différentes espèces. In: Fourrages (183): 365-376.

Taube, F.; Vogeler, I.; Kluß, C.; Herrmann, A.; Hasler, M.; Rath, J.; Loges, R.; Malisch, C. (2020): Yield progress in forage maize in NW Europe – breeding progress or climate change effects? In: Frontiers in Plant Science (11): Article 1214.

Van Der Ploeg, A.; Van Der Meer, M.; Heuvelink, E. (2007): Breeding for a more energy efficient greenhouse tomato: past and future perspectives. In: Euphytica (158): 129-138.

Van Boxsom, A.; Retailleau, J.M. (2020): Un progrès génétique indéniable mais sous-exploité. In: Perspectives Agricoles (476): 36-37.

Vear, F.; Bony, H.; Joubert, G.; de Labrouhe, D.; Pauchet, I.; Pinochet, X. (2003): 30 years of sunflower breeding in France. In: Oléagineux, Corps gras, Lipides (10): 66-73.

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

Voss-Fels, K.P.; Stahl, A.; Wittkop, B.; Lichthardt, C.; Nagler, S.; Rose, T.; Chen, T.W.; Zetzsche, H.; Seddig, S.; Baig, M.M.; Ballvora, A.; Frisch, M.; Ross, E.; Hayes, B.J.; Hayden, M.J.; Ordon, F.; Leon, J.; Kage, H.; Friedt, W.; Stützel, H.; Snowdon, R.J. (2019): Breeding improves wheat productivity under contrasting agrochemical input levels. In: Nature Plants (5): 706–714.

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

White, E.; Wilson, F. (2006): Responses of grain yield, biomass and harvest index and their rates of genetic progress to nitrogen availability in ten winter wheat varieties. In: Irish Journal of Agricultural and Food Research (45): 85-101.

Zimmermann, B.; Zeddies, J. (2000): Review: productivity development in sugar beet production and economic evaluation of progress in breeding. In: Agrarwirtschaft (49): 195-205.

Annex C: CPVRs by country of applicant

Registered CPVR (stock) by country of applicant, end of 2021

	Country	%	number
NL	**Netherlands**	**33.6**	**9,660**
FR	**France**	**16.5**	**4,745**
DE	**Germany**	**13.6**	**3,925**
US	United States	10.0	2,885
CH	Switzerland	5.2	1,487
DK	**Denmark**	**3.1**	**897**
UK	United Kingdom	2.7	785
IT	**Italy**	**2.5**	**729**
ES	**Spain**	**2.3**	**648**
BE	**Belgium**	**2.1**	**608**
JP	Japan	1.4	406
PL	**Poland**	**0.7**	**206**
AU	Australia	0.7	196
TH	Thailand	0.7	191
CZ	**Czechia**	**0.7**	**190**
AT	**Austria**	**0.6**	**187**
IL	Israel	0.6	186
NZ	New Zealand	0.6	167
SE	**Sweden**	**0.4**	**127**
HU	**Hungary**	**0.3**	**84**
CA	Canada	0.2	69
ZA	South Africa	0.2	68
IE	**Ireland**	**0.2**	**64**
TW	Taiwan	0.2	45

	Country	%	number
CR	Costa Rica	0.1	27
RS	Serbia	0.1	23
FI	**Finland**	**0.1**	**18**
KR	South Korea	0.1	17
SK	**Slovakia**	**0.1**	**15**
IN	India	0.0	13
CN	China	0.0	12
EC	Ecuador	0.0	11
SI	**Slovenia**	**0.0**	**11**
EL	**Greece**	**0.0**	**9**
CL	Chile	0.0	8
PF	French Polynesia	0.0	8
NO	Norway	0.0	7
BR	Brazil	0.0	6
LV	**Latvia**	**0.0**	**5**
LU	**Luxembourg**	**0.0**	**4**
RU	Russia	0.0	4
CO	Colombia	0.0	3
MU	Mauritius	0.0	3
CY	**Cyprus**	**0.0**	**2**
HR	**Croatia**	**0.0**	**2**
LK	Sri Lanka	0.0	2
MX	Mexico	0.0	2
PA	Panama	0.0	2
PE	Peru	0.0	2
PR	Puerto Rico	0.0	2
PT	**Portugal**	**0.0**	**2**
UA	Ukraine	0.0	2

	Country	%	number
AR	Argentina	0.0	1
BY	Belarus	0.0	1
JM	Jamaica	0.0	1
MC	Monaco	0.0	1
MD	Moldova	0.0	1

Note: EU Member States are shown in boldface.

Annex D: CPVRs by region and crop type

Registered CPVR (stock) by NUTS 3 of applicant (end of 2021)

Only regions where at least 5 CPVRs were identified are included.

	region	Number	%	Arable	Orn.	Veg.	Fruit
NL	Delft en Westland	2 198	11.63	7	1,349	831	23
NL	Kop van Noord-Holland	1 324	7.00	53	414	870	49
NL	Groot-Rijnmond	1 224	6.48	40	659	497	57
NL	Groot-Amsterdam	1 014	5.36	18	992	4	10
FR	Aveyron	699	3.70	699	15	35	0
FR	Puy-de-Dôme	698	3.69	698	0	24	0
NL	Agglomeratie Leiden en Bollenstreek	561	2.97	4	561	0	0
DE	Pinneberg	512	2.71	2	508	0	8
NL	Midden-Limburg	504	2.67	21	1	454	50
FR	Pyrénées-Atlantiques	409	2.16	409	0	0	0
FR	Maine-et-Loire	378	2.00	70	86	287	5
NL	Oost-Zuid-Holland	375	1.98	3	373	0	3
DK	Nordsjælland	356	1.88	0	356	0	0
DE	Soest	329	1.74	326	12	2	0
NL	Veluwe	325	1.72	40	195	107	3
DE	Stuttgart, Stadtkreis	299	1.58	0	299	0	0
FR	Drôme	277	1.47	15	2	153	124
FR	Nord	265	1.40	263	0	25	0
BE	Arr. Roeselare	215	1.14	0	215	0	0
FR	Var	195	1.03	0	195	0	1
DK	Østsjælland	180	0.95	180	13	0	0
FR	Haute-Garonne	175	0.93	174	1	0	0

	region	Number	%	Arable	Orn.	Veg.	Fruit
FR	Yvelines	162	0.86	159	0	16	0
BE	Arr. Gent	157	0.83	5	146	6	0
DK	Fyn	155	0.82	8	146	6	0
DE	Mainz-Bingen	147	0.78	0	139	11	4
NL	Flevoland	145	0.77	109	35	0	24
FR	Pyrénées-Orientales	143	0.76	0	0	0	143
DE	Rendsburg-Eckernförde	138	0.73	138	0	25	0
NL	Alkmaar en omgeving	138	0.73	0	138	0	1
DE	Celle	136	0.72	136	0	7	0
CZ	Hlavní město Praha	134	0.71	91	1	12	42
ES	Murcia	134	0.71	0	42	2	90
NL	Zuidoost-Zuid-Holland	131	0.69	0	130	1	0
DK	Østjylland	129	0.68	91	38	1	0
FR	Dordogne	129	0.68	0	129	0	0
ES	Barcelona	122	0.65	7	49	39	31
AT	Wiener Umland/Nordteil	112	0.59	112	0	0	0
FR	Landes	106	0.56	102	4	0	0
DE	Harz	105	0.56	104	1	0	0
NL	Noordoost-Noord-Brabant	102	0.54	0	99	1	2
NL	Midden-Noord-Brabant	100	0.53	0	99	1	1
FR	Finistère	97	0.51	88	3	6	0
SE	Stockholms län	95	0.50	75	20	3	0
DE	Mecklenburgische Seenplatte	93	0.49	93	0	0	0
DE	Meißen	92	0.49	0	92	0	0
NL	Utrecht	89	0.47	6	82	5	0
DE	Straubing-Bogen	85	0.45	85	0	0	0
NL	West-Noord-Brabant	82	0.43	0	37	44	4

	region	Number	%	Arable	Orn.	Veg.	Fruit
FR	Gard	80	0.42	0	0	55	25
DE	Landkreis Rostock	75	0.40	75	0	0	0
NL	Overig Zeeland	73	0.39	43	25	6	1
NL	Noord-Limburg	72	0.38	10	20	38	16
NL	Zuidwest-Drenthe	69	0.37	17	69	0	0
DE	Münster, Kreisfreie Stadt	63	0.33	0	63	0	0
NL	Zaanstreek	63	0.33	0	63	0	0
IT	Forlì-Cesena	60	0.32	6	3	37	23
FR	Vaucluse	58	0.31	0	3	0	58
ES	Navarra	55	0.29	0	12	7	48
NL	Zuidoost-Noord-Brabant	55	0.29	19	33	2	1
FR	Pas-de-Calais	52	0.28	52	0	0	0
FR	Mayenne	50	0.26	0	50	0	0
BE	Arr. Leuven	47	0.25	37	0	0	10
FR	Haut-Rhin	47	0.25	4	2	47	0
NL	Agglomeratie's-Gravenhage	47	0.25	1	47	0	0
PL	Leszczyński	45	0.24	45	0	1	0
PL	Skierniewicki	43	0.23	25	2	1	18
BE	Arr. Dendermonde	42	0.22	5	39	0	0
IT	Bologna	42	0.22	40	0	0	2
DE	Hamburg	41	0.22	41	0	0	0
DE	Erlangen-Höchstadt	40	0.21	38	1	1	1
ES	Córdoba	40	0.21	18	19	0	3
FR	Bouches-du-Rhône	40	0.21	1	0	38	2
FR	Rhône	39	0.21	34	0	0	5
HU	Fejér	39	0.21	33	4	0	0
IT	Pavia	39	0.21	39	0	0	0

	region	Number	%	Arable	Orn.	Veg.	Fruit
NL	IJmond	37	0.20	0	37	0	0
ES	Sevilla	36	0.19	17	0	0	19
FR	Oise	36	0.19	36	0	0	0
ES	Valencia / València	35	0.19	5	9	3	22
IT	Alessandria	35	0.19	35	0	0	0
NL	Zuidwest-Gelderland	34	0.18	0	25	0	26
IT	Ferrara	33	0.17	0	22	0	33
NL	Oost-Groningen	33	0.17	33	0	0	0
NL	Agglomeratie Haarlem	33	0.17	0	33	0	0
DE	Schleswig-Flensburg	32	0.17	32	0	8	0
NL	Overig Groningen	32	0.17	0	32	4	0
ES	Tarragona	31	0.16	26	5	0	1
DK	Sydjylland	30	0.16	25	5	0	0
ES	Huelva	30	0.16	0	29	0	30
ES	Madrid	28	0.15	15	12	3	11
FR	Seine-Maritime	27	0.14	27	0	0	0
AT	Waldviertel	26	0.14	26	0	0	0
FR	Haute-Vienne	26	0.14	26	0	0	0
IT	Novara	26	0.14	25	0	1	0
IT	Milano	26	0.14	14	0	20	0
DE	Uckermark	25	0.13	25	0	0	0
IT	Ravenna	25	0.13	15	7	0	10
BE	Arr. Turnhout	24	0.13	0	24	0	0
FR	Gironde	24	0.13	0	20	4	20
FR	Allier	24	0.13	0	16	0	8
PL	Poznański	24	0.13	24	0	3	0
FR	Lot-et-Garonne	23	0.12	0	11	0	12

	region	Number	%	Arable	Orn.	Veg.	Fruit
DE	Neustadt a. d. Aisch-Bad Windsheim	22	0.12	22	0	0	0
DE	Lippe	22	0.12	22	0	0	0
IT	Bolzano-Bozen	21	0.11	0	11	0	11
NL	Noord-Overijssel	20	0.11	1	19	0	0
CZ	Jihomoravský kraj	19	0.10	17	0	2	0
DE	Ludwigsburg	19	0.10	0	10	9	0
FR	Loiret	19	0.10	1	18	1	0
IT	Macerata	18	0.10	18	0	0	0
ES	La Rioja	17	0.09	0	0	0	17
FR	Somme	17	0.09	17	0	0	0
NL	Zuidoost-Friesland	17	0.09	0	17	0	0
DE	Rastatt	16	0.08	13	0	4	0
DE	Deggendorf	16	0.08	16	0	0	0
DE	Helmstedt	16	0.08	16	0	0	0
IT	Vercelli	16	0.08	16	0	0	0
SE	Skåne län	16	0.08	0	14	0	0
ES	Zaragoza	15	0.08	1	0	0	14
NL	Arnhem/Nijmegen	15	0.08	7	8	0	0
AT	Oststeiermark	14	0.07	7	0	13	0
CZ	Plzeňský kraj	14	0.07	14	0	0	0
DE	Dresden, Kreisfreie Stadt	14	0.07	0	13	0	3
IT	Imperia	14	0.07	0	14	0	0
BE	Arr. Hasselt	13	0.07	0	1	0	13
IT	Trento	13	0.07	0	2	0	13
NL	Zuidoost-Drenthe	13	0.07	2	11	0	0
DE	Freiburg im Breisgau, Stadtkreis	12	0.06	1	0	0	11
DE	Lüchow-Dannenberg	12	0.06	12	0	1	0

	region	Number	%	Arable	Orn.	Veg.	Fruit
DE	Borken	12	0.06	0	12	0	0
ES	Castellón / Castelló	12	0.06	0	6	0	11
SK	Nitriansky kraj	12	0.06	11	1	0	0
BE	Arr. de Bruxelles-Capitale/Arr. van Brussel-Hoofdstad	11	0.06	0	11	0	0
BE	Arr. Mouscron	11	0.06	0	11	0	0
DK	Vestjylland	11	0.06	11	0	7	0
FR	Aisne	11	0.06	0	0	0	11
FR	Gers	10	0.05	4	6	4	0
IT	Terni	10	0.05	10	0	0	0
NL	Noord-Friesland	10	0.05	10	0	0	0
CZ	Královéhradecký kraj	9	0.05	0	0	0	9
CZ	Moravskoslezský kraj	9	0.05	9	0	0	0
DE	Neuburg-Schrobenhausen	9	0.05	9	0	0	0
DE	Ammerland	9	0.05	0	9	0	0
IT	Matera	9	0.05	0	9	0	9
NL	Zeeuwsch-Vlaanderen	9	0.05	7	2	0	0
AT	Linz-Wels	8	0.04	8	0	0	0
DE	Pfaffenhofen a. d. Ilm	8	0.04	8	0	0	0
DE	Wittmund	8	0.04	8	0	0	0
DE	Krefeld, Kreisfreie Stadt	8	0.04	8	1	0	0
DE	Mönchengladbach, Kreisfreie Stadt	8	0.04	0	8	0	0
DK	Vest- og Sydsjælland	8	0.04	8	0	0	0
FR	Indre-et-Loire	8	0.04	0	0	8	0
BE	Arr. Namur	7	0.04	5	0	0	2
DE	Salzlandkreis	7	0.04	2	1	5	0
FI	Kanta-Häme	7	0.04	7	0	0	0

	region	Number	%	Arable	Orn.	Veg.	Fruit
FR	Charente	7	0.04	0	7	0	0
PL	Miasto Kraków	7	0.04	7	0	0	0
DE	Regensburg, Landkreis	6	0.03	6	0	0	0
DE	Kleve	6	0.03	0	6	0	0
NL	Noord-Drenthe	6	0.03	1	5	0	0
PL	Koszaliński	6	0.03	6	0	0	0
SI	Savinjska	6	0.03	6	0	0	0
BE	Arr. Brugge	5	0.03	0	5	0	0
DE	Lüneburg, Landkreis	5	0.03	5	0	0	0
ES	Almería	5	0.03	0	1	4	0
FR	Bas-Rhin	5	0.03	5	0	0	0
IT	Como	5	0.03	0	5	0	0
IT	Padova	5	0.03	4	1	0	0
IT	Pisa	5	0.03	0	5	0	0
NL	Achterhoek	5	0.03	0	5	0	0
NL	Het Gooi en Vechtstreek	5	0.03	0	5	0	0
PL	Puławski	5	0.03	0	5	0	0
SI	Osrednjeslovenska	5	0.03	5	0	1	0

Annex E: CPVRs by country and crop type

Registered CPVR (stock) by country and crop (per cent), end of 2021

Country	Agricultural	Ornamental	Fruit	Vegetable	Forest
			%		
Argentina	0.00	100.00	0.00	0.00	0.00
Australia	6.12	81.12	21.43	0.51	0.00
Austria	94.12	2.14	1.07	6.95	0.00
Belarus	0.00	100.00	0.00	0.00	0.00
Belgium	9.70	84.05	5.10	2.63	1.81
Brazil	16.67	66.67	16.67	0.00	0.00
Canada	20.29	30.43	49.28	2.90	5.80
Chile	25.00	0.00	75.00	0.00	0.00
China	0.00	16.67	66.67	16.67	0.00
Colombia	66.67	33.33	66.67	0.00	0.00
Costa Rica	0.00	88.89	11.11	0.00	0.00
Croatia	0.00	50.00	0.00	0.00	100.00
Cyprus	50.00	50.00	50.00	0.00	0.00
Czechia	70.53	1.05	27.37	7.37	0.00
Denmark	37.12	64.21	0.00	1.56	0.00
Ecuador	0.00	100.00	0.00	0.00	0.00
Finland	55.56	44.44	5.56	0.00	0.00
France	62.68	15.60	11.76	15.34	0.48
French Polynesia	0.00	100.00	0.00	0.00	0.00
Germany	53.02	44.18	3.39	3.41	0.33
Greece	44.44	11.11	33.33	22.22	0.00
Hungary	53.57	25.00	15.48	4.76	4.76

Country	Agricultural	Ornamental	Fruit	Vegetable	Forest
			%		
India	0.00	100.00	0.00	0.00	0.00
Ireland	59.38	40.62	0.00	0.00	1.56
Israel	4.84	46.77	19.89	38.71	0.00
Italy	41.70	28.40	30.45	10.43	3.16
Jamaica	0.00	100.00	0.00	0.00	0.00
Japan	1.48	88.42	2.46	8.13	0.25
Latvia	40.00	40.00	0.00	0.00	20.00
Luxembourg	50.00	0.00	50.00	0.00	0.00
Mauritius	0.00	100.00	0.00	0.00	0.00
Mexico	0.00	50.00	50.00	0.00	0.00
Moldova	0.00	0.00	100.00	0.00	0.00
Monaco	0.00	0.00	100.00	0.00	0.00
Netherlands	7.17	62.83	2.98	29.72	0.35
New Zealand	5.39	65.27	32.34	2.99	1.20
Norway	14.29	57.14	57.14	0.00	0.00
Panama	0.00	50.00	100.00	0.00	0.00
Peru	0.00	100.00	0.00	0.00	0.00
Poland	55.83	33.50	11.65	2.43	5.83
Portugal	100.00	0.00	0.00	50.00	0.00
Puerto Rico	0.00	100.00	0.00	0.00	0.00
Russia	0.00	25.00	100.00	0.00	0.00
Serbia	39.13	56.52	4.35	4.35	0.00
Slovakia	73.33	6.67	6.67	13.33	0.00
Slovenia	100.00	0.00	0.00	9.09	0.00
South Africa	2.94	38.24	58.82	2.94	0.00
South Korea	5.88	88.24	17.65	0.00	0.00
Spain	18.67	32.41	50.46	10.49	0.31

Country	Agricultural	Ornamental	Fruit	Vegetable	Forest
			%		
Sri Lanka	0.00	100.00	0.00	0.00	0.00
Sweden	61.42	33.86	3.15	4.72	3.94
Switzerland	35.84	25.62	5.51	40.22	0.27
Taiwan	0.00	100.00	0.00	0.00	0.00
Thailand	0.00	100.00	0.00	0.00	0.00
Ukraine	0.00	100.00	0.00	0.00	50.00
United Kingdom	25.48	64.97	10.57	6.75	0.38
United States	56.15	29.71	13.86	10.43	0.24

Glossary

AWU	Annual Working Unit
BSPB	British Society of Plant Breeders
CBD	Convention of Biological Diversity
CBI	(Dutch) Centre for the Promotion of Imports from Developing Countries
CIS	Commonwealth of Independent States
CNV	Constructed Normal Value
CO_2	Carbon Dioxide
CPVO	Community Plant Variety Office
DEFRA	Department for Environment Food and Rural Affairs
DG Grow	Directorate General Internal Market, Industry, Entrepreneurship & SMEs
DMK	Deutsches Maiskomitee
DUS	Distinctness, Uniformity and Stability
EC	European Commission
EEA	European Environment Agency
EPO	European Patent Office
ETP	European Technology Platform 'Plants for the Future'
EU	European Union
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FNVA	Farm Net Value Added
FRUMATIS	Fruit Reproductive Material Information System
F2F	Farm to Fork
GDP	Gross Domestic Product
GEF-BIO	Global Environment Facility Benefits Index of Biodiversity
GHG	Greenhouse Gas
GIPB	Global Partnership Initiative for Plant Breeding Capacity Building
INRAE	Institut National de la Recherche l’Agronomique, l’Alimentation et l’Environnement

IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IQR	Interquartile Range
ISF	International Seed Federation
ISTA	International Seed Testing Association
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
MENA	Middle East and North Africa
NBI	National Biodiversity Index
NIST	National Institute of Standards and Technology
NLI	National List
OECD	Organisation for Economic Co-operation and Development
OSR	Oilseed Rape
PBR	Plant Breeder’s Rights
PEM	Partial Equilibrium Model
PPP	Plant Protection Product
PRM	Plant Reproductive Material
PVP	Plant Variety Protection
PVR	Plant Variety Right
R&D	Research and Development
RoW	Rest of the World
SDG	Sustainable Development Goals
SITC	Standard International Trade Classification
SME	Small and Medium Sized Enterprise
TFP	Total Factor Productivity
UBA	Umweltbundesamt
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UPOV	International Union for the Protection of New Varieties of Plants
USDA	United States Department of Agriculture
VCU	Value for Cultivation and Use

IMPACT OF THE COMMUNITY PLANT VARIETY RIGHTS SYSTEM ON THE EU ECONOMY AND THE ENVIRONMENT

ISBN 978-92-9156-318-0   doi: 10.2814/467391   TB-05-22-112-EN-N