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Do EIP-AGRI operational groups improve farmers' performance? An analysis of treatment effects in intensive farming systems

The Operational Groups (OGs) of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) were introduced by the 2014-2020 Common Agricultural Policy to foster competitive and sustainable farming and forestry. The objective of this paper is to assess the economic and environmental impacts of participating in the EIP-AGRI OGs located in the Italian region of Emilia-Romagna. Performance of participants in OGs is compared with that of non-participants, who are selected by applying propensity score matching techniques to an Italian farm accountancy data network sample of 3204 farmers observed in the period 2017-2020. Logistic regressions are used to measure both propensity scores and the average treatment effect on the treated, while one-to-many optimal matching without replacement is adopted to form the control group. The resulting sample is composed of 270 observations, of which 45 are treated subjects. Results indicate that the OGs analysed might have contributed to improving fertiliser management and profitability levels in participating farms, but they failed to preserve biodiversity and reduce the consumption of pesticides and other inputs such as water, energy, and fuels. To increase the effectiveness of OGs, policy makers are advised to condition projects on the actual experimentation and implementation of agricultural innovations and apply a performance-based system of indicators for the assessment of the ex-ante and ex-post impacts of farm management.

Keywords: European Innovation Partnership for Agricultural Productivity and Sustainability; Operational Groups; farm performance; treatment effects; propensity score matching

JEL classification: Q12

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Introduction

The Operational Groups (OGs) of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) represent an important policy instrument that was introduced by the 2014-2020 Common Agricultural Policy (CAP) to foster competitive and sustainable farming and forestry by using an interactive approach to innovation (European Commission, 2019; Van Oost and Vagnozzi, 2021). OGs take the form of groups of actors having diverse practical and scientific backgrounds, such as farmers, agribusinesses, researchers, and advisors, who come together for a practical reason, i.e., to respond to real problems through the implementation of innovative solutions. To be financed, OGs are asked to draw up a plan containing a description of the innovative project to be developed, tested, adapted, or implemented as well as a description of the expected results and the contribution to the EIP objective of enhancing productivity and sustainable resource management. Moreover, they are required to disseminate the results of projects through the EIP network in order to favour the adoption and the diffusion of innovation amongst farmers (Art. 55-57 of Regulation EU No 1305/2013).

The assessment of OGs involves several aspects related to the implementation of the funding programme, the selection of projects, and their results and effects (Gehrlein and von Kutzleben, 2016). The existing studies about OGs mainly focus on the first two aspects as well as on key factors for successful projects, governance, and consistency with policy objectives, while little or no emphasis is placed on the assessment of impacts (Cristiano and Proietti, 2018; Eckerberg *et al.*, 2023; Giarè and Vagnozzi, 2021; Harrahill *et al.*, 2022; Knotter *et al.*, 2019; Maziliauskas *et al.*, 2018; McCarthy *et al.*, 2021; Molina *et al.*, 2021; Parzonko *et al.*, 2022; Piñeiro *et al.*, 2021; Schreuder *et al.*, 2022). Factors related to availability and methods of collection of project data as well as the stage at which these studies were carried out may explain this shortcoming. The evaluation of the results represents a step that is fundamental to understanding the real effectiveness of OGs. Through a comparison of impacts with initial objectives, it makes it possible to verify whether the OG setting should be adjusted to remove its limits and improve its potential in the 2023-2027 programming period.

The aim of this paper is to assess the economic and environmental impacts of participating in OGs on farmers. In other words, the objective is to verify if the participation in OGs, through the application and the experimentation of agricultural innovations, helped to improve performance of farmers. To the authors' knowledge, this research represents one of the first attempts in this direction and can therefore be considered as a novel contribution.

For the purposes of this study, propensity score matching is adopted (Caliendo and Kopeinig, 2008; Guo *et al.*, 2020; Rosenbaum and Rubin, 1983). This is a statistical technique that matches treated subjects with one or more untreated cases based on their propensity scores. This helps to reduce selection bias in quasi-experimental and observational studies. In this study, the treatment is represented by the participation in concluded projects of OGs while the potential outcomes are assessed by comparing the variations of a set of monetary and quantitative indicators measured in the period 2017-2020 for both treated and untreated subjects. Monetary indicators include output, variable costs, fertiliser and pesticide expenditure, expenditure on water, energy and fuels, and net farm income. Quantitative indicators comprise the used quantity of phosphorus and nitrogen contained in fertilisers, the used quantity of fertilisers and pesticides, and the number of cultivated crops.

Logistic regressions are used to measure both propensity scores and the Average Treatment effect on the Treated (ATT), i.e., the average effect of treatment on those subjects who ultimately received the treatment (Imbens, 2004). As covariates, a set of socio-economic variables that are supposed to affect both the treatment and the outcomes are analysed.

This research is carried out by using the Farm Accountancy Data Network (FADN) sample of Italian farmers. FADN is employed to retrieve information about the variables investigated concerning the farmers participating in OGs whose projects were concluded. The focus of this study is on the Italian region of Emilia-Romagna. This region is a particularly suitable case for this analysis. According to Italian National Rural Network (NRN) statistics, in Italy, in September 2021, there were overall 656 OGs, of which 213 (over 30%) concentrated in Emilia-Romagna. The second region for number of OGs is Sicily with 61 projects financed. Moreover, according to the national database of OGs (containing detailed information about 633 OGs), 92 out of 144 projects for which it is possible to know if they were completed are in Emilia-Romagna. Another reason why this region represents an interesting case concerns its main morphological characteristics: about 70% of Utilised Agricultural Area (UAA) is situated on flat land compared with a national average of 33%. This has made possible a wide diffusion of mechanisation and intensive agriculture with significant negative impacts on the environment (Menta *et al.*, 2017). OGs are therefore called upon to favour the diffusion of more environmentally friendly techniques and reduce the pressure of agriculture on the environment.

The rest of this paper is organised as follows. Section 2 offers a brief overview of existing studies on OGs. In addition, it examines the main issues in measuring the effects of OGs related to the availability and collection of data and the type of impacts to be assessed consistently with the objectives of EIP-AGRI. Section 3 illustrates the methodology, the variables and the data used. Sections 4 and 5 present and discuss the results of this analysis, respectively. Finally, Section 6 provides some concluding remarks.

Literature review

The main question when evaluating EIP-AGRI is to which extent innovation, cooperation, and building the knowledge base in rural areas are supported by Rural Development Policy (RDP) interventions (European Commission, 2014). To answer this question, aspects such as the implementation of the funding programme, the selection of projects, and their results and effects need to be examined in more detail as part of the evaluation (Gehrlein and von Kutzleben, 2016). In terms of implementation, the programmed funding objects, funding conditions, and procedures are relevant. The central issue is whether regulations are capable of fostering innovations. As regards the selection procedure, the criteria that guide the decision on financing projects are also of great importance because the identification of innovative projects that respond to real problems of farmers strongly depend on them. However, if the objective is to evaluate the real effectiveness of the funded projects, the knowledge of their results and impacts becomes essential.

In literature, existing studies about OGs have focused on topics such as progress in implementation of OGs (Knotter *et al.*, 2019; Schreuder *et al.*, 2022), key factors for successful projects (Harrahill *et al.*, 2022; Maziliauskas *et al.*, 2018; McCarthy *et al.*, 2021; Molina *et al.*, 2021; Parzonko *et al.*, 2022), performed functions (Piñeiro *et al.*, 2021), governance processes (Giarè and Vagnozzi, 2021), and consistency with the objectives of European strategies (Cristiano and Proietti, 2018; Eckerberg *et al.*, 2023; Giarè and Vagnozzi, 2021).

More specifically, Knotter *et al.* (2019) assessed the state-of-play of the setting-up and implementation of OGs until 2018. By combining several methods of investigation (cluster analysis, survey, and case studies), they concluded that OGs are effective in tackling farmers' needs in a practical and collaborative way on topics related to both competitiveness and environmental sustainability. Schreuder *et al.* (2022) reviewed the OGs focused on topics related to grassland using the EIP-AGRI database and an online survey. They observed that the themes addressed by OGs are less focused on environmental issues than the recommendations coming from specific EIP-AGRI focus groups.

Maziliauskas *et al.* (2018) identified the external and internal factors that influence the effectiveness of OGs by a force field analysis. They found that the biggest negative impact comes from the lack of cooperation between partners and that internal factors such as partner involvement and constant monitoring of achievements based on a list of indicators play an important role in a project's success. McCarthy *et al.* (2021) explored the motivations of a small group of actors who established an OG in Ireland using an assemblage-based approach. Their main conclusion is that the motivations of different subjects involved influence each other and take into consideration future scenarios and new possibilities. The outcomes of the EIP-AGRI initiative are therefore affected by this process of reciprocal influence. Molina *et al.* (2021), through the analysis of a case study of an Italian OG, highlighted the factors that could influence and foster the interactive innovation process. They concluded that farmers are active players in the design and implementation phases and that motivation, commitment, trust, and an open communication among different actors are key factors for the success of a project. Parzonko *et al.* (2022) analysed the role of innovation brokers in the setting up of OGs in Poland by a survey addressed to a selected group of people who participated or showed interest in a web initiative realised by an advisory centre to support the creation of OGs during the COVID-19 pandemic. They demonstrated that the innovation broker played a key role in identifying subjects willing to cooperate, obtaining funds and preparing project proposals and documents related to the functioning of the OG. Harrahill *et al.* (2022) examined the degree of involvement of farmers in an Irish OG aimed at producing and transforming biomass into energy. By using social network analysis combined with interviews conducted with farmers and non-farmer participants in the OG, they found that, despite farmers were highly involved as input suppliers, the level of influence they exerted in several other areas, such as the logistical and managerial ones, was relatively limited and this can hinder the success of future projects having similar objectives.

Piñeiro *et al.* (2021) conducted an online survey addressed to members of Spanish OGs in order to identify the intermediary functions carried out by OGs. They found that OGs can manage the entire innovation process by encouraging collaboration, sharing information, and developing joint projects. OGs also make innovation demand emerge by identifying opportunities, developing studies, and seeking solutions that meet the needs of OGs and their members. Finally, they search for economic and institutional support and encourage external collaboration to find resources and disseminate knowledge and solutions.

Cristiano and Proietti (2018) investigated the relationship between Italian OGs and research programs, specifically Horizon 2020, by collecting data from direct interviews, semi-structured questionnaires, focus groups, and workshops. They highlighted that there is no interaction between research and innovation projects, and this slows down innovation processes and contrasts with the objectives of EIP-AGRI of creating synergies and value added by integrating different policy tools. Giarè and Vagnozzi (2021) compared the rules and implementation criteria adopted by some Italian managing authorities to finance OGs in order to analyse the impact of different governance choices on the functioning of OGs. They concluded that rules and criteria are inadequate in some cases, mainly regarding the definition of innovation needs, the involvement of all actors, the construction of a common strategy, and the connection with the measures addressed to finance investments, and this can negatively affect the effectiveness and consistency of projects with the objectives of RDP. More recently, Eckerberg *et al.* (2023) analysed the state's steering capacity of spreading "green innovation" in the agricultural sector of Sweden through the implementation of EIP-AGRI. By examining the information from the national database of OGs financed in Sweden and from interviews with key individuals engaged in the program administration, they found that, in contrast with policy objectives both at the general policy level and in the EIP-AGRI regulation, "green innovation" was only marginally supported by prioritising aspects related to competitiveness and placing less emphasis on those related to the environment and climate change.

Although these studies offer interesting indications for the aims of evaluating the EIP-AGRI initiative, no conclusion is provided about the real impact of participation in OGs on farm performance. One reason is related to the fact that several studies were conducted when few or no projects had yet been completed. Another reason that makes impact assessment difficult concerns data availability. The main instrument used for dissemination of innovative projects aimed at rural development and agriculture is represented by the publication of project data on online databases (Ibáñez-Jiménez *et al.*, 2022). The official database of European OGs can be freely consulted on the EIP-AGRI website. The available data (last access in December 2022) provide clear information about the objectives pursued, the activities to be carried out and the main innovations planned. However, little or no information is provided with reference to the results obtained. This mainly depends on the system of data collection that was implemented to retrieve information about OGs. In fact, the data requested adhere to an official template, which only asks for some qualitative information (European Commission, 2016). In addition, only a part of this information is categorised and is thus in a format suitable for processing. Moreover, much desirable information, such as the detailed characteristics of the participating farmers as well as the changes in economic aggregates (output, costs, inputs, income, etc.) following the execution of the project, is not present, impeding the environmental and economic impact assessment of OGs.

At the time this research was conducted, several projects were completed, and the relevant impacts could therefore be assessed. For the investigation of results and impacts, different methodologies can be adopted such as document analyses (interim and final reports), ad-hoc surveys, and self-assessment of performance (Gehrlein and von Kutzleben, 2016). However, these methods not only are costly and time-consuming, but the relevant results could be affected by the widespread absence of internal accounting systems, especially in countries such as Italy, which prevents farmers from knowing exactly if and how the variables of interest have changed over time. Further issues, which can negatively affect the goodness of the results, are interpretation difficulties and farmers' reluctance to provide truthful answers in consideration of the public subsidies received. An alternative approach involves the use of an already existing and official accounting system, i.e., the FADN data, by matching the information about the partnership of OGs with that contained in FADN. This system offers a great quantity of socio-economic and environmental information and can therefore be used to effectively assess the performance of farmers participating in OGs (treated), comparing it with that of farmers who did not participate (untreated).

Another important issue in evaluating OGs concerns what kind of impacts should be measured. A central question should be if and to what extent the productivity of farms has increased. Another crucial question is whether progress toward sustainability has been achieved. This is because improvements in productivity and sustainability represent the main objectives of the EIP-AGRI initiative. Therefore, the assessment of the impacts on these two main aspects is of great importance.

Productivity is commonly defined as the relationship between outputs and inputs. There are several ways to measure productivity, which depend on the purpose of measurement and the availability of data (OECD, 2001). In this study, output is measured as market value and is expressed per hectare. Therefore, land productivity is considered. The notion of sustainable agriculture is particularly complex, and this makes its use and implementation quite hard (Velten *et al.*, 2015). According to Pretty (2008), the key principles for sustainability are: to integrate biological and ecological processes into food production processes, to minimise the use of those non-renewable inputs that are harmful to the environment or to the health of farmers and consumers, and to make productive use of the knowledge and skills of farmers as well as of people's collective capacities to work together to solve common agricultural and natural resource problems. Agricultural sustainability is thus a very broad concept involving three "pillars": environmental, economic, and social (Purvis *et al.*, 2019). This study only concentrates on some environmental and economic aspects. As regards the environmental dimension, the focus is on the capability of reducing environmental impact by diminishing the used quantity of inputs and the level of specialisation, i.e., the tendency towards monoculture, which can undermine biodiversity (Altieri, 1999), soil fertility (Liu *et al.*, 2006), and the capability of facing climate change (Lin, 2011). Besides the rationalisation in the use of inputs, specialisation is another issue that can be faced by OGs through projects aimed at introducing new or rediscovered crop varieties. With reference to economic sustainability, this study focuses on farmers' ability to reduce their costs and improve their profitability, i.e. generate income. Both productivity and sustainability are tightly connected with profitability. An increase in the output-input ratio, as well as the adoption of environmentally friendly techniques that serve to reduce the quantity of used inputs, can increase profitability. The latter is one of the motivations, or, in some cases, may be the only motivation, which might induce farmers to decide to participate in OGs. Understanding the impact of EIP-AGRI on profitability is thus extremely important for policy makers since the degree of participation in OGs and, by extension, the success of this policy instrument, which has also been proposed again for the 2023-2027 programming period, strongly depends on it.

Materials and methods

The model

Propensity score matching allows the building of matched sets of treated and untreated subjects who share similar propensity scores (Caliendo and Kopeinig, 2008; Guo *et al.*, 2020; Rosenbaum and Rubin, 1983). A propensity score is defined as the conditional probability of being selected into the treatment group given a set of covariates or observed characteristics for group members, i.e.:

$$p(\mathbf{X}) = Pr\{Tr = 1|\mathbf{X}\} = E\{Tr|\mathbf{X}\} \qquad (1)$$

where $Tr=\{0,1\}$ is an indicator variable for treatment group selection and $\mathbf{X}$ is a multidimensional vector of covariates. Propensity scores therefore describe the likelihood that a population member would be selected into the treatment group based on a set of model covariates. Propensity score estimates are used to construct a comparison group. The Average Treatment Effect (ATE), based on an outcome measure (Y), is then estimated as:

$$ATE = E\{Y_1 \mid Tr = 1\} - E\{Y_0 \mid Tr = 0\} \qquad (2)$$

where Y_1 and Y_0 are the outcome measures for treated and untreated subjects, respectively. The ATE refers to the entire population. The ATT, used in this study, is a related measure of treatment effect and measures the ATE only on those subjects who received the treatment (Imbens, 2004).

In contrast to randomised designs, propensity scoring techniques use a set of covariates to model the treatment group selection process. Moreover, these methods cannot adjust for unobserved covariates. The main assumption is therefore that observations with the same propensity score have the same distributions for observable and unobservable characteristics. This connects propensity scoring with the assumption of ignorable treatment group assignment and the conclusion that the ATE estimate is unbiased (Stone and Tang, 2013).

Following a commonly used approach (Austin, 2011; D'Agostino, 1998; Rosenbaum and Rubin, 1983), propensity scores are estimated by logistic regression where the dichotomous outcome is treatment group assignment (1 and 0 for treated and untreated subjects, respectively) and predictors are a set of measured covariates. Once propensity scores are computed, the following step consists in creating balanced intervention and comparison groups. There are several approaches for creating these groups, some of which include exact matching, nearest neighbour matching, and optimal matching (Rosenbaum, 1989; Rubin, 1973). Further decisions concern the number of nonparticipants to be matched to each participant (one-to-one or one-to many matching) and whether replacement (i.e., matching nonparticipants multiple times to participants) is allowed. The choice can be made on the basis of different considerations (Stuart, 2010). Several studies have empirically demonstrated the potential benefits of one-to-many matching and proposed the optimal matching ratio for decreasing bias but increasing power (Austin, 2010; Cenzer *et al.*, 2020; Rassen *et al.*, 2012). In particular, Cenzer *et al.* (2020) focused on situations where the number of treated subjects is very small. Through a Monte Carlo simulation, they showed that, when the number of treated subjects available is between 25 and 50, the use of optimal matching without replacement and with one-to-five matching ratio proves to be the best option. Compared to greedy matching (such as nearest neighbour matching), optimal matching is a more complex approach whose goal is to find the matched samples with the smallest average absolute propensity score distance across all the matched pairs. In consideration of the limited size of the sample available (see Section 3.2), this method is therefore adopted in this study.

Once the matches are created, the quality of the matches is assessed in order to ensure that the comparison group has a distribution of propensity scores similar to the intervention group. Matches are assessed by comparing the balance both numerically and visually (Stuart, 2010). Visual diagnosis of balance is conducted here by inspecting distribution of propensity scores before and after matching. Numerical diagnosis of balance is instead carried out by evaluating the covariate balance. This is made by comparing the standardised difference of group propensity score means (SMD). For continuous and dichotomous variables, SMD for covariate X takes the following form, respectively:

$$SMD_X = \frac{\bar{X}_1 - \bar{X}_0}{\sqrt{(Var_1 - Var_0)/2}} \quad (3)$$

$$SMD_X = \frac{\hat{p}_1 - \hat{p}_0}{\sqrt{\hat{p}_1(1-\hat{p}_1) + \hat{p}_0(1-\hat{p}_0)/2}} \quad (4)$$

where $\bar{X}_1$ and $\bar{X}_0$ are sample means, Var_1 and Var_0 are sample variances, and, finally, $\hat{p}_1$ and $\hat{p}_0$ are the prevalence of dichotomous variables in the treated and untreated units, respectively. X is considered as balanced if the absolute SMD value is lower than 0.25 (Imbens and Wooldridge, 2009).

The ATT is then estimated by running a logistic regression over matched subjects with cluster-robust standard errors (Abadie and Spiess, 2022), where the dichotomous variable is the outcome analysed while the only predictor is represented by the treatment group selection. The regression gives an estimate of the logarithm of odds ratio, i.e., the ratio of the probability that a given outcome occurs in treated subjects to the probability that the same outcome occurs in untreated units.

Analyses were conducted using packages MatchIt 4.4.0, for propensity score matching; stats, for logistic regressions; lmtest 0.9-40 and sandwich 3.0-2, for estimating cluster-robust standard errors, in statistical software R 4.2.1.

The variables and the dataset used

The outcomes analysed in this study concern both economic and environmental aspects and are measured as monetary and quantitative indicators. For the choice of indicators, the approach followed is that of Cisilino *et al.* (2019), who carried out a conceptually similar analysis consisting in evaluating the environmental and economic effects of organic farming subsidies using propensity score matching techniques applied to a sample of FADN farms. More specifically, the monetary indicators used to assess performance of farmers are output (i.e., total revenues), variable costs, fertiliser and pesticide expenditure, and net farm income. Since the rationalisation in the use of water and energy represents another important objective of EIP-AGRI, expenditure on water, energy, and fuels is also considered. All variables are expressed per hectare. The quantitative indicators used to measure farm performance are instead the used quantity of phosphorus and nitrogen contained in fertilisers, the used quantity of pesticides, and the number of cultivated crops as an indicator of biodiversity. The overall quantity of fertilisers is also considered to integrate the analysis of the pesticides used. The quantity of used water, energy and fuels could not be analysed because of data unavailability. Quantities of fertilisers, phosphorus, nitrogen, and pesticides are expressed as quintals and per hectare. Outcomes are assessed as binary variables, which take one if the average variation of the indicators is positive and zero if null or negative.

As for the covariates to be included in the propensity score model, the choice is not straightforward since there are several possible variables that can be selected (Austin, 2011). They can be all baseline covariates, all baseline covariates that are associated with treatment, all covariates that influence the outcome (i.e., the potential confounders), and all covariates that affect both treatment and the outcome (i.e., the true confounders).

Since the propensity score is defined to be the probability of treatment assignment, there are theoretical reasons in favour of the inclusion of only those variables that affect treatment assignment (Austin, 2011). However, Austin *et al.* (2007) showed that including potential or true confounders does not introduce additional bias and results in estimates of treatment effect with greater precision. Similarly, Brookhart *et al.* (2006) suggested that potential confounders should be preferred to variables only affecting treatment since the inclusion of the latter increase the variance of the estimated treatment effect without a concomitant reduction in bias. In practice, it is quite hard to distinguish between different types of variables. Moreover, most baseline covariates likely affect both treatment assignment and the outcome. Therefore, it is better to include all measured baseline characteristics in the propensity score model. However, an important condition is that variables are measured at baseline and are not post-baseline covariates, since the latter may be influenced or modified by the treatment (Austin, 2011).

The data used in this study come from the Italian FADN. This database offers a very large set of variables. To contain the number of features, a subset of all variables available was selected. Data selection was focused on variables that can affect both the participation in OGs and outcomes. Moreover, the selection process was led by the need to consider both farmer and farm characteristics as well as various economic, environmental, social, and formal aspects in such a way to focus the analysis on a homogeneous sample. Subjective factors related to personal attitudes and motivations, which could also influence participation (Molina *et al.*, 2021), were neglected for data unavailability. As regards farmer characteristics, gender, age, education, and access to measures of RDP are considered while, with reference to farm features, altitude, productive specialisation, organic farming, on-farm diversification, legal form, land, livestock, labour, family work, and machinery are investigated. Most variables are categorical except for on-farm diversification, land, livestock, labour, family work, and machinery, which are measured as continuous. Gender takes value of one for females and zero for males. Age is modelled by a dichotomous variable taking unitary values if farmers are young according to the threshold set by the CAP for accessing specific measures in favour of farmers with no more than 40 years of age. Education is also a binary variable taking one in the case of a high-medium level of education. The variable relating to access to measures of RDP takes the value of one (zero) if farmers applied (did not apply) for measures of RDP other than those relating to OGs (i.e., measure 16.1). This variable is introduced since both participation in OGs and outcomes can also be affected by the knowledge of RDPs and the activation of other RDP measures. Altitude is represented by two binary variables that take unitary value if farms are localized in flat areas and in hills, respectively, while they are zero if farms are situated in the mountains. Productive specialisation is measured by four dummies related to arable crops, horticulture, livestock, and permanent crops, respectively. Zero values indicate mixed specialisation. The organic farming variable takes value of one if farms are certified as organic, there is at least one organic product, or there is one process that is carried out with organic methods. On-farm diversification is measured as a share of revenues produced by on-farm diversification activities. Legal form is represented by two dummies indicating if a farm is registered as either an individual holding or a company, which take value of zero in the case of other legal forms. Land is measured as number of hectares of UAA, livestock as number of units, labour as number of Annual Worked Hours (AWH), family work as a share of Annual Work Units (AWU), and, finally, machinery is measured as machine power in terms of number of kilowatts (kW).

Information about the participation of farms in completed OG projects is not available in the FADN data and was retrieved from the national database of OGs that is managed by the Italian NRN. This database is publicly available on the Innovarurale website. It was built on the basis of the European one, in order to share the same information and reduce the workload for those who have to introduce the data, but, unlike the European database, it contains more information such as the details of the partners involved. At the time of this research, the FADN data were available until 2020. Therefore, the projects concluded within 2020 are considered. The relevant typology, objectives, duration, and expected results are reported in Table 1.

The observations available in FADN are represented by different farms observed in few or more years. Since the farms that are present within FADN are subject to be changed over years, the analysis is conducted on pooled data. Outcomes are derived by calculating an average of annual variations of the indicators described above from 2017 to 2020. The period analysed mostly overlaps the one of realisation of the concluded projects, which have a duration of up to 36 months. Including periods prior to 2017 (i.e., 2016, corresponding to the start of some projects) was not possible for issues related to the correct application of the chosen matching ratio, which, in turn, depend on the characteristics of FADN. To remove a possible bias deriving from different periods in which farms are observed, the applied propensity score matching technique is time constrained. More specifi-

Table 1: Typology, objectives, duration, and expected results of the concluded OG projects related to the farms observed in the FADN sample, Emilia-Romagna, Italy.

Project	Typology*	Objectives	Start year	Duration (months)	Expected results**
1	Practice	Application of innovative protection strategies to fruit crops	2016	36	Pesticides (–)
2	Mixed	Application of sustainable techniques and methodologies for protection, irrigation, and nutrition in viticulture	2016	36	Water (–) Pesticides (–)
3	Practice	Improvement of forage systems to support the production of quality cheeses	2016	36	Output (+)
4	Research	Improving the management of soils for the maintenance of organic matter and carbon sequestration	2016	36	Output (+)
5	Practice	Introducing ancient cereals and hemp as a trap crop for the reduction of inputs	2016	36	Crops (+) Fertilisers (–) Pesticides (–)
6	Practice	Introducing innovative products to increase the resistance of plant production to adversities	2016	36	Pesticides (–)
7	Practice	Reducing the consumption of antibiotics in milk production	2016	36	Variable costs (–)
8	Practice	Enhancing by-products of the wine industry to produce energy products, nutraceuticals, and fertilisers	2017	36	Output (+) Fertilisers (–) Energy (–)
9	Practice	Enhancing by-products of vegetable supply chains for food, agronomic and energy purposes	2017	24	Output (+) Fertilisers (–) Energy (–)
10	Practice	Implementing conservation agriculture techniques and bioenergetic buffer strips	2017	24	Water (–) Fertilisers (–) Pesticides (–) Energy (–)
11	Research	Monitoring of the carbon footprint of the fruit sector	2017	36	Output (+) Fertilisers (–)
12	Practice	Reducing ammonia emissions from pig shelters with sewage recovery for soil fertilisation	2017	36	Fertilisers (–)

* "Research" identifies projects that are mainly addressed to monitoring activities and production of methodological guidelines, "practice" refers to projects that involve the application and the experimentation of agricultural innovations in the participating farms, while "mixed" identifies projects that combine research with practical activities.
** A common expected result is an increase in farm income, which may come from an increase in output and/or a decrease in costs.
Source: Authors' elaborations on the national database of OGs

cally, farms of a given year and observed for a given period are only matched with similar observations of the same year and having the same period of observation.

Table 2 shows some descriptive statistics about the sample used. The total number of observations available over the period 2017-2020 amounts to 3204, of which 45 related to farms that participated in OGs. Compared to the average, there are several differences in treated subjects, some of which are particularly evident. It turns out that participants obtain lower revenues, incur lower variable costs, pay less expenditure for the consumption of water, energy, and fuels, and make use of lower quantities of nitrogen, phosphorus, and pesticides per hectare. Moreover, much more than the average, they are younger, have higher levels of education, are more familiar with RDP measures, use organic methods, are formally established as companies, and are specialised in livestock (44% against an average of 18%). Finally, they have on average a far larger number of livestock units (246 against 53), consistently with the prevalent productive specialisation, and there are not treated subjects who are specialised in horticulture.

Table 2: Descriptive statistics about the sample used, Emilia-Romagna, Italy, 2017-2020.

	Treated (n=45)				All (n=3204)			
	Mean	**Std. dev.**	**Min**	**Max**	**Mean**	**Std. dev.**	**Min**	**Max**
Monetary outcome indicators								
Output (euro/ha)	7,972	6,404	1,384	41,290	15,152	167,674	360	6,697,958
Variable costs (euro/ha)	3,523	4,262	516	29,147	9,910	142,397	4	5,964,421
Fertilisers (euro/ha)	377	434	0	1,943	357	889	0	36,737
Pesticides (euro/ha)	302	336	0	1,241	356	2,528	0	141,922
Water, energy, and fuels (euro/ha)	169	145	4	723	305	3,005	0	135,196
Farm income (euro/ha)	3,683	2,676	281	11,035	3,946	26,731	–12,493	846,879
Quantitative outcome indicators								
Fertilisers (q/ha)	0.58	1.08	0	4.87	1.17	5.74	0	181.78
Nitrogen (q/ha)	0.009	0.021	0	0.123	0.015	0.060	0	1.457
Phosphorus (q/ha)	0.004	0.009	0	0.049	0.011	0.041	0	0.834
Pesticides (q/ha)	0.01	0.01	0	0.06	0.02	0.21	0	11.08
Crops per farm (no.)	4.20	2.46	1	10	4.28	2.44	0	19
Farm characteristics								
Female	0.09	0.29	0	1	0.11	0.31	0	1
Young (40 years)	0.13	0.34	0	1	0.06	0.24	0	1
With high-medium level education	0.64	0.48	0	1	0.45	0.50	0	1
Accessing to RDP	0.73	0.45	0	1	0.47	0.50	0	1
Located in flat land	0.64	0.48	0	1	0.70	0.46	0	1
Located in hills	0.22	0.42	0	1	0.23	0.42	0	1
With organic production	0.29	0.46	0	1	0.12	0.33	0	1
Individual holding	0.40	0.50	0	1	0.73	0.45	0	1
Company	0.60	0.50	0	1	0.27	0.45	0	1
Specialised in arable	0.11	0.32	0	1	0.34	0.47	0	1
Specialised in horticulture	0.00	0.00	0	0	0.07	0.26	0	1
Specialised in permanent crops	0.36	0.48	0	1	0.30	0.46	0	1
Specialised in livestock	0.44	0.50	0	1	0.18	0.39	0	1
Diversified (share of revenues)	0.03	0.11	0	0.51	0.02	0.11	0	1
Land (ha of UAA)	68.64	75.63	3.12	275.25	37.56	73.02	0.22	1,754.00
Livestock (units)	246.57	669.15	0.00	4,226.00	53.22	275.27	0	8,184.20
Labour (AWH)	8,176.98	10,982.61	1,800.00	72,320.00	4,540.11	7,500.64	900	201,960
Family work (share of AWU)	0.75	0.32	0.11	1.00	0.84	0.26	0	1.00
Machinery (kW)	381.33	626.08	31.00	2,284.00	278.67	315.87	0	4,816

Source: Authors' elaborations on Italian FADN data

Results

Figure 1 shows the distribution of propensity scores calculated for treated and untreated subjects. As can be noted, raw distributions are largely different, and this justifies the use of matching techniques to remove potential sources of bias. After matching, distributions are mostly identical, so demonstrating the effectiveness of the procedure of propensity score matching applied to balance the sample and reduce the selection bias.

Table 3 shows the standardised differences of covariate means between treated and control participants before and after matching. The normalised differences are in almost all cases lower than the same differences calculated before

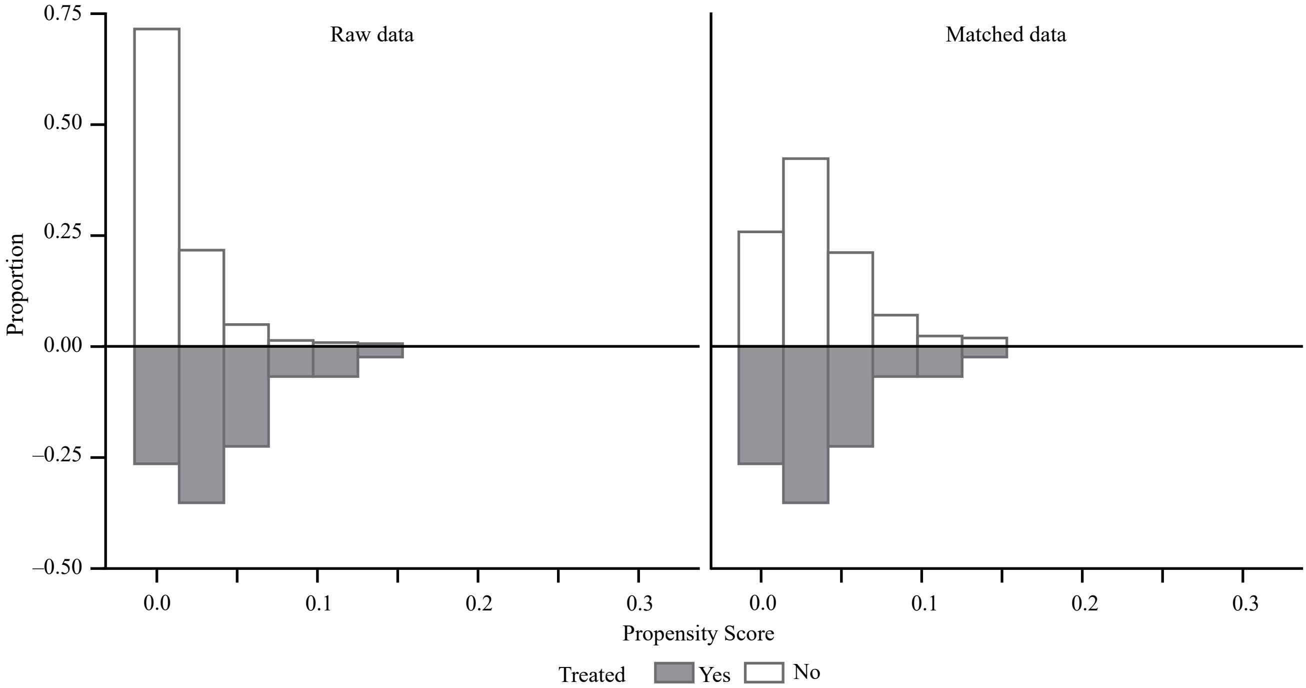

Figure 1: Distribution of the propensity scores calculated for treated and untreated subjects before and after matching.
Source: Authors' elaborations on Italian FADN data

Table 3: Group means and standardised differences of means between treated and untreated subjects before and after propensity score matching.

Variables	All data			Matched data		
	Treated (n=45)	Untreated (n=3204)	Std. diff.	Treated (n=45)	Untreated (n=225)	Std. diff.
Gender (Female = 1; Male = 0)	0.09	0.11	–0.076	0.09	0.07	0.062
Age (Young = 1; Old = 0)	0.13	0.06	0.221	0.13	0.10	0.092
Education (High-medium level = 1; Low level = 0)	0.64	0.44	0.419	0.64	0.63	0.037
Access to RDP (Yes = 1; No = 0)	0.73	0.47	0.602	0.73	0.74	–0.020
Altitude (Mountains = reference)						
Flat	0.64	0.70	–0.124	0.64	0.69	–0.093
Hills	0.22	0.23	–0.030	0.22	0.19	0.086
Typology (Organic = 1; Conventional = 0)	0.29	0.12	0.371	0.29	0.25	0.078
Legal form (Others = reference)						
Individual holding	0.40	0.73	–0.673	0.40	0.43	–0.054
Company	0.60	0.27	0.675	0.60	0.57	0.054
Productive specialisation (Mixed = reference)						
Arable	0.11	0.35	–0.745	0.11	0.07	0.127
Horticulture	0.00	0.07	–0.284	0.00	0.00	0.000
Permanent	0.36	0.30	0.115	0.36	0.39	–0.065
Livestock	0.44	0.18	0.530	0.44	0.47	–0.054
Diversification (share of revenues)	0.03	0.02	0.073	0.03	0.02	0.089
Land (ha of UAA)	68.64	37.12	0.417	68.64	53.91	0.195
Livestock (units)	246.57	50.51	0.293	246.57	170.82	0.113
Labour (AWH)	8,176.98	4,489.03	0.336	8,176.98	7,305.84	0.079
Family work (share of AWU)	0.75	0.84	–0.311	0.75	0.73	0.057
Machinery (kW)	381.33	277.22	0.166	381.33	377.64	0.006

Note: the variables related to time and period of observation, which are used for exact matching, are not shown. The relevant standardised differences are zero after matching.
Source: Authors' elaborations on Italian FADN data

Table 4: % of subjects that experience positive variations of monetary and quantitative outcome indicators and results of logistic regressions for estimating the ATT of participation in EIP-AGRI OGs.

	Matched data		Regression results		
	% Treated	**% Untreated**	**Coefficient**	**Robust std. error**	**Odds ratio**
Monetary outcome indicators					
Output (euro/ha)	64.4	64.0	0.019	0.341	1.020
Variable costs (euro/ha)	46.7	56.4	–0.393	0.337	0.675
Fertilisers (euro/ha)	46.7	59.1	–0.502*	0.305	0.605
Pesticides (euro/ha)	68.9	49.8	0.804**	0.353	2.234
Water, energy, and fuels (euro/ha)	84.4	71.6	0.769**	0.391	2.158
Farm income (euro/ha)	84.4	68.9	0.897**	0.447	2.452
Quantitative outcome indicators					
Fertilisers (q/ha)	53.3	62.2	–0.365	0.308	0.707
Nitrogen (q/ha)	53.3	57.3	–0.162	0.278	0.805
Phosphorus (q/ha)	44.4	59.6	–0.610*	0.337	0.524
Pesticides (q/ha)	62.2	55.1	0.294	0.341	1.342
Crops per farm (no.)	24.4	42.7	–0.833**	0.390	0.435

* Statistically significant at 10%; ** Statistically significant at 5%; *** Statistically significant at 1%.
Source: Authors' elaborations on Italian FADN data

matching. Moreover, they are below the suggested rule of thumb of 0.25 standard deviations (in absolute value). Therefore, these results support the conclusion that the matching procedure performs well, also at level of single covariates, in eliminating possible sources of bias.

Table 4 reports the percentages of treated and untreated subjects that experience positive variations concerning a set of economic and environmental indicators as well as the ATT derived by regressing outcomes on the participation of farmers in OGs.

As regards monetary indicators, the majority of participants is characterised by increases in output and farm income and decreases in variable costs and fertiliser expenditure per hectare. However, 69% and 84% of treated subjects increase expenditure on pesticides and expenditure on water, energy, and fuels, respectively. Control group exhibits outcome variations having similar directions about output, expenditure on water, energy, and fuels, and farm income. The main differences concern pesticide expenditure, which decreases in a half of observations, and variable costs and fertiliser expenditure, which, conversely, increase in 56% and 59% of observations, respectively.

Comparing treated with untreated subjects, from regression analysis it turns out that the coefficient associated with fertiliser expenditure is significant and negative. This means that it is more probable that fertiliser expenditure decreases in farmers participating in OGs. The relevant odd ratio indicates that there is an approximately 40% reduced probability that fertiliser expenditure increases in treated subjects compared to control units.

A further significant coefficient is the one concerning expenditure on pesticides. In this case, the coefficient reveals that the participants in OGs have a larger likelihood to experience an increase in this kind of expenditure in comparison with control units. The corresponding odds ratio indicates that treated subjects have a probability of increasing pesticide expenditure that is 2.2 times the odds of nonparticipants.

The coefficient related to water, energy, and fuels expenditure is also positive and significant. Thus, it is more likely that this expenditure increases in farmers participating in OGs. The probability that water, energy, and fuels expenditure increases is, similarly to pesticide expenditure, 2.2 times higher in treated than in untreated subjects, as the relevant odds ratio shows.

A last significant coefficient among monetary indicators is the one related to farm income. The relevant value suggests a higher probability that farm income increases in treated rather than in untreated units. According to the relevant odds ratio, this probability is 2.5 times higher.

With reference to quantitative indicators, results show that a slightly higher percentage of participants in OGs have increased the overall quantity of fertilisers and the quantity of nitrogen contained in fertilisers, while most participants have used a reduced quantity of phosphorus per hectare. The use of pesticides has increased in 62% of participants and about 75% have decreased the number of crops cultivated. Control group shows more contrasting results. Compared to the participants in OGs, the use of fertilisers and the quantity of nitrogen increase to a larger extent, i.e., in 62% and 57% of observations, respectively. Furthermore, the used quantity of phosphorus increases in a higher share of units (60% against 44%), while the use of pesticides and the number of crops per farm increase in a lower share of subjects, respectively in 55% and 43% of observations.

Looking at regression results, a significant and negative coefficient related to the used quantity of phosphorus per hectare can be observed. Therefore, in treated there is a lower propensity to increase the use of phosphorus. The relevant odds ratio is around 0.5. The probability that the use of phosphorus increases in participants is thus about 50% lower compared to control units.

The coefficient associated with the number of crops per farm is also significant and negative. This implies that in treated subjects there is a higher tendency to decrease the number of crops cultivated. The odds ratio being around 0.4, the probability that the number of crops cultivated increases in treated is therefore about 60% lower compared to control units.

Discussion

Impacts and policy implications

OGs were designed to meet the objectives of increasing productivity and sustainability in agriculture, which, for a farm, could translate into an increase in profitability levels. The results obtained in this study show that OGs may have allowed the participating farms an improvement in fertiliser management that has given rise to decreases in the fertiliser expenditure, a possible substitution of fertilisers with products having environmental lower impact, and increases in income. This could be indicative of the effectiveness of the projects to rationalise the use of fertilisers that fall within the scope of those analysed.

However, these positive impacts are accompanied by negative dynamics that run counter to the environmental objectives of EIP-AGRI in line with what other studies have highlighted (Eckerberg *et al.*, 2023). In fact, the results show, compared to nonparticipants, a higher expenditure on water, energy, and fuels, a greater expenditure on pesticides and a higher increase in the level of specialisation with possible and well-known negative consequences on water quality, health, biodiversity, soil fertility, and climate change. The used quantity of pesticides also increases, although with no significant differences compared to nonparticipants. These variations are unexpected in consideration of the projects financed, which include those aimed at rationalising the use of water, reducing pesticides, and increasing biodiversity.

A first reason for these results can be the different degree of involvement of participants. Maziliauskas *et al.* (2018) warned that there is the risk that there could be partnerships that are only formal. This implies that not all partners are involved in the same way. The consequence is that any positive impacts will be concentrated only on a part of the farms and that the impact assessment focused on a different sample will not be able to highlight these impacts.

A further reason can relate to the nature of the projects. In the 2014-2020 programming period, several projects providing only feasibility studies and monitoring activities were funded in addition to those intended for actual experimentation and introduction of agricultural innovations. These studies produce contextual analyses depicting the current situation and provide methodological guidelines to lead other farms or the participating farms themselves towards paths of greater sustainability and productivity. Consequently, the effects will only be seen in the future provided that the results of the monitoring are concretely used for the benefit of a more virtuous management and that the guidelines developed are put into practice. However, this could be a great limitation of OGs. Having funded surveys and methodological studies without providing conditions of effective applicability might in fact compromise the effectiveness of OGs and public spending to finance them.

Other factors underlying the results could be linked to the trade-off between objectives and to the selection criteria of the partners. Projects by their nature tend to focus on certain aspects of farm management. This means that all other aspects could be neglected. In this case, the risk is that a farmer that has been selected, for example, to experiment with the use of by-products for energy purposes deriving from the production of arable crops could be able to reduce the consumption of non-renewable energy but could specialise in certain productions (the degree of specialisation measured by the number of cultivated crops therefore increases) and could continue to make extensive use or even increase the use of pesticides and other inputs. This raises issues relating to both the link between the choice of partners and the type of project and the consistency with the objectives of EIP-AGRI during the phases of project preparation and selection. The choice of the partners by the OG, first, and then, the evaluation of the project's fundability by policy makers should in fact consider the characteristics of farmers, the impacts deriving from the current management, and any potential changes resulting from the implementation of the project. In the example given above, a project aimed at reducing potentially harmful inputs to the environment or at introducing new varieties in favour of biodiversity would have been more suitable for that type of farm. It is also true that the calls for selection of OG projects published by the Emilia-Romagna managing authority already included the consistency between the composition of the partnership and the objectives of the project among the evaluation criteria (Regione Emilia-Romagna, 2020). However, this criterion, like others, is not a necessary condition but contributes to the determination of an overall score and is not among the criteria that produce the highest scores. In addition, the criterion is rather generic and susceptible to discretionary evaluations based on the statements provided by those presenting the project.

There is therefore the need to revise governance processes to improve the effectiveness of OGs as other studies have stressed (Giarè and Vagnozzi, 2021). Based on the considerations made above, the managing authorities of RDPs are first called to be more selective by excluding projects that do not explicitly provide for experimentation and the introduction of innovations. This means that projects including only feasibility studies and monitoring activities should be rejected. Furthermore, the managing authorities should require farmers, during the project proposal presentation phase, to clearly indicate the management situation by providing quantitative and verifiable data on the current impacts to allow the evaluation of the coherence between the project objectives and farm characteristics and, therefore, the opportunity to admit that farm into the partnership. In addition to the indicators of the current management situation, participants should also be required to quantify the results achieved, as part of the necessary and constant monitoring of activities (Maziliauskas *et al.*, 2018). This enables both the OG and policy evaluators to calculate variations and thus measure the effects deriving from the application of innovations. Knowledge of the impacts, which could be checked on a sample basis with on-site checks, would not only help to improve the effectiveness and orient the future setting of OGs but could also be a reason for reducing public contributions in the event of unjustifiable results and in contrast with the initial objectives. The provision of possible penalties associated with results could in turn act as a strong incentive for OGs to be more tailored and selective during its constitution by presenting projects and forming partnerships that are more involved and more consistent with the aims of EIP-AGRI.

The policy framework that is proposed here responds to the principles of the performance-based approach adopted by the 2023-2027 CAP. This approach, also called New Delivery Model, gives more emphasis to policy performance compared to the previous programming period. Basically, it provides for the verification of the level of achievement of predefined target indicators at level of Member States, the requirement of an action plan in the event of excessive discrepancies between targets and realisations and the suspension of payments if the action plan is not submitted or manifestly insufficient (art. 128–129 of Regulation EU No. 2021/2115).

However, the approach suggested here presents four main differences. First, it would be applied at level of single projects. Second, two list of indicators could be drawn up according to the implementation phase of the project. A first one can be broader and consider different aspects of farm management. i.e., economic, social, and environmental aspects. These indicators can be used for initial selection. In fact, their value calculated at an early stage for potential farms applying to participate in the project could be compared with those of farms having similar characteristics. The aim is to measure the impact of farm management, relatively to the competitive context in which farms operate, and to evaluate the real need for innovation and the opportunity to include them within the partnership. This is because marked differences with the comparison group could signal management criticalities that can be resolved through the application of economic, environmental, or social innovations. In this regard, the FADN data could be effectively used to identify a battery of possible indicators and make comparisons as Arzeni *et al.* (2021) showed.

A second list could contain a selection of all indicators initially identified and based on the type of project. These indicators would be employed after the project has been approved for monitoring and final assessment. For instance, in the case of projects aimed at reducing the used quantity of water, indicators such as the incidence of both the amount of water used and the expenditure for water consumption per hectare could be monitored. Third, the action plan is represented here by all the corrective actions that the OG undertakes during the implementation of the project following the constant monitoring activities in order to reduce the gap between objectives and results. Fourth, penalties are applied once the project is completed under two hypotheses. One occurs if the plan is not implemented as established. This situation was already contemplated by the managing authorities of RDP. The other circumstance would occur if the opposite effects were produced with respect to the initial objectives. In the example above, they would be applied if the ratio of used quantity of water to hectares increased rather than decreased. This is to avoid the application of sanctions in situations where innovations, even if correctly applied according to the plan, are neutral, i.e., they do not produce significant effects as expected because of external and unpredicted factors.

The official guidelines for measuring the progress of the OGs financed under the 2023-2027 CAP substantially confirm the previous ones (European Commission, 2016). The main focus is on the need to classify projects rather than improve their performance (Annex VI of Commission Implementing Regulation EU 2022/1475). The risk, therefore, is that the distortions highlighted by this study will not only be removed but even exacerbated. However, thanks to the greater flexibility attributed by the reformed CAP at national level, Member States can decide to integrate the current monitoring and controlling system, in compliance with the general principles, in order to increase the effectiveness of OGs. The framework proposed here could be a possible option in this direction.

Data implications

The results of this study may be influenced by the data used. A first source of influence can be the size of the sample analysed. This study focuses in fact on a regional case, the Emilia-Romagna region, and on a small percentage of farmers that participated in concluded OGs (about 6%). This depends on the characteristics of FADN, which collects data from a representative but still limited sample, and on the fact that there are several OGs still not concluded or that are not officially concluded.

Another source of influence concerns the construction of the sample and the methods of calculating outcomes. The farmers analysed are observed during the treatment, i.e., during the implementation period of the OG projects. Due to a planned turnover of the units observed, FADN does not always allow for each farm an analysis of the periods preceding and following that in which the project was implemented. One of the requirements of propensity score matching techniques is that the treatment should not influence the confounders analysed, otherwise endogeneity problems could arise. This is what can happen if variables are measured during treatment. In this regard, one of the assumptions of this study is that an inverse relationship between treatment and confounders does not exist or is so weak that it does not affect the results. This assumption can be considered plausible as the OG projects have a limited scope and do not alter the main characteristics of farms, which form the basis for the construction of the control group. A further assumption underlying this study is that the potential effects measured in terms of impact direction occur during the implementation of the project and can therefore already be measured without waiting for a certain period to pass from the end of the project. This assumption can also be reasonably accepted in all those cases in which a practical application of innovations is provided and considering that the last period of the project is generally dedicated to the dissemination of results, while practical activities of experimentation and application of agricultural innovations are carried out in the initial and especially in the intermediate phases.

It is evident that a more accurate analysis of the impacts produced by OGs on farmers will be possible as soon as all projects are completed. Nevertheless, this does not affect the usefulness of this study, which, in addition to representing a first attempt to analyse the impact of a sample of OGs in a given regional context for the benefit of the programming that has just begun, provides some useful practical and methodological indications for setting future analyses. Nor can the usefulness of the FADN data be called into question. This is because FADN, besides making a large amount of information available about a sample of farms that is representative of regional (and national) agriculture, makes it possible to compare the farms participating in OGs with similar farms that did not take part in them, without having to resort to further and costly investigations.

Concluding remarks

This paper analysed the possible impacts produced by a sample of OGs of EIP-AGRI on the economic and environmental performance of the participating farms. The focus was on the Italian region of Emilia-Romagna. This is an ideal laboratory to test the effectiveness of OGs because it is the region with the highest number of financed OGs and for the prevailing characteristics of regional agriculture that make innovations capable of reducing environmental impacts highly desirable.

This study compared a group of farmers participating in OGs with one of nonparticipating farms having very similar characteristics and selected by using a propensity score matching technique applied to the FADN data. This research reveals conflicting results. On the one hand, it turns out that there are possible improvements in fertiliser management and in profitability levels induced by participation in OGs, while, on the other hand, there emerge an increased consumption of water, energy, and fuels, an increased use of pesticides, and a greater loss of crop diversity. Overall, it can therefore be argued that the OGs analysed may have provided the participating farmers with a comparative economic advantage. This is a strong incentive for participation and therefore represents an encouraging result for the future of this political instrument. However, those OGs may not have achieved some of the most important objectives related to environmental sustainability. Possible factors that could be at the origin of this result are the financing of projects that only provide for feasibility studies, a different degree of involvement of farmers, and the selection criteria of OGs, which may be not very effective in ensuring full consistency between the characteristics of agricultural partners, the type of project, and the objectives of EIP-AGRI. For these reasons, policy makers are advised to condition projects on the actual experimentation and implementation of agricultural innovations and introduce a performance-based system of indicators for the assessment of the ex-ante and ex-post impacts of farm management.

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Edith Johana MEDINA-HERNÁNDEZ*, Evelyn BARCO-LLERENA and Kelly Johanna MARBELLO-YEPES*****

Food security in the world: Disparities and opportunities by country income levels

This article examines the performance of ten food security indicators across 91 countries in the world, categorised by their income levels, to identify differences and similarities. The variations and covariations observed in a multivariate way are outlined through Biplot plots that summarise the results of a Principal Component Analysis (PCA). The results show a direct link between the economic factors of the countries, food security, nutrition, and its derivatives. High-income countries are the best place for their populations to access a nutritious and quality food supply to meet the dietary energy needs needed for an active life. In contrast, low- and lower-middle-income countries still have critical indicators of the prevalence of severe or moderate food insecurity, malnutrition, and other related diseases, such as anaemia.

Keywords: food security; multivariate analysis; sustainable development; SDG 2.

JEL classifications: Q18, O13

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Introduction

Food security has become a critical pillar for socio-economic development in all world nations. Within the framework of the Sustainable Development Goals (SDGs), it is a specific objective among the seventeen proposed SDGs because SDG 2 seeks to generate global public policy actions to curb the suffering of hunger and the factors that lead to food insecurity among the population. Itis commonly understood as signifying restricted, inadequate, or uncertain access to healthy and nutritious food that allows the population to meet the energy requirements for a healthy and productive life.

According to the 2022 edition of the report on the state of food security and nutrition at the global level (FAO, 2022), the world is going backwards in its efforts to end hunger, drifting away from meeting the goals of SDG 2 by 2030. This is an effect of the COVID-19 pandemic, which has influenced the deterioration of food security in both developed and developing countries due to fluctuations in food supply and demand, increased costs, and market closures (Zurayk, 2020).

The Sustainable Development Report 2022 (Sachs *et al*., 2022) throws this into sharp relief. As the map in Figure 1 shows, the promotion of food security globally currently faces significant challenges, with the situation being most

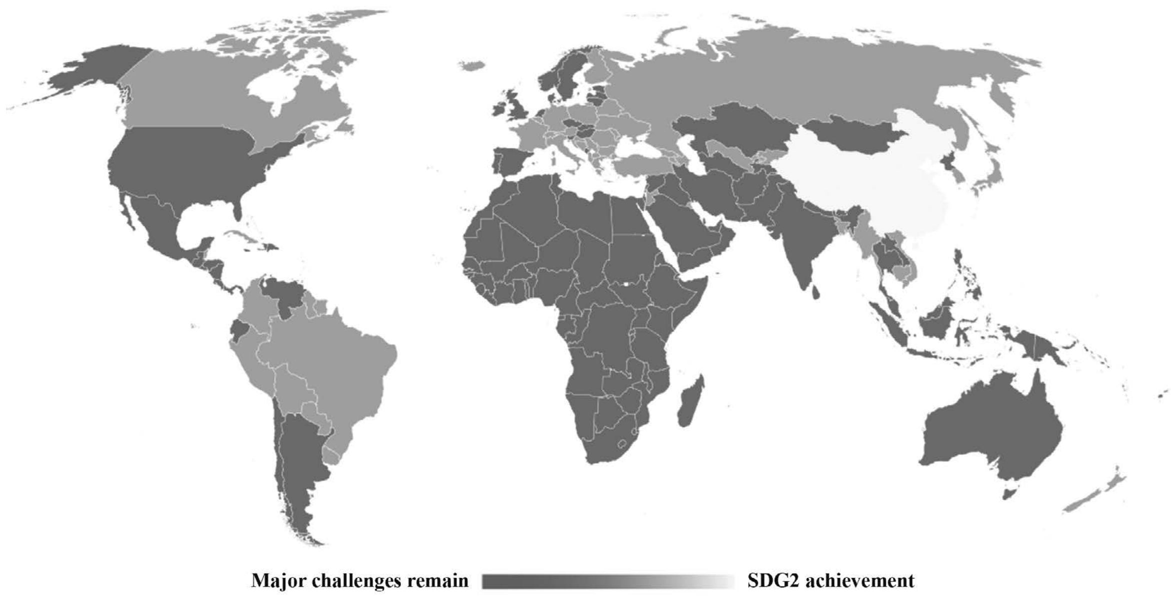

Figure 1: Current overview of the achievement of SDG2 in the world.
Source: Own composition based on data from Sustainable Development Report (2022)

acute among the nations of Africa, South, and West Asia, and even in developed countries such as Australia or the United States. States (regions plotted in orange). In these territories, the shortage of agricultural workers, the closure of food production due to the pandemic, and changes in consumer demand (Alabi and Ngwenyama, 2023), have together limited food supply chains in the post-COVID-19 era.

However, COVID-19 is not the only factor to have generated barriers to the production, access, and consumption of food by populations. As Awad (2023) observes, although food insecurity and malnutrition have been attributed mainly to conflicts, climate change, and economic crises in recent years, weak governments, low-income growth, and inadequate access to education for people represent additional barriers to addressing food security in an inclusive manner globally.

Consequently, it is necessary to acknowledge the factors that determine the prevalence of food insecurity in the world. At the macro level, this means the socio-political context of nations, their cultural characteristics, the prevalence of social structures and classes, public health policies, or even policies associated with food production that restrict the use of agricultural inputs that reduce output, farmers' incomes, and increase food prices (Baquedano *et al*., 2022). At the micro level, this means the socio-economic characteristics of the population and their housing economy, including gender and education of the household head, income, and poverty status of the households (Dasgupta and Robinson, 2022).

Concerning poverty specifically, several authors discuss how it connects with food insecurity (Zezza and Tasciotti, 2010; Mahadevan and Hoang, 2016; Seaman *et al*., 2014; Chegini *et al*., 2021) because it is a structural and multidimensional problem that encompasses various dimensions of deprivation related to human needs, such as food consumption, health, education, security, decent work, among others. Consequently, more policies based on the tenets of socio-economic inclusion need to guide the distribution of wealth and the promotion of economic participation to reduce inequality and improve food security and nutrition outcomes worldwide (Tamasiga *et al*., 2023).

In the recent academic literature, it is possible to reference authors who analyse the different factors that affect the population's food security, specifically through indicator analysis and modelling techniques. Valenzuela-Cobos *et al*. (2022) studied food sustainability in Ecuador using the PCA Biplot and GGE Biplot techniques to analyse flour samples of two cocoa mixtures, as this is the leading agricultural export product in the country. In their results, these researchers concluded that mixtures of cocoa husk flour with soybean meal can be used as ingredients to produce novel foods.

Kumar-Singh *et al*. (2022) evaluated food security indicators among the nations belonging to the South Asian Association for Regional Cooperation (SAARC), under changing climate scenarios and with a projection to 2050. This research concluded that food security indicators can be grouped according to four dimensions: availability of food, access to food, the use of its potential, and the stability of its production. Additionally, it was concluded that Bangladesh has the highest future projection of food security for its population in the region, followed by Sri Lanka. In contrast, the Maldives and Afghanistan were found to face critical scenarios based on the climate change scenarios evaluated.

Finally, Nouman *et al*. (2022) studied the impact of the green revolution on food security in Pakistan, using annual time series data from 1975-2017. By applying an autoregressive model, these authors concluded that agricultural machinery, agricultural credit, the use of fertilisers, high-quality seeds, fuel consumption, and the increase in the cultivated area of cereals; are the critical factors for a green revolution, which will improve food security in the country.

Taking all the above into consideration, this study analyses the current perspective of food security in the world by studying, from a multidimensional perspective, the behaviour of different indicators related to the framework of monitoring the progress of countries to meet the targets of SDG 2. To this end, three research questions are posed: Are statistically significant differences observed between food security indicators according to the countries' income levels? Which indicators generate the most remarkable differences? Which countries currently present the most critical challenges in seeking food security for their populations?

Materials and methods

Indicators and countries under analysis

Several international organisations regularly compile and publish information on food security indicators to promote sustainable development across nations, including those presented in Table 1. These are the indicators of interest in this study and are part of the FAOSTAT data repository of the Food and Agriculture Organization of the United Nations (FAO, 2023b), the Sustainable Development Goal indicators website (UN, 2023) and the World Bank Open Data portal (World Bank, 2023).

Indicators such as AGDP and AIGE are associated with agricultural indices measured in different nations around the world. In contrast, others correspond to estimates related to people's dietary and energy requirements (ADER, ADES, or DESU). The other indicators in Table 1 represent measures of the health and well-being of populations, specifically related to the prevalence of food insecurity and malnutrition.

The analysis of the behaviour of the food security indicators and their existing interrelationships is based on a study of the 91 countries included in the Table 2, which are grouped by the income levels defined by the World Bank. According to this classification, low-income economies have a gross domestic product (GDP) per capita of US$1,085 or less; in lower-middle-income countries, it ranges from US$1,086 to US$4,255; in upper-middle-income countries, the range is US$4,256 to US$13,205; and high-income nations have a GDP per capita of US$13,205 or more. Meanwhile, the 3-letter abbreviation of the countries' names has been used according to the ISO 3166 ALPHA-3 codification for the purposes of graphic representation.

Table 1: Food security indicators included in the analysis.

CODE	Variable	Source
ADER	Average dietary energy requirement (kcal/cap/day)	https://www.fao.org/faostat/en/#data/FS (indicator: 21057)
ADES	Average dietary energy supply adequacy (percent) (3-year average)	https://www.fao.org/faostat/en/#data/FS (indicator: 21010)
AGDP	Agriculture value added share of GDP (%)	https://unstats.un.org/sdgs/dataportal/database (indicator: AG_PRD_AGVAS)
AIGE	Agriculture orientation index for government expenditures	https://unstats.un.org/sdgs/dataportal/database (indicator: AG_PRD_ORTIND)
CVCC	Coefficient of variation of habitual caloric consumption distribution (real number)	https://www.fao.org/faostat/en/#data/FS (indicator: 21058)
DESU	The dietary energy supply used in the estimation of the prevalence of undernourishment (kcal/cap/day) (3-year average)	https://www.fao.org/faostat/en/#data/FS (indicator: 22000)
MSFI	Prevalence of moderate or severe food insecurity (%)	https://unstats.un.org/sdgs/dataportal/database (indicator: AG_PRD_FIESMS)
NSFP	Number of severely food insecure people (thousands of people)	https://unstats.un.org/sdgs/dataportal/database (indicator: AG_PRD_FIESSN)
PWAN	The proportion of women aged 15-49 years with anaemia (%)	https://unstats.un.org/sdgs/dataportal/database (indicator: SH_STA_ANEM)
UNSH	Prevalence of undernourishment (% of the population)	http://data.worldbank.org/indicator/SN.ITK.DEFC.ZS

Source: Own composition

Table 2: List and abbreviations of countries analysed.

Code	Country	Code	Country	Code	Country	Code	Country
				Low-income economies			
BFA	Burkina Faso	ETH	Ethiopia	LBR	Liberia	MWI	Malawi
COD	Congo, Dem. Rep.	GMB	Gambia	MDG	Madagascar		
				Lower-middle-income countries			
AGO	Angola	HND	Honduras	MRT	Mauritania	PHL	Philippines
BEN	Benin	IDN	Indonesia	MNG	Mongolia	SEN	Senegal
CPV	Cabo Verde	KEN	Kenya	MAR	Morocco	LKA	Sri Lanka
CIV	Cote d'Ivoire	KGZ	Kyrgyz Republic	MMR	Myanmar	TZA	Tanzania
EGY	Egypt	LAO	Lao	NPL	Nepal	UKR	Ukraine
SLV	El Salvador	LBN	Lebanon	NGA	Nigeria	VUT	Vanuatu
GHA	Ghana	LSO	Lesotho	PAK	Pakistan	VNM	Vietnam
				Upper-middle-income countries			
ALB	Albania	CRI	Costa Rica	KAZ	Kazakhstan	PER	Peru
ARM	Armenia	ECU	Ecuador	MYS	Malaysia	SRB	Serbia
AZE	Azerbaijan	FJI	Fiji	MUS	Mauritius	ZAF	South Africa
BLZ	Belize	GEO	Georgia	MEX	Mexico	THA	Thailand
BWA	Botswana	GTM	Guatemala	NAM	Namibia		
BRA	Brazil	JAM	Jamaica	MKD	North Macedonia		
BGR	Bulgaria	JOR	Jordan	PRY	Paraguay		
				High-income nations			
AUS	Australia	FIN	Finland	JPN	Japan	ROU	Romania
AUT	Austria	FRA	France	KOR	Korea, Rep.	SVK	Slovak Republic
BEL	Belgium	DEU	Germany	KWT	Kuwait	ESP	Spain
CAN	Canada	GRC	Greece	LTU	Lithuania	SWE	Sweden
CHL	Chile	HUN	Hungary	NLD	Netherlands	GBR	United Kingdom
CZE	Czech Republic	IRL	Ireland	NZL	New Zealand	USA	United States
DNK	Denmark	ISR	Israel	NOR	Norway	URY	Uruguay
EST	Estonia	ITA	Italy	PRT	Portugal		

Source: Own composition

Methodology

This study is a quantitative analysis that can be considered both descriptive and exploratory. It seeks to analyse the relationships between different food security indicators to identify both the most preponderant and those that determine the differences and similarities between countries. All the results were obtained using the statistical software R. Initially, a descriptive analysis was carried out to interpret the measures of central tendency of the food security indicators examined. Kruskal-Wallis and Dunn nonparametric hypothesis tests were afterwards applied to identify statistically relevant differences among income levels of the countries. Bivariate correlations between pairs of indicators were also calculated.

Finally, by using the Principal Component Analysis (PCA) technique, the behaviour of the bivariate and multidimensional associations observed was analysed by plotting the results of the reduction of the dimensionality of the data using Biplot graphs. According to Peña (2002), the main components have a double utility. First, they enable optimal representation of small numerical datasets. Second, they transform the original correlated variables into new uncorrelated variables, facilitating the interpretation of the data.

This technique aims to achieve the best representation of the attributes of the analysed information in the least number of dimensions possible. Graphically, through a Biplot, it is possible to summarise the information of variables (indicators represented by vectors) and individuals (countries, according to their 3-letter acronym) using the same reference system, providing the best Beta-barycentric representations and achieving the same quality of representation for the rows and columns of the data matrix (Galindo-Villardón *et al*., 1996).

Recently, analyses involving Biplot graphics have enjoyed a significant boom in scientific research, given their versatility in terms of the representation of results for the analysis of large-magnitude data. This is because they enable researchers to reference recent research in the field of agricultural sciences (Tatis-Diaz *et al*., 2022; Omrani *et al*., 2022; Silva *et al*., 2021), public health (Riera-Segura *et al*., 2022; Pozo *et al*., 2021), as well as studies with indicators in the field of sustainability (Medina-Hernández *et al*., 2023; Ruswandi *et al*., 2022; Valenzuela-Cobos *et al*., 2022; Martínez-Regalado *et al*., 2021).

Results

Descriptive analysis

Before presenting the results obtained through the multivariate analysis that allows the observed multidimensional associations to be summarised, it is pertinent to the discussion to show a descriptive exploration of the indicators under analysis and make comparisons among countries grouped by income levels. Table 3 summarises the basic statistics of each indicator. A marked tendency for all indicators to reflect differences in countries' income levels can be observed. For example, in the case of indicators associated with the dietary energy requirements of the population (ADER, ADES, and DESU), to the extent that the income level of the countries increases, the greater the median of these indicators is observed. On the contrary, the central tendency measures decrease as the income level of countries increases, among the indicators related to the prevalence of food insecurity or malnutrition such as MSFI, NSFP and UNSH.

To test the statistical significance of the differences observed in Table 3, and after examining that the indicators presented outliers, the data were evaluated as non-normal, and the Kruskal-Wallis test was performed, whose results are summarised in Table 4. For all the indicators examined, P values lower than a significance level $\alpha = 0.05$ were obtained. Therefore, with 95% confidence, it can be concluded that there are considerable differences between at least two of the income levels compared. Therefore, Table 4 also presents the results of the Dunn test, to test specifically between which levels the differences are recorded

Table 3: Basic statistics on indicators by country income levels.

Statistic	Income Level	ADER	ADES	AGDP	AIGE	CVCC	DESU	MSFI	NSFP	PWAN	UNSH
Median	1.Low	2,253.0	112.0	23.0	0.10	0.30	2,569.0	169.0	6,804.9	42.4	21.6
	2.Lower M.	2,313.0	120.5	13.3	0.15	0.28	2,847.0	90.1	2,490.4	32.9	5.7
	3.Upper M.	2,381.0	121.0	6.6	0.31	0.27	2,901.0	88.2	754.1	23.5	8.2
	4.High	2,483.0	135.0	1.9	0.40	0.21	3,365.0	23.6	417.9	13.2	2.5
	All Countries	2,391.0	123.0	6.0	0.25	0.26	2,922.0	60.7	1173.8	22.8	5.2
Mean	1.Low	2,262.9	111.1	30.0	0.12	0.31	2,516.7	180.2	13,126.5	40.0	20.8
	2.Lower M.	2,325.8	121.5	15.1	0.21	0.28	2,827.5	106.8	9,603.1	33.1	10.1
	3.Upper M.	2,375.4	119.4	7.0	0.46	0.28	2,837.8	87.3	3,538.6	23.6	11.5
	4.High	2,471.6	133.7	2.1	0.53	0.23	3,307.0	25.4	1,316.6	14.6	4.0
	All Countries	2,384.2	124.3	9.6	0.38	0.27	2,969.8	79.4	5,385.2	24.7	9.2
Standard deviation	1.Low	67.1	14.5	17.4	0.08	0.05	388.3	63.7	12,738.7	10.0	14.6
	2.Lower M.	98.8	12.7	7.7	0.15	0.06	345.4	60.0	15,176.3	12.6	10.3
	3.Upper M.	102.5	12.5	3.7	0.47	0.07	375.5	49.1	4,976.1	7.3	11.1
	4.High	88.4	11.3	1.4	0.46	0.04	321.9	14.1	3,643.6	4.5	3.4
	All Countries	116.2	14.1	10.3	0.40	0.06	429.2	64.1	10,382.1	12.3	10.2

Source: Authors' computations

Table 4 shows no statistically significant differences between the first two income levels in any indicators examined. This implies that although the World Bank considers nations that have a GDP per capita less than 1,085 US dollars as compared to those that increase to 4,255 dollars (respectively, income levels 1. Low and 2. Lower Middle) to be in different categories, in terms of food insecurity, the world's poorest nations have the highest prevalence of food insecurity. In complete contrast, the most industrialised countries and those with stable economies have the most favourable conditions. Note that the comparisons between levels 1. Low and 4. High (presented in the fifth column) are all significant.

To describe the bivariate correlations observed between pairs of indicators, Figure 2 presents a matrix of Spearman correlations (since non-normality was identified in the data),

Table 4: Kruskal-Wallis and Dunn test for differences by income level.

		dunn.test					
	kruskal.test	**1.Low**	**1.Low**	**1.Low**	**2.Lower M.**	**2.Lower M.**	**3.Upper M.**
		2.Lower M.	**3.Upper M.**	**4.High**	**4.Upper M.**	**4.High**	**4.High**
ADER	3.1x10-7 ****	0.242	0.069	7.3x10-5 ****	0.242	6.7x10-6 ****	0.007 **
ADES	4.4x10-5 ****	0.349	0.438	0.001 **	0.615	0.004 **	0.001 **
AGDP	1.9x10-14 ****	0.171	0.003 **	0 ****	0.006 **	0 ****	3.0x10-4 ***
AIGE	9.0x10-6 ****	0.504	0.011 *	0.001 ***	0.011 *	2.1x10-4 ***	0.504
CVCC	1.9x10-5 ****	0.646	0.646	0.001 **	0.918	0.001 ***	0.001 ***
DESU	4.9x10-7 ****	0.329	0.329	1.1x10-4 ***	0.859	6.6x10-5 ****	1.8x10-4 ***
MSFI	4.9x10-11 ****	0.153	0.074	4.0x10-7 ****	0.441	1.0x10-7 ****	6.6x10-6 ****
NSFP	3.2x10-5 ****	0.227	0.038 *	0.001 **	0.089	3.8x10-4 ***	0.197
PWAN	2.3x10-10 ****	0.246	0.035 *	3.8x10-6 ****	0.065	0 ****	0.001 ***
UNSH	1.76x10-6 ****	0.158	0.176	9.5x10-5 ****	0.746	0.001 ***	3.1x10-4 ***

Note: Significance levels are $\alpha = 0.1$ (*), $\alpha = 0.05$ (**), $\alpha = 0.01$ (***) and $\alpha < 0.01$ (****).
Source: Authors' computations

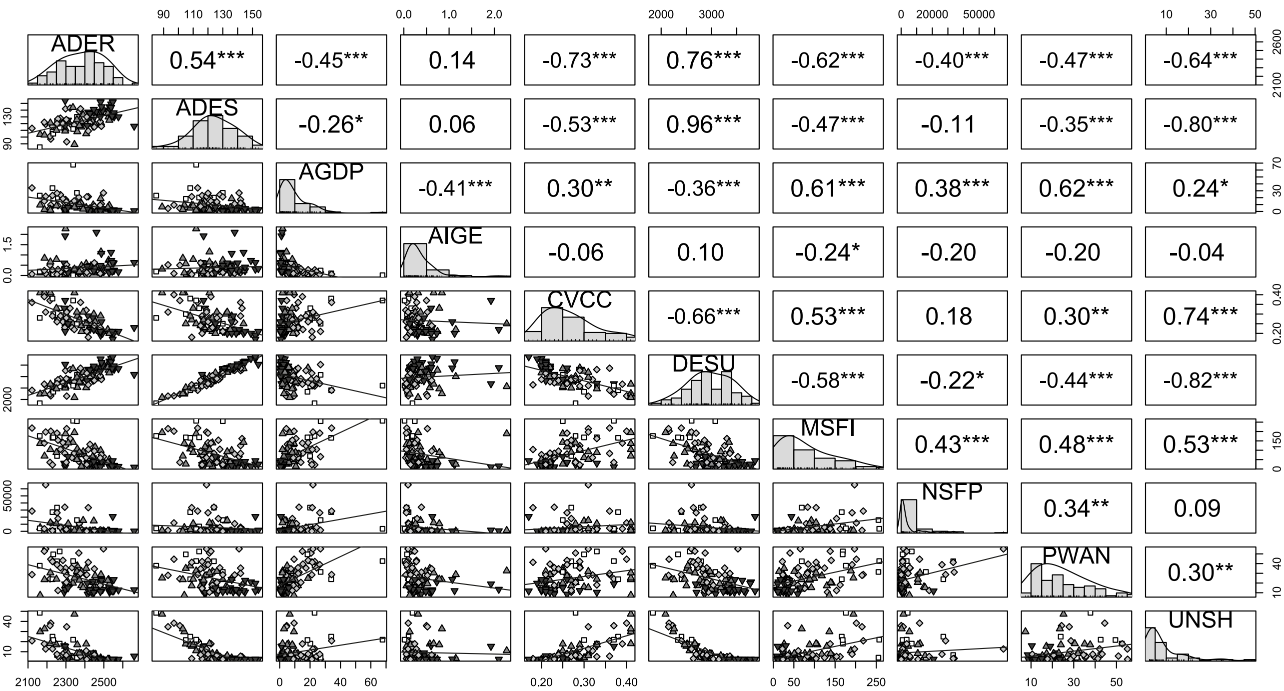

Figure 2: Bivariate correlation matrix between pairs of indicators.

Note: Significance levels are denoted as and
Source: Authors' elaboration in the statistical software R.

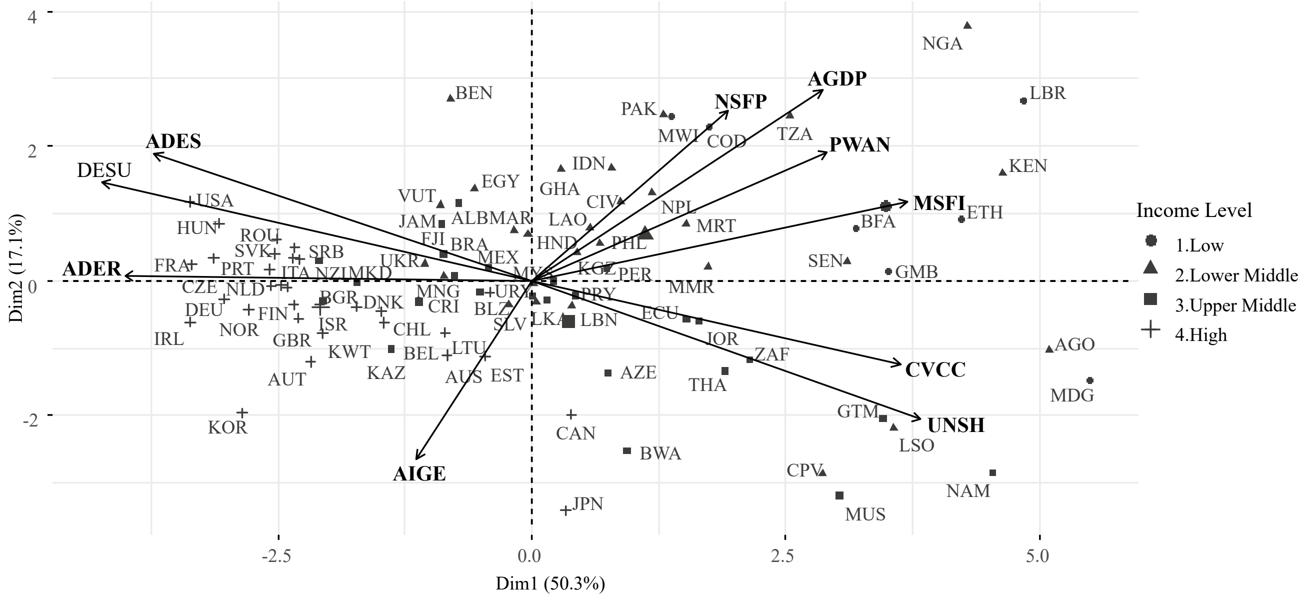

Figure 3: Food Security Indicators Biplot - PCA Analysis (Plain 1-2).

Source: Authors' elaboration in the statistical software R

differentiating countries' income levels with colours in the lower triangle. In the upper triangle of the matrix, the presented value corresponds to the calculated correlation for all countries and the stars denotes their statistical significance. It can be observed that different indicators show correlations with each other, reflecting an association by pairs.

Figure 2 shows a direct and strong covariation (with a value of 0.96) between the adequacy of the dietary energy supply (ADES) and the dietary energy supply used in estimating the prevalence of malnutrition (DESU) with a significance level of $\alpha<0.01$. In contrast, regarding the negative associations observed, there is also a negative correlation of -0.61 between the prevalence of moderate or severe food insecurity (MSFI), and the agriculture value added share of GDP (AGDP) index. This implies that in countries where agriculture accounts for a larger share of GDP, people are less likely to have the resources to obtain the food they need to live healthy, and well-being lives.

On the other hand, to give but one example of indicators among which no significant correlations are perceived, one can mention the observed association between ADES and CVCC, estimated at -0.06. This implies that an increase or decrease in one of these indicators provides no information about the behaviour of the other.

Multivariate analysis

To provide a multivariate summary of the variations and covariations observed between the indicators studied, Figure 3 presents the plane 1-2 of the Biplot that summarises the reduction of the dimensionality of the data. In this plane, 67.4% of information variability is shown (50.3% in the first dimension and 17.1% in the second). Therefore, when interpreting the associations observed at the level between vectors (which represent the relevant indicators) and the relative positions of countries (shown by colours according to income levels), 67.4% of all that could be said about the performance of food security indicators analysed.

The first pattern highlighted in Figure 3 is the countries' ordering from right to left according to income levels, which shows the relative advantage that high-income countries have in ensuring the food security of their populations. To the right of the graph and upwards (in the direction of the first quadrant of the plane) are the low- and lower-middle-income countries, in the direction of the vector cluster: MSFI, PWAN, NSFP, and AGDP, which positively covary with each other and are located in opposition to the AIGE vector.

These vectors represent, respectively, the prevalence indicators of moderate or severe food insecurity, the number of severely food insecure people, the proportion of women of reproductive age with anaemia, the value added of agriculture in GDP, and the agricultural orientation index for government expenditures. Observing the AIGE vector with an angle close to 180° relative to AGDP vector implies that although people in lower-income countries work in cultivating land for food production, Government expenditures to favour and promote productive initiatives in the agricultural sector tend to be low. This limits food production, access, and supply among populations, especially in rural areas.

To the left and up the plane of Figure 3 (in the direction of the second quadrant) are located the vectors ADES, DESU, and ADER, and those high- or upper-middle-income countries where the majority of inhabitants have access to sufficient food to meet their energy needs, and where governments promote food security and health policy. In contrast, down and to the right (in the direction of the fourth quadrant of the plane) are the countries with the highest rates of undernourishment. In six African countries, such percentages are greater than 30% of the population: Madagascar (MDG, 48.5%), Namibia (NAM, 47.2%), Angola (AGO, 38.3%), Cape Verde (CPV, 35.8%), Lesotho (LSO, 34.7%) and Mauritius (MUS, 32.7%).

Regarding the ranking of countries against axis 2, it should be noted that the heterogeneity observed between nations is generated by the AIGE vector, which is located closest to this axis and represents the estimate of the agricultural orientation index for government expenditures. Japan (JPN), Canada (CAN), Botswana (BWA), and the Republic of Korea (KOR) stand out for having the best values in the world in this index. It should also be noted that nations that are observed close to the midpoint of the plane (near the origin), as is the case of Latin American countries, tend to have "average values" for all the indicators analysed.

Discussion

In this study, differences statistically significant were observed among all the food security indicators examined when comparing the low and the high-income nations. Among lower-income countries prevalence of food insecurity and related (acute or chronic) diseases was observed that reflect low nutrient and food energy availability among vulnerable consumers (Unnevehr, 2015).

This outcome underscores the existing relationships between food security and sustainable development, socioeconomic factors, nutrition policy, governance, strategies to combat poverty, inequality, hunger, and food security management (Akbari *et al.,* 2022). Aspects that, after the occurrence of the COVID-19 health emergency, have revealed the vulnerability of global food systems to food safety risks, economic crises, and food price volatility (Panghal *et al.,* 2022).

Therefore, it is essential for developing nations to establish clear social policies that translate into tangible actions to reduce hunger and ensure the right to adequate and timely food. This is crucial to reduce health risks for the most vulnerable populations due to poor food safety (Gundersen and Ziliak, 2015). Additionally, policymakers in developing economies must prioritise job security to mitigate the adverse effects of income inequality on food security (Haini *et al.,* 2023).

In relation to the findings related to middle-income countries, particularly from the results of the multivariate analysis done, it was evident that they do not exhibit unfavourable conditions in all the studied indicators. These nations are actively working to implement public policy that favour investments on agricultural infrastructure, research, and development, and to transform their food systems governance (Lin *et al.,* 2022). However, they still face significant challenges in eradicating hunger and malnutrition in all its forms (FAO, 2023a). Furthermore, they also require seeking to lead the sustainable development from the fulfilment of the targets of SDG 2.

The analysed data indicate that such leadership currently primarily comes from developed nations. As Filippini *et al.* (2019) specify, high-income countries are implementing Urban Food Policies in three key areas: i) agriculture for food security; ii) governance and food economy; and iii) sustainable and healthy consumption. Regarding the first area, the results of this study related to the Agriculture Orientation Index for Government Expenditures (AIGE) showed that the agricultural sector plays a strategic role in improving food availability, both for developing countries (Pawlak and Kołodziejczak, 2020) and for the rural population of high-income countries (Kent *et al.,* 2022).

In summary, and as emphasised by FAO (2022), it is imperative for global agri-food systems to transform, become more resilient, and provide nutritious food at lower costs, ensuring affordable healthy diets for all in a sustainable and inclusive manner. Only by doing so can we aspire to achieve the SDG 2 targets in all nations, and not just the most developed ones.

Conclusions

This analysis highlights that the countries with better economic resources are those that best guarantee their populations that they can access the food that allows them to supply the caloric energies necessary to develop a whole and healthy life, free of malnutrition, and other related diseases, such as anaemia. In contrast, among lower-income countries, food insecurity is higher.

This result leads us to conclude that we must continue looking for strategies to address existing disparities between nations that generate systemic economic, political, and cultural inequalities, and re-politicise inequality (Collins, 2022), to favour a more equitable global food balance. Moreover, in the current geopolitical situation, global food security is threatened by the confluence of increasing demand for food due to a growing population and the inability of the food production system to meet the increasing demand due to climate change, worsening soil fertility, and the challenges to water availability (Rahut *et al*., 2022).

Public policy actions aimed at reducing the existing structural inequalities between countries according to their income levels, will also contribute to the fulfilment of SDG 2, given the connected nature of the objectives of the 2030 agenda. Addressing global sustainability challenges in this way endeavours to minimise poverty, inequality, and hunger globally as well as to deal with climate change and environmental degradation (Arora and Mishra, 2022).

Finally, it is worth noting this limitation of the study: it did not examine indicators associated with the components of food systems, such as consumer environments, the nature of food, access to food, or the nature of their retailing points (Moustier *et al.,* 2013). These aspects could provide a more detailed perspective on how countries should address the food security of their populations and so merit being addressed in future research aimed at providing targeted recommendations for specific groups of countries.

In addition, it is advisable for future studies to utilise multivariate analysis techniques to analyse SDG 2 indicators, trends and conditions that quantify the time required for the different economies of the world to achieve the Agenda 2030 goals. This is crucial because, as Pradhan (2023) observes, failing to meet SDGs will negatively affect the lives of billions of people and worsen socioeconomic and environmental crises, even though the COVID pandemic has decelerated or reversed the process of the Agenda.

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Socio-economic Implications of Banning Conventional Farrowing Crates in EU Pig Farming: A CAPRI-based Scenario Analysis

This paper presents an analysis of the potential socio-economic implications of the European Commission's policy initiative to ban the use of cages in EU livestock farming, with a specific focus on conventional farrowing crates in the pig sector. Using the CAPRI (Common Agricultural Policy Regionalised Impact) tool, a multi-purpose comparative-static partial equilibrium modelling framework, the study examines two scenarios: an immediate phase-out of conventional farrowing crates by 2025 and a 10-year transition period until 2035. The simulation results indicate that the ban would lead to a significant decline in pork production in the EU, with production decreasing by 23.6% in the immediate phase-out scenario and by 8.4% in the 10-year transition scenario. The decline in production affects domestic demand and weakens the EU's net trade position. However, the ban would also result in an increase in consumer prices and producer prices for pork, partly moderating the decline in profits for the pig sector. Moreover, the study highlights the interconnectedness of agricultural policies and the importance of a global assessment of their impact on greenhouse gas (GHG) emissions. The simultaneous decline in EU pork exports and increase in EU pork imports trigger emission leakage: while GHG emissions from EU pork production are significantly reduced, the Global Warming Potential (GWP) of non-EU pork production increases by 4.2%. We find that the length of the transition period fundamentally defines the potential economic effects on the EU pig industry, the impacts on trade balance, and on global environmental effects. This finding emphasises that the implementation details of policy initiatives must be carefully designed to address both domestic and foreign challenges arising from the sustainable transformation of livestock farming practices in the EU.

Keywords: cage ban, pig sector, socio-economic implications, CAPRI, agricultural policy

JEL classificationa: Q13, Q18

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Introduction

On June 30, 2021, the European Commission unveiled a policy initiative (C(2021) 4747 final) (European Commission, 2021a) to ban the use of cages in EU livestock farming, including conventional farrowing crates (confinement) in the pig sector. The main objective of this paper is to analyse the potential socio-economic implications of the ban on conventional farrowing crates at both the European and global levels. It draws inspiration and recapitulates some of the key findings from the report published by Copa-Cogeca (the largest European farmers' umbrella organisation), titled *An assessment of the impacts the phasing out of cages in EU livestock farming: the pig and layer sectors*, which the authors of this paper co-authored. The findings presented here are based on scenario analyses utilising the CAPRI (Common Agricultural Policy Regionalised Impact) tool, a multi-purpose comparative-static partial equilibrium modelling framework.

There is a significant scientific literature comparing the efficiency and economic performance of sows in different housing systems, but the results presented in these studies are mixed. The variation in findings can be attributed to specific conditions such as pig breed, scale of operation, feeding systems, assumptions, and other factors under which the assessments were conducted. A major shortcoming of the literature is the generalisation of housing system descriptions without providing detailed information about their designs.

In their 2004 study, McGlone *et al.* (2004) conducted meta-analyses on scientific literature to examine the impact of housing systems on sow behaviour, performance, and physiology. Their findings showed that sows kept in individual stalls consistently exhibited equal or superior reproductive performance compared to sows in other housing systems. For instance, the farrowing rate in individual stalls was equal to or higher than in alternative systems, including group housing with dynamic social groups.

Multiple studies reported that the use of conventional farrowing crates resulted in a higher number of piglets weaned per litter compared to free farrowing pen systems (Chidgey *et al.,* 2015; Quendler *et al.,* 2009). Lactating sows in group housing systems with electronic sow feeders (ESFs) had poorer litter weaning performance compared to sows housed individually in stalls (Bates *et al.,* 2003). Furthermore, studies have shown that the incidence of piglet crushing is higher in free farrowing groups compared to sows housed in farrowing crates (Zhang *et al.,* 2020; Hales *et al.,* 2015; Buoio and Costa, 2020; Ko *et al.,* 2022). Farrowing crates consistently yielded the highest average number of weaned piglets per litter, 3-6% more than farrowing pens with temporary crating (Ko *et al.,* 2022).

Sows in group housing systems, particularly those with ESFs, exhibited higher injury scores compared to sows in individual stalls or tethers (McGlone *et al.,* 2004). Sows in free farrowing pens had a significantly higher proportion of culling, both overall and specifically due to lameness, compared to stall-housed sows. Anil *et al.* (2005) identified lameness and poor reproductive performance as the major reasons for culling sows in pens with ESFs.

Quendler *et al.* (2009) conducted an evaluation of labour time requirements and economic performance across eight different housing systems using farrowing pens and crates.

In terms of labour demand, sow pens had the highest time requirements for routine, special, and monitoring tasks, ranging from 4.20 (farrowing crate) to 5.99 (farrowing pen) hours per sow per year. The difference in labour time for sow pens was as high as 22.3%, while for farrowing crates, it was less than 10%, indicating more efficient work operations. The output per sow or piglet varied based on litter size and piglet weight, with gross margins for the systems ranging from €318 (farrowing pen) to €412 (farrowing crate) per sow per year, or €16.5 (farrowing pen) to €19.6 (farrowing crate) per piglet sold. Notably, significant gross margin differences of up to 29.3% were observed for sow pens compared to up to 7.7% for farrowing crates, highlighting variations in design.

The CAPRI scenarios presented in the followings were designed based on these findings and on data for individual EU Member States from the InterPIG (a global network of pig sector economists and experts) 2021 database.

Methodology

CAPRI was specifically developed for analysing the agricultural sector, with a primary focus on the European Union (EU). Those interested in detailed information about CAPRI can refer to the documentation (2022).

CAPRI was designed to assess the potential impacts of agricultural, environmental, and trade policies in advance (ex-ante). It consists of two interconnected main components: a set of supply models for the European agricultural sector and a market module which covers global agri-food markets.

The supply part of CAPRI calculates the optimal EU agricultural supply by maximizing profits and then passes this information to the market module. Conversely, the market module calculates adjustments in global agri-food trade and provides price feedback to the CAPRI supply models. This interconnectedness ensures a comprehensive evaluation of policy impacts on the agricultural sector.

The CAPRI database reconciles various data sources in a consistent manner, aiming to produce a complete database for the simulation exercise. The CAPRI database is composed of several parts, constructed in a sequence:

1. starting from the Complete and Consistent (COCO) database for the European countries,
2. the regionalised database for European NUTS-2 regions (CAPREG), which is the regionalised version of the COCO database and includes additional (regional level) domains from Eurostat, and data from the Farm Structure Surveys (FSS) and the Farm Accountancy Data Network (FADN),
3. the FAOSTAT global database for international agri-food markets, which serves as the key data source for the market module of CAPRI,
4. and additional databases, such as a database on EU agricultural policies, including financial subsidies under the EU Common Agricultural Policy (CAP), covering both direct payments and rural development support, and a database incorporating several domains from Eurostat in a consistent form (CAPRI-FAO database).

Pig breeding and pig fattening are two separate but interlinked activities in CAPRI. The pig breeding activity produces piglets for fattening, as well as meat from sows after their productive life cycle is over. The pig fattening activity uses piglets as production inputs and produces pork as the primary output. Both activities produce manure, depicted in CAPRI with its NPK-nutrient content, which is treated as a partly marketable intermediate product. In most regions, it has value for covering the nutrient needs of crops as a fertiliser source. Figure 1 depicts the relevant production inputs and outputs of the two pig activities.

Assigning herd size, process length, activity levels, yields, and other production-related data to the countries and sectors often requires significant re-aggregation from the slaughtering statistics. Furthermore, technical coefficients are also consolidated in the respective data consolidation models of the COCO database. These consolidation models aim to complete the often-incomplete time-series/input data

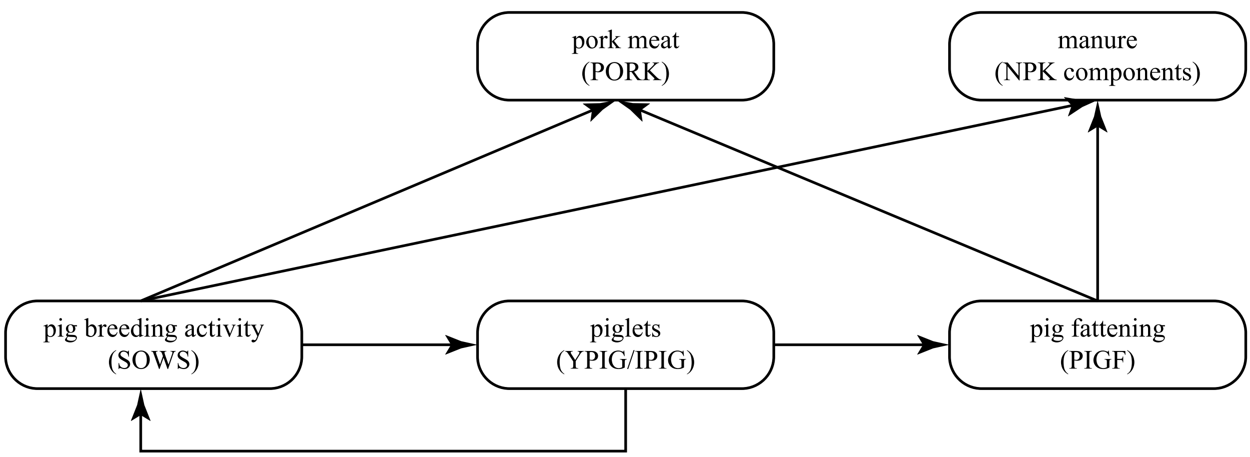

Figure 1: Input-output flows of pig activities in CAPRI.
Source: Own compilation

Table 1: InterPIG prior information in the CAPREG cost allocation model.

CAPRI cost item	InterPIG data
Feed cost (FEED), including own produced (fedg) and purchased feed (fedp)	Feed cost per sow/year (EUR)
Pharmaceutical inputs (IPHA)	Vet-Med & breeding cost per sow/year (EUR)
Maintenance and buildings related costs (REPM, REPB)	Building & equipment maintenance per sow place/year (EUR)
Electricity and heating costs (ELEC, EGAS)	Energy cost per sow/year (EUR)
Other costs (INPO)	Miscellaneous costs per sow/year (EUR)

Source: Own compilation

and ensure consistency between different data sources and the CAPRI structure.

Data from the InterPIG database for 2021 were collected to refine physical efficiency parameters and improve cost estimations for pig breeding[1]. The InterPIG dataset includes country averages from major pig-producing Member States and some Eastern Member States of the EU.

The standard CAPRI approach derives sow replacement rates from annual livestock inventories, assuming sows are first mated at 240 days old. For this study, country-specific replacement rates were obtained from the InterPIG database. These new rates directly impact input coefficients for pig breeding.

The adjusted physical efficiency parameters were incorporated into the COCO database generation part of CAPRI. The baseline process adopts these new values and adjusts the projected physical efficiency parameters for selected years as possible deadlines for full transition.

CAPRI uses FADN data to estimate input use and costs for production activities. The FADN database covers the EU with standardised questionnaires for farm accounts. However, production costs are not detailed at the agricultural activity level. Thus, input/cost allocation models were developed.

Input (or cost) allocation describes how aggregate input demand is distributed to production activities, with resulting activity-specific input coefficients measured in value (e.g., €/ha) or physical terms (e.g., kg/ha). For inputs other than nutrients and feed, FADN sample results were combined with current national input demand from the Economic Accounts for Agriculture (EAA) and standard gross margin estimations using the Highest Posterior Density (HPD) framework.

CAPRI's cost estimation follows a Bayesian approach, maximising the HPD estimator with prior information and structural constraints. The prior information includes: (1) FADN-based estimates at the activity level, (2) unit value statistics from EAA, and (3) standard gross margins from Eurostat. Input coefficients and costs were estimated for historical and base years in CAPREG. Base year estimates were then projected for agreed-upon simulation years, considering input-saving technological progress and macroeconomic inflation projections.

The cost estimation for pig breeding was extended with additional prior information from the InterPIG database for 2021, covering feed, veterinary costs, building and equipment maintenance expenses, energy, and miscellaneous costs (Table 1).

CAPRI baseline

To model alternative transition periods, the CAPRI baseline was simulated for 2025 and 2035 using the same calibrated model. The CAPRI baseline includes approved agricultural, environmental, and trade policies, including measures from the 2014-2020 CAP implemented at the EU Member State or regional level. The future development of agricultural markets was calibrated to the European Commission's medium-term outlook for agricultural markets and income (European Commission, 2020). This outlook provides commodity market projections within a consistent modelling framework, using external sources for assumptions on macroeconomic developments (GDP growth, exchange rates, crude oil prices, inflation, and population growth).

Himics *et al.* (2014) provide more details and a comprehensive discussion of the CAPRI calibration process. For 2035, beyond the time horizon of the EU Agricultural Outlook, we extrapolated and supplemented the European Commission's projections with additional information from other sources, such as projections from the GLOBIOM and PRIMES models, to arrive at the CAPRI reference scenario for 2035.

First, trend projections were prepared from the historical period up to 2035. The base year for the CAPRI version used in this study is 2017, a three-year average of 2016-2018. The CAPRI database included data up to 2019. After this ex-post period, projections for agricultural markets and agricultural production were established.

To validate the CAPRI baseline, key baseline results were compared to historical data/statistics and projections from other studies and modelling exercises. The validated baseline results include market developments in the sectors of interest, covering EU agricultural production and demand, prices, and international trade. Data sources for the comparison included Eurostat, FAOSTAT, national statistics on agricultural production and prices, and preliminary AGMEMOD baseline results from 2022.

[1] InterPIG EU Member States include Austria, Belgium, Czech, Denmark, Finland, France, Germany, Ireland, Hungary, Italy, Netherlands, and Spain. Of the non-InterPIG EU countries, for Poland data were provided by Edward Majewski and Agata Malak-Rawlikowska from the Warsaw University of Life Sciences, for Portugal and Greece the French InterPIG data, for Bulgaria, Croatia, Romania, and Slovakia the Hungarian InterPIG data, for Lithuania the Polish data were used. The sow herds in Cyprus, Latvia, Estonia, Slovenia, Luxembourg, and Malta are too small to be taken into consideration for any adjustments.

Scenario assumptions

The scenario exercise is a comparative static analysis that compares the simulated state of the economy with the policy change (i.e., the full implementation of the ban on the use of cages in EU livestock production as part of the revamped EU animal welfare legislation) to the baseline.

In the CAPRI simulations, switching to alternative housing systems in the pig sector includes the use of temporary crating or non-confinement in farrowing, or specialising in fattening. The pig sector simulations cover two different transition periods: (A) an immediate phase-out by 2025, and (B) a 10-year transition period until 2035.

- Scenario A (immediate transition, full EU policy impact): In this scenario, all farmers are assumed to transition by January 1, 2025.
- Scenario B (transition by 2035, full EU policy impact): In this scenario, farmers are assumed to refrain from further transitioning before the deadline. However, it is important to note that this assumption does not consider the future ban on conventional farrowing crates set by national legislation in Austria (by 2033) and Germany (by 2036). This is because the minimum recommendation for farrowing pen footprint by the European Food Safety Authority Panel on Animal Health and Welfare is 6.6 m² per sow, which is higher than the minimum set by national legislation in both Austria (5.5 m²) and Germany (6.5 m²). Additionally, in Germany, incentives to invest in modernising pig farms are assumed to be limited due to producing losses over the past 5 and even 10 years, on average, as indicated by InterPIG data.

Both scenarios use a 5% nominal social discount factor, as recommended by the Commission (European Commission, 2021b). The differences between livestock housing systems were grasped through technological parameters gathered from literature reviews and expert consultations. These parameters were then converted into changes in the input/output efficiency of the CAPRI production activities, except for Sweden, which already has compulsory free farrowing systems since 1993, and Finland, where comparable values were provided by the largest pork integrator in the country.

The following technical parameters were considered in setting up the scenarios:

1. sow replacement rate: +22.0% (capped to not exceed the corresponding value for Sweden from the 2021 InterPIG database)
2. litters per sow/year: -1.9%
3. pre-weaning mortality: +17.0% (capped to not exceed the corresponding value for Sweden from the 2021 InterPIG database).

Other technical parameters were included in the CAPRI analysis only through their impact on costs. For instance, changes in stocking density or the need for additional space were combined as investment cost assumptions, while labour intensity indicators influenced labour costs.

The transition to alternative housing systems also affects feed costs. Although direct feed cost estimations were available for the various systems, the approach used in CAPRI was to model changes in feeds by modifying related technical parameters. This was because CAPRI employs a cost-minimising modelling approach for feed, deriving feed costs from feed use/feed mix and the corresponding feed prices.

The feed-related technical parameters in CAPRI include those that define feeding efficiency and feed requirements for sows. When these feed efficiency-related parameters were adjusted due to the transition to alternative housing systems, feed costs were affected. Specifically, for sows kept in temporary and non-confinement stalls, an increase of 7.3% in kg of feed per sow per year was assumed, based on AHDB (2020).

The transition to alternative housing systems incurs additional costs, which can be categorised as follows: (1) the cost of investing in new buildings and equipment, (2) costs associated with decreasing physical efficiency, and (3) costs related to increasing labour intensity. The compliance cost estimations were derived from a systematic comparison between cage-free compliant and non-compliant housing systems. The comparison was based on economic and technological indicators collected from literature and experts.

The estimated changes in specific production cost elements for sows kept in temporary and non-confinement stalls are as follows:

1. Vet-Med and breeding cost per sow/year: +7.5%
2. energy cost per sow/year: +1.0%
3. building and equipment maintenance per sow/place: +63.9%
4. miscellaneous costs per sow/year: +1.0%
5. average cost of labour per sow: +22%.

An increase of 30% in the average cost of sow places with temporal and non-confinement was estimated at the country level. This estimation was based on expert consultations, extensive literature reviews, and InterPIG country-specific data. The significant cost increase is attributed to factors such as the need for increased space and circumference of individual pens, the creeping area, and the special equipment required for temporal confinement (AHDB, 2020; Baxter *et al.,* 2011; Seddon *et al.,* 2013).

The average cost of sow places with temporal and non-confinement reflects the average investment required for implementing alternative housing systems in both existing and new buildings.

A market premium for cage-free products is not considered in the analysis due to two main assumptions: (1) the price premium for cage-free products will erode as the entire sector transitions to alternative housing systems, (2) all consumers, including price-sensitive ones, will shift to consuming cage-free products, driven by the EU's demand for compliance of imported goods with EU animal welfare rules, which will result in conventional system products not being available on the EU market.

Despite the absence of a market premium, the CAPRI simulations do yield new producer and consumer equilibrium prices for the relevant products, which represent the average for pork from different alternative housing systems. In the partial equilibrium framework of CAPRI, the increase in consumer prices is triggered by the rise in average production costs. This is significant since the demand for food items in the EU is relatively inelastic. Consequently, compliance costs are largely passed on to consumers in our analysis by design.

Table 2 presents the assumed share of free farrowing sows in commercial pig farms across EU Member States. As official EU statistics are not available, estimates were provided by InterPIG experts. For non-InterPIG EU Member States, the estimates for the current share of free farrowing sows were derived from consultations and by considering similarities in the pig sector between countries.

Results and Discussion

In the following section, we present the simulated impacts on supply balances and prices, with a focus on the income effects, which serve as the main drivers of the optimisation philosophy behind CAPRI. Additionally, we will discuss the most significant environmental aspects from the global perspective.

The modelling exercise outcomes are reported as percentage differences, representing the net change induced by the new policy (ban on conventional farrowing crates) against the CAPRI baseline for specific simulation years (2025 and 2035).

Pork production in the EU is projected to decline markedly in both scenarios, with the rate inversely proportional to the time frame envisaged for implementing the new policy. Production plummets by 23.6% against the CAPRI baseline when farmers are required to transition immediately (Scenario A). However, extending the transition deadline by 10 years (Scenario B) significantly lessens this negative development to 8.4% (Table 3).

Depending on the length of the transition period, the decline in pork production triggers changes across the EU meat supply balances. The model predicts two major effects: (1) a decrease in domestic demand and (2) a weakening of the pork trade balance. The decrease in the domestic use of pork is primarily marked in the short-term horizon for the EU-27, with 8.8% in Scenario A (Table 3). Regarding trade, the EU is not a major importer of pork on the global market, sourcing less than 200 thousand tonnes of pork (live animals and processed products included) from third countries annually between 2019-2021 (Eurostat – Comext, not shown). Nevertheless, in Scenario A, pork imports surge almost eleven-fold in volume terms against the CAPRI baseline as production declines drastically, and net trade of the EU-27 crumbles by 93.5%. The dependence on imported pig meat appears considerably smaller when the transition deadline is shifted from 2025 to 2035, increasing in Scenario B to 92.7% (Table 3).

A comparison of pig farming across the EU macro-regions (EU-14 and EU-13) provides important insights into the scenario outcomes. Regardless of the length of the transition period, the new policy appears to have a lasting dividing effect on the economic performance of the EU-West (EU-14) and EU-East (EU-13) livestock sectors. Irrespective of the transition period's length, the percentage decline in pork supply is considerably higher in the EU-East compared to the

Table 2: Assumed share of commercial sow herds in temporal and non-confinement housing systems in EU Member States.

EU-14	Scenario A	Scenario B	EU-13	Scenario A	Scenario B
AT*	5%		BG	1%	
BE*	5%		CY	-	
DE*	1%		CZ*	5%	
DK*	5%		EE	5%	
EL	1%		HR	5%	
ES*	1%		HU*	1%	
FI*	40%		LT	5%	
FR*	4%		LV	5%	
IE*	1%		MT	-	
IT*	1%		PL	5%	
LU	-		RO	1%	
NL*	2%		SK	1%	
PT	1%		SI	5%	
SE*	100%				

Note: * = EU Member States of InterPIG.
Source: Own compilation

Table 3: Estimated changes in the EU pork balance against the CAPRI baseline in response to the ban on conventional farrowing crates.

	EU-27		EU-14		EU-13	
	Scenario		Scenario		Scenario	
	A	B	A	B	A	B
Supply	–23.6%	–8.4%	–21.2%	–7.9%	–37.2%	–11.4%
Domestic use	–8.8%	–2.0%	–7.2%	–1.5%	–13.5%	–2.0%
Imports	+1,086.4%	+92.7%	533.8%	75.3%	3,135.1%	131.3%
Exports	–87.1%	–39.3%	–86.8%	–38.7%	–96.1%	–56.4%
Net trade	–93.5%	–40.0%	–89.6%	–39.2%	–212.0%	–66.9%

Source: Own compilation

EU-West (Table 3, and for estimated changes at the Member State and NUTS-2 levels see Figure 2). The stronger resilience of the pig sector in the EU-West is highlighted by the changes in trade indicators. In fact, the decline in production is better offset by the drop in exports, making trade with third countries act as a buffer, absorbing most of the loss.

The average producer price of pork surges by 47.4% in the EU-27 against the CAPRI baseline in Scenario A (Table 4). When a 10-year long transition period is allowed (Scenario B), the rise in the producer price for pork becomes much smaller due to a more moderate shock caused by the ban on cages compared to Scenario A under the prevailing market conditions projected in the CAPRI baseline.

Increases in consumer prices are, in part, driven by the increases in production costs, resulting in a 15.3% hike for pork against the CAPRI baseline at the level of the EU-27 in Scenario A. Both producer and consumer prices for pork exhibit a larger increase in the EU-East (Table 4). This is due to the lag in transitioning to cage-free housing systems in the EU-13. It is important to note that in the CAPRI baseline, producer prices of pork remain at a higher level in the EU-West throughout the projection period.

Profits in the pig sector of the EU-27 shrink by a considerable 37.8% against the CAPRI baseline in Scenario A (Table 5), explaining the sizeable decline in pork production. Although the estimated impacts on profits in the pig sector erode over time, the 28.2% drop in Scenario B can still be considered relatively high.

Taking a closer look at the EU macro-regions, the profit loss in the pig sector is markedly higher in the EU-West (41.5%) than in the EU-East (21.6%) in Scenario A (Table 5). However, this position appears to reverse over time due to the improving relative competitiveness of the pig sector in the EU-West (Scenario B).

The ban on conventional farrowing crates in the EU pig sector would have significant repercussions on the production and consumption of agricultural products in non-EU countries. In terms of greenhouse gas (GHG) emissions, it becomes evident that non-EU pork production would experience a 4.2% increase in Global Warming Potential (GWP) against the CAPRI baseline (Table 6), amounting to 5.76 million metric tons of CO_2 equivalent. This increase is primarily driven by the declining exports of pork from the EU-27 and the rising demand for imported pork in Scenario A.

In contrast, within the EU-27, pork production sees a notable reduction in GHG emissions, with a 22.3% drop in GWP (equivalent to 7.94 million metric tons of CO_2 equivalent) when compared to the CAPRI baseline (Table 6). Consequently, at the global level, the overall GWP of the pig sector declines by 1.3%.

Table 4: Estimated changes in EU pork prices against the CAPRI baseline in response to the ban on conventional farrowing crates.

Prices	EU-27		EU-14		EU-13	
	Scenario		Scenario		Scenario	
	A	B	A	B	A	B
Producer	+47.4%	+11.0%	+45.6%	+10.7%	+57.6%	+12.9%
Consumer	+15.3%	+3.2%	+14.5%	+2.9%	+17.9%	+4.2%

Source: Own compilation

Table 5: Estimated changes in the profits of EU pork against the CAPRI baseline in response to the ban on conventional farrowing crates**.**

	EU-27		EU-14		EU-13	
	Scenario		Scenario		Scenario	
	A	B	A	B	A	B
Profits	–37.8%	–28.2%	–41.5%	–27.5%	–21.6%	–31.7%

Source: Own compilation

Table 6: Estimated changes in the GWP of the EU, non-EU, and global pork sector, measured in CO_2 equivalents (net emissions).

	EU-27		non-EU		World	
	Scenario		Scenario		Scenario	
	A	B	A	B	A	B
GWP	–22.3%	–7.9%	+4.2%	+1.7%	–1.3%	–0.2%

Source: own compilation

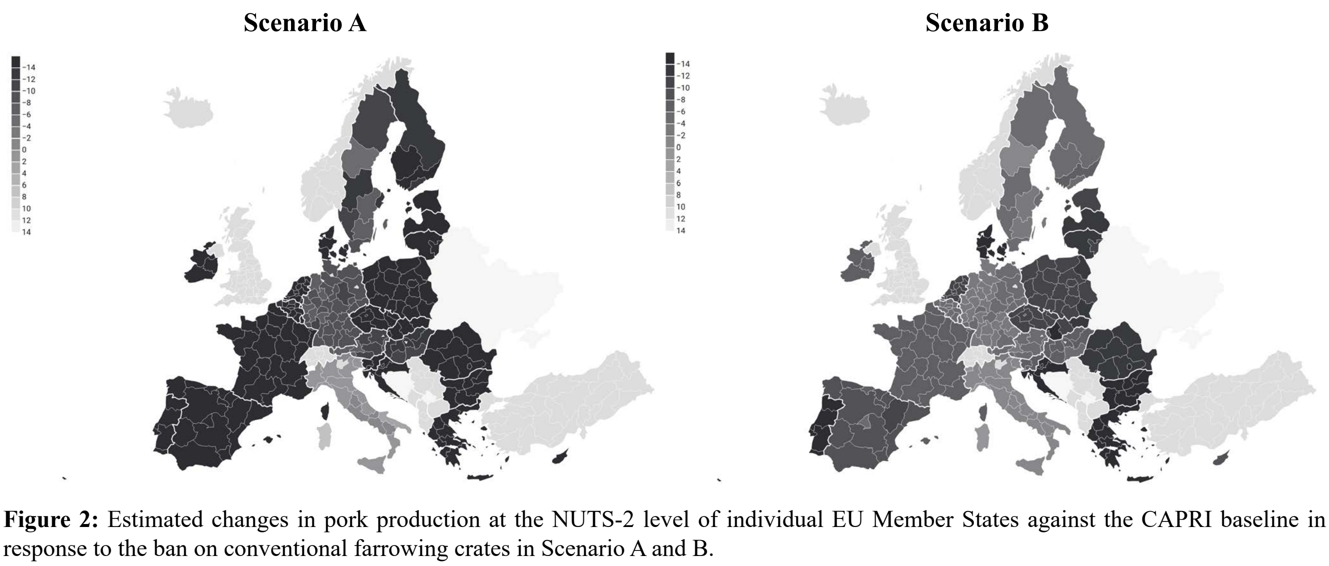

Figure 2: Estimated changes in pork production at the NUTS-2 level of individual EU Member States against the CAPRI baseline in response to the ban on conventional farrowing crates in Scenario A and B.

Note: NUTS2 regions with missing data are intentionally left empty, but recently reorganised region's data are interpolated. Note that for some countries with multiple NUTS2 regions CAPRI provides only country-level representation (i.e., DK, LT, SI, CR).

Source: Own compilation

Conclusions

Agricultural policy design in the European Union is becoming increasingly sophisticated, posing challenges for the modelling community to fully capture the complexities of upcoming legislation. It can be likened to an arms race, where only a few modelling tools can keep pace with the rapid output of the European Union's legislative measures, providing reliable *ex ante* quantitative assessments before enactment.

This paper focuses on one policy initiative linked to the animal welfare enhancing efforts within the broader context of the EU's Farm to Fork and Biodiversity Strategies. Using a comprehensive modelling approach, the impact of one specific sector (the pig sector) is evaluated in detail. Our simulation results suggest that implementing the ban on conventional farrowing crates would lead to reduced pork production in the EU, with trickle-down effects on the EU's trade balance. That decrease in pork production translates to profit losses for the European pig industry, which are only partly offset by higher consumer prices. We also find that these simulated impacts largely depend on the transition period. In Scenario B, where compliance is delayed by a decade, the adverse effects of transitioning are mitigated, by allowing ample time to fully depreciate fixed assets typical in the industry, resulting in less than a 10% drop in supply.

Like our results, a draft report from DG SANTE (European Commission, 2021a) also recommends a 10-year phase-in period for the ban, which could reduce the overall economic loss by providing sufficient time for the orderly market exit of the most vulnerable smallholders. Our results also underline that the ban on farrowing cages not only impacts domestic production and consumption in the EU but also global GHG emissions. The decrease in EU pork meat exports leads to an increase in GHG emissions elsewhere, as some non-EU countries increase their pork production and exports to take over market shares on global markets. Our findings thus highlight the multifaceted impacts of agricultural policies and their impact on global climate and environment. Policymakers should consider the potential ripple effects of agricultural and food policies (here an animal welfare enhancing ban on farrowing cages) and develop comprehensive strategies to deal with the trade-offs between domestic and foreign economic and environmental impacts.

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Consumer segmentation based on commitment to local products in Hungary

Local products and short supply chains play an important role in national economies, as well as in creating a sustainable economy and society. In our research, we examined Hungarian consumer attitudes using a model related to the consumption of local products. The model analyses the reasons for buying or not buying local products. To explore consumer attitudes, we launched a nationally representative consumer survey of 500 people. The data obtained were analysed by factor and cluster analysis, which led to well-separated consumer segments being identified. The main arguments in favour of buying local products were a sense of security (local character) stemming from the knowledge of a product's origin, a belief in their health properties, and support for local communities. We were able to identify three factors by factor analysis. These are External and Internal Product Features, Purchasing Benefits from Emotional Commitment, and Support for Local Producers and Local Merchants. Four clusters were identified along the factors: Emotional (36.5%), Local Patriots (15.0%), Passive (21.2%), and Conscious (27.3%). Each segment can be targeted with different marketing messages. The Conscious can be influenced with more rational messages, the Local Patriots and the Emotional with more emotional messages. The primary target group for local products is the Conscious, to whom the Local Patriots and the Emotional can be added. It is also possible to target the three groups through certain messages. However, Passives are difficult to address because their behaviour is characterised by a high degree of disinterest.

Keywords: local product, distribution, short supply chain (SSC), short food supply chain (SFSC), preferences, local sustainability

JEL classification: Q13

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Introduction

All around the world an appreciation of local products and short supply chains has been brought about by various factors (like increasing ethnocentrism, ethical behaviour, sustainability, local producer support, and the special circumstances of a pandemic situation). In some areas, this has been justified not only by the support provided for the local economy, but also by the cessation of international trade, which has resulted in the transformation and rethinking of food supply chains (Fei *et al.,* 2020; Hailu, 2020; Enthoven and Van den Broeck, 2021). On the consumer side, the issue of food safety has also emerged as a reason (Coluccia *et al.,* 2021; Pakravan-Charvadeh *et al.,* 2021; Kovács *et al.,* 2022). However, consumer patterns and cultural habits have been relatively rearranged since the Covid-19 pandemic, as attitudes towards local products now resemble what they were before, and perhaps have even become strengthened (Nagy-Pető *et al.,* 2023).

The economic and social impact of short supply chains is discussed in detail in the international literature. Although short supply chains do not have a uniformly accepted name and definition, perhaps the essence of the concept is best expressed by Renting *et al.* (2003): a short supply chain is a system in which market players are in direct contact with each other or are directly involved in food supply, production, processing, distribution, and consumption. It also follows that the short supply chain is also closely related to the concept of local products. In some research, these two concepts are considered synonymous, but this is not correct (Enthoven and Van den Broeck, 2021). Although the concept of a local product is also not subject to a strict definition, since it may vary according to regional, climatic or population characteristics, its main feature is the sale of the product in a short supply chain, i.e. minimising the distance between consumer and producer (Peters *et al.,* 2008; Granvik *et al.,* 2012). In most cases, consumers and retailers consider local products to be those made within narrower borders than the country border, such as the regional, or most often the county, border (Brian, 2012). In addition, local products and the short supply chain have become important buzzwords in international studies on sustainable food supply chains (Granvik *et al.,* 2012; Barska and Wojciechowsky-Solis, 2020; Enthoven and Van den Broeck, 2021).

In the case of short supply chains, proximity typically justifies the use of the term (Pearson *et al.,* 2011), which, however, can be interpreted from several perspectives. One is geographical, which is relative – especially for different consumers or different nations or cultures – so, for example, for a US citizen a local product may originate from within 40 km or from a particular state (Pirog and Rasmussen, 2008). Official legal regulations are more permissive for American products, and depending on the territory of the state, they can come from up to 644 km away, if they are made in the given state (Benedek and Balázs, 2014). According to Hungarian regulations, a product originating from somewhere not more than 40 km away or within a county border is allowed to keep the local name (with the exception of sales in Budapest, where any local product in Hungary can retain its local status) (Act 2005 / CLXIV and 4/2010 / VII. Decree 5 of Hungary; Benedek and Balázs, 2014). The other approach is the small social distance, i.e. the direct sales framework (Benedek and Balázs, 2014), in which the number of actors in the sales chain is low or there is no intermediary between the producer and the consumer (zero level channel). Small farm size, environmentally conscious production, and organic farming can be typical (even without certification, because consumers do not demand this due to the direct connection with the product). The third perspective is environmental proximity, which reduces the environmental burden of transportation and warehousing, thus making short supply chains more sustainable compared to traditional trade (Benedek and Balázs, 2014; De Fazio, 2016). Some forms of short supply chains in Hungary look back to old traditions, such as producers' markets or direct sales.

Many types of short supply chains exist and are constantly evolving along consumer needs, and they can be grouped according to three sales systems and perceptions. These are direct sales (zero-level channel), community marketing-based sales, and the extended supply chain (Renting *et al.,* 2003; Benedek and Balázs, 2014). These can be found all over the world, from personal sales, through hub systems, to trademark systems.

In most countries, local products have become increasingly popular over the past decade. This is also confirmed by individual country studies (Granvik *et al.,* 2012; Jensen *et al.,* 2019; Wunsch, 2020). According to international surveys by Wunsch (2019), the proportion of those who prefer local products is 79% in Romania, 71% in Sweden, 70% in Italy, and 69% in Hungary. Of the 11 countries surveyed, Britain and Belgium "bring up the rear", with both countries registering 51%. A Danish study identified two consumer groups that are strongly committed to buying local products, accounting for 38% of the sample studied (Jensen *et al.,* 2019).

Reasons for favouring local products include good quality (Megicks *et al.,* 2012) like freshness and taste (Penney and Prior, 2014; Skallerud and Wien, 2019), avoidance of food-borne disease, food safety, positive added value and the possibility of environmental protection (Megicks *et al.,* 2012). On the other hand, we can see ethics as a key driver (Megicks *et al.,* 2012) in the sense that consumers aim to support local producers, retailers, culture and economies (social responsibility) (Carrington *et al.,* 2010; Megicks *et al.,* 2012; Penney and Prior, 2014; Birch and Memery, 2020), therefore, it has a societal benefit as well (Birch *et al.,* 2018). Ethical shopping is based on conscious and planned decisions, where, in addition to individual interests, the interests and values of the public also play a decisive role (Megicks *et al.,* 2008; Birch *et al.,* 2018), which, in addition to local economy support, aid animal and human welfare or fair prices (Birch *et al.,* 2018; Dahlhausen *et al.,* 2018). The close relationship between ethical duty and self-identification is a key factor here, as a given ethical issue becomes part of the personality and can strongly influence purchasing decisions (Shaw *et al.,* 2000). This is all the more important because although ethical issues related to food have received a lot of attention in recent years, the experience is that a positive consumer attitude towards local products does not necessarily lead to actual conscious shopping, i.e. an attitude-behaviour gap is observed (Carrington *et al.,* 2010; Penney and Prior, 2014).

In addition, in several research studies a relationship was found between the preference for organic, fresh, and premium foods (Mirosa and Lawson, 2012; Hempel and Hamm, 2016), health awareness, conscious shopping in general, and local product preference (Mirosa and Lawson, 2012).

The consumer community which is most receptive to local products are young-middle-aged (30-40 years old), well-educated people with a good financial background (Mintel, 2008; De Schutter, 2017; Enthoven and Van den Broeck, 2021). However, for Henseleit *et al.,* (2007) in their German study, these demographic characteristics were not relevant; instead, in this context the influence of cognitive and normative factors was found to be stronger.

The willingness to pay a premium for local products varies by research and country. While in some studies a willingness to pay a premium appears (Shahbandeh, 2020), in other studies price is the most important deterrent (Henseleit *et al.,* 2007; Megicks *et al.,* 2012). Difficult availability and narrow product mix have been identified as additional barriers (Megicks *et al.,* 2012). In addition, there is the "one-stop-shop" phenomenon among urban consumers (Penney and Prior, 2014), since shopping at a supermarket is more convenient than visiting a range of outlets to find the local products (Penney and Prior, 2014).

Although many factors appear to be barriers to buying local products, it is worth emphasising that in addition to rational arguments for ethics and social responsibility, local product purchasing also has an emotional and entertainment aspect. The purchase itself, in addition to its basic function, carries these elements (non-functional outcomes) (Megicks *et al.,* 2012), so in addition to buying a local product in supermarkets, it is worth highlighting sourcing in producer markets, which are now becoming fashionable, with many benefits for consumers (Woodruffe-Burton and Wakenshaw, 2011), including the opportunity to form relationships with producers and farmers which can increase interpersonal engagement with stakeholders on the market (Penney and Prior, 2014). Even if the increase in the number of producer markets does not confirm this (Coppola, 2020; Engelmann, 2020), we can still refer to the popularity of this form of sales in the media (as recreation, fashion, awareness, status consumption). In Hungary, the operation of producer markets takes place in a strict, legally regulated form, which is justified by the fact that their number has increased significantly since 2012 and further growth is expected in the future.

Another trend in relation to local products and services is the importance of online evaluation (Kurnia *et al.,* 2018) before and after shopping. Feedback has a major impact on the perception of local businesses' products and services (Bright Ideas, 2020). Related to this is the demand for online local product purchases, which has been further strengthened by the epidemic (Balogh-Kardos and Gál, 2022). According to predictions, for example, consumers in Poland will do 40% (compared to the current 7%) of their food shopping online by 2026 (Barska and Wojciechowska-Solis, 2020). This is also confirmed by the survey by Nielsen (2019) conducted at an international level.

Based on this background, this paper examines Hungarian consumer attitudes using a model related to the consumption of local products analysing the reasons for buying or not buying them.

Methodology

Sampling method

Data collection was carried out in 2019 by means of personal interviews, with interviews conducted at the respondents' homes. The primary research was based on a national questionnaire-based survey representative of gender (Chi-square (χ^2) (1) = 1.477; probability value (p) = 0.224) and age group (χ^2(2) = 5.241; p = 0.263). In the sampling process, representativeness was also ensured for regions (χ^2(6) = 0,607; p = 0.996) and settlement types (χ^2(2) = 1,149; p = 0.563), so their structure perfectly matched the quota set in advance by the Hungarian National Statistical Office (quota sampling). In the assigned settlements, a random walking method was used to ensure total randomness in selection. The essence of the method is that each interviewer was given a randomly selected starting address in the given settlement. From the starting address, in ascending order by house number, the interviewers began the questioning at the third house on the same side of the street, and then, if they were done there, they continued at the next third house. During the compilation of the sampling plan, it was also ensured that the interviewers should not differentiate between questioning in a district with detached houses or in a district with blocks of flats. Among the residents of the household visited, the appropriate person for the interview was selected by using the so-called birthday key method. Hence, from among the residents of the households visited, those participants whose birthday was the closest to the date of the survey were selected for the interview. With this method, randomness was ensured only in each stratum. In Hungary the number of people in the age group examined is approximately 8 million (Hungarian Central Statistical Office, 2019a), and with a 95% confidence level and a 5% margin of error (on the basis of Gill and Johnson, 2010), the required sample size is 385 respondents. Consequently, the sample size (500 persons) was appropriate for reaching the research objectives. Table 1 shows the percentage distribution of the socio-demographic groups of the individuals involved in the survey and the population composition according to the previously mentioned four factors.

Table 1: Distribution of the sample according to the most important background variables (N=500) and population composition according to representative variables.

Label	Sample Distribution		Population Distribution[1]
	Count	%	%
Male	235	47.0	47.8
Female	265	53.0	52.2
16–29 years	96	19.2	18.3
30–39 years	83	16.6	16.0
40–49 years	93	18.5	19.6
50–59 years	73	14.7	15.1
60+ years	155	31.0	31.0
Budapest	90	18.0	17.9
Other town	275	55.0	52.6
Village	135	27.0	29.5
Western Transdanubia	51	10.2	10.1
Central Transdanubia	54	10.8	10.8
Southern Transdanubia	46	9.2	9.0
Northern Great Plain	74	14.8	14.8
Central Hungary	152	30.4	31.0
Northern Hungary	58	11.6	11.5
Southern Great Plain	65	13.0	12.8
Primary school	64	12.9	
Vocational school	154	30.7	
High school	202	40.5	
Higher education	80	15.9	
Can live on it very well and can also save	35	7.0	
Can live on it but can save little	175	35.0	
Just enough to live on but cannot save	241	48.2	
Sometimes cannot make ends meet	22	4.4	
Have regular financial problems	1	0.2	
Not known/No answer	26	5.2	

Source of data: Hungarian Central Statistical Office (2019a; 2019b)

Structure of the questionnaire

The questionnaire of the attitude survey we conducted was based on the work of Megicks *et al.* (2012). Megicks *et al.* (2012) developed a series of statements based on focus group research that were validated during a large-sample questionnaire survey and then formed into factors (Figure 1) and clusters.

In our questionnaire, we first asked who buys a local product (403 people, 80.6%) and who does not (97 people, 19.4%). Subsequently, we formulated two question blocks based on the validated statement series of Megicks *et al.* (2012) for local product buyers (18 statements) and non-local product buyers (11 statements). The statements were evaluated on a Likert scale of 1 to 5 in each case by the respondents, where 1 means 'do not agree at all', and 5 means 'strongly agree'. At the end of the questionnaire, the socio-demographic background variables were added: gender, age, education, subjective sense of income, type of settlement, and region.

Methods used

To attain the research objectives, multivariate statistical tools were primarily used. First, exploratory factor analysis (EFA) was performed on the model. Although Megicks *et al.* (2012) examined the inhibitors of purchasing local products as well, in this study only the reasons could be examined by factor analysis because of the low number of non-buyers in the sample. The aim of the EFA was to explore whether the pre-hypothesised factor structure appeared in our sample and whether we were able to measure the desired attitudes (factors that can be defined as latent variables). Then, we examined the reliability of the scales within the measurement model of the revealed latent variables using the Cronbach's alpha index and the composite reliability index plus omega. The reliability test was followed by a confirmatory factor analysis (CFA). The purpose of the CFA was to prove the convergent validity, i.e., whether our empirical model fits the assumed model. Discriminant validity was tested according to the Fornell–Larcker criterion. For further examination, data reduction by principal component analysis (PCA) was performed separately on the latent variables to obtain latent variables free of cross-loadings.

The segmentation was performed by cluster analysis, which consisted of two main steps: first, the number of clusters/segments was determined by hierarchical cluster analysis, and then the cluster analysis was carried out using the K-means method, in which the cluster means were determined by the applied program. Before the cluster analysis nearest neighbour method was used to detect any outliers. As a result, we concluded that we should not exclude any respondent from further examination. After this we applied hierarchical cluster analysis with Ward's method and squared Euclidean distance to determine the number of clusters. Several possible solutions were run with hierarchical cluster analysis, where the number of clusters were determined by the dendogram. This confirmed our prior estimation of the number of clusters (i.e. four). To find the best clusters (where the coefficient of variation is low) we developed another solution with K-means clustering, but in this case the number of clusters has already been set and the determination of cluster centres has been left to the algorithm. Finally, we accepted this solution. To validate the results of K-means clustering, i.e., whether the clusters are significantly different from each other, we analysed the clusters along each dimension (factor) by ANOVA. To further examine the clusters, cross-tabulation analysis and simple hypothesis tests were applied.

For CFA, v3.5.0. of R Statistics in the RStudio editor was used (The R Foundation, Vienna, Austria), and all additional tests were performed in v23.0. of IBM SPSS Statistics (Armonk, New York, USA).

Results

Reasons for buying local products

First, we will outline the basic statistical indicators of each statement. The reasons for choosing local products are illustrated in Table 2. According to the results, the three most supported reasons are origin identification, health, and support for local producers. While the mode is always 5 for the

Figure 1: Validated factors.
Source: Authors' own creation, based on Megicks *et al.* (2012)

first 11 statements (there is great agreement on these factors), the heterogeneity increases for the other statements. For the consumers surveyed, ethical behaviour is a less relevant factor when buying local food; however, respondents consider this statement rather to be true for themselves (Skewness: -0.365). This means that ethics is present in the ranks of factors that influence purchasing. At the same time, the feeling of nostalgia affects consumers' local product buying habits to an even lesser extent. Respondents identified least of all with the fun of local product shopping and the feeling of guilt. The mode in these cases was 1.

Reasons for not buying local products

Consistent with the research conducted by Megicks *et al.* (2012), we analysed the reasons for rejecting local products by non-customers (97 people, 19.4%) (Table 3). The main reasons for rejection are perceived extra time and energy, excessive travel, difficult availability, and the inconvenience of shopping. Among the reasons for not buying, the high price level was only ranked sixth. Less relevant rejection criteria than those listed are incomplete promotion of local products, deficiencies in labelling, scarcity of product range, and deficiencies in pricing. The mode is in all cases 1, i.e. the refusal to buy local products can in most cases be caused not by particular factors but by basic aversion or disinterest.

Factor analysis

In the next step, an EFA was performed on attitude statements of reasons for buying local products. In doing so, some statements appeared in several factors, so they were removed from the analysis. These were items of knowledge of origin, naturalness, and reduction of transport distance.

Factor analysis was used to distinguish three reliable (KMO MSA = 0.89; Bartlett: Sig: $p < 0.001$; Cronbach's Alpha = 0.876) and well-defined dimensions (Table 4). In the case of the first factor, the product characteristics include not only the content properties, but also the external properties and environmental friendliness. In the case of the second

Table 2: Reasons for buying local products (N=403).

Attitude statements	Statistical indicator				
	Mean	Median	Mode	Std. Deviation	Skewness
I buy local produce because I know where it comes from.	4.55	5.00	5	0.724	-1.871
I buy local produce because it is wholesome.	4.22	5.00	5	1.023	-1.634
I buy local produce because it supports local producers.	4.20	4.00	5	0.968	-1.273
I buy local produce because I can buy the amount I want.	4.18	5.00	5	1.080	-1.451
I buy local produce because the shopping experience is satisfying.	4.16	4.00	5	1.051	-1.430
I buy local produce because it is natural.	4.16	4.00	5	1.075	-1.562
I buy local produce because it is free from preservatives.	4.12	5.00	5	1.187	-1.502
I buy local produce because it reduces food miles.	4.07	4.00	5	1.118	-1.246
I buy local produce because it supports local retailers.	4.06	4.00	5	1.081	-1.149
I buy local produce because it has a good appearance.	3.82	4.00	5	1.205	-0.938
I buy local produce because it is free from chemicals	3.76	4.00	5	1.256	-0.959
I buy local produce because it is environmentally friendly.	3.76	4.00	4	1.232	-1.094
I buy local produce because it lasts longer.	3.68	4.00	5	1.268	-0.800
I buy local produce because it is ethical.	3.30	3.00	3	1.337	-0.365
I buy local produce because shopping for it brings back memories of the past.	3.30	3.00	4	1.388	-0.385
I buy local produce because it is nostalgic.	3.05	3.00	3	1.410	-0.157
I buy local produce because shopping for it is fun.	2.78	3.00	1	1.460	0.141
I buy local produce because I feel guilty if I do not.	2.24	2.00	1	1.446	0.748

Source: Authors' own composition

Table 3: Reasons for not buying local products among those who reject them (N=97).

Attitude statements	Statistical indicator				
	Mean	Median	Mode	Std. Deviation	Skewness
I don't buy local produce because to do so is time consuming.	2.75	3.00	1	1.792	0.047
I don't buy local produce because it requires extra effort.	2.64	2.00	1	1.809	0.134
I don't buy local produce because I have to travel farther to do so.	2.62	3.00	1	1.704	0.107
I don't buy local produce because it is not readily available.	2.60	3.00	1	1.766	0.119
I don't buy local produce because it is inconvenient.	2.54	2.00	1	1.714	0.199
I don't buy local produce because it is expensive.	2.50	3.00	1	1.725	0.196
I don't buy local produce because it is not well promoted.	2.43	2.00	1	1.753	0.361
I don't buy local produce because food produced elsewhere is sometimes better.	2.13	2.00	1	1.481	0.645
I don't buy local produce because it is not well labelled.	2.12	1.00	1	1.587	0.705
I don't buy local produce because the range of products is limited.	2.10	2.00	1	1.487	0.620
I don't buy local produce because the price is not always clear.	2.07	1.00	1	1.602	0.771

Source: Authors' own composition

factor, it is primarily traditional character and nostalgia which appear, coupled with ethics and the entertaining nature of shopping, thus showing emotional commitment. The third factor is clearly aimed at strengthening local interests and the local economy, i.e. supporting local producers and local traders is the main motivation.

Examination of the Applicability of the Model

In the suitability studies of the model, we set up three criteria: reliability, fit, and difference validity (Hair *et al.,* 2010). All three eligibility criteria were tested for the items and latent variables provided by the EFA.

The reliability of the variables included in the study was assessed using three indicators: Cronbach's alpha, McDonald's omega (calculated by maximum likelihood method), and the composite reliability index (Hair *et al.,* 2010). A common feature of all the indicators used is that the acceptance range is above 0.6 and the examined items are considered reliable above 0.8 (Table 5).

Then, CFA analysis can be used to test whether our model fits the presupposed structure (Brown, 2006; Harrington, 2009). In the present case, the *a priori* structure was given by the literature and the results of the EFA. According to the results of the CFA, it can be stated that our model, with the 14 measurement variables, is suitable for further studies in terms of its factor structure. In the analysis, the only concession we made was that we allowed covariance between the measurement variables belonging to the given latent variable in the model. The results of the CFA are summarised in Table 6, including the acceptance range for each indicator.

The difference validity test was performed according to the Fornell–Larcker criterion. According to this, the correlation coefficient between the latent variables of the model

Table 4: Results of exploratory factor analysis.

Attitude statements	Factors		
	External and internal product features	**Purchasing benefits from emotional commitment**	**Support for local producers, local traders**
I buy local produce because it is free from preservatives.	0.760		
I buy local produce because it is free from chemicals.	0.718		
I buy local produce because it is wholesome.	0.686		
I buy local produce because it is environmentally friendly.	0.639		
I buy local produce because it has a good appearance.	0.567		
I buy local produce because it lasts longer.	0.557		
I buy local produce because I can buy the amount I want.	0.514		
I buy local produce because it is nostalgic.		0.867	
I buy local produce because shopping for it brings back memories of the past.		0.819	
I buy local produce because shopping for it is fun.		0.777	
I buy local produce because I feel guilty if I do not.		0.659	
I buy local produce because it is ethical.		0.554	
I buy local produce because it supports local retailers.			0.915
I buy local produce because it supports local producers.			0.817
Variance explained (%)	**38.668**	**15.346**	**11.369**
Cronbach's coefficient alpha	**0.846**	**0.875**	**0.887**

Notes: Extraction Method: Maximum Likelihood. Rotation Method: Varimax with Kaiser Normalization. KMO MSA=0.890, Total variance explained=65.383%.
Source: Authors' own composition

Table 5: Reliability indicators of the scales used.

Latent Variable / Reliability Index	Cronbach's alpha	McDonald's omega	Composite Reliability (CR)
External and internal product features	0.838	0.848	0.827
Purchase benefits from emotional commitment	0.876	0.874	0.858
Support for local producers, local traders	0.889	-[1]	0.858

Note: [1] Cannot be calculated due to the low number of items.
Source: Authors' own composition

Table 6: Summary of the results of the CFA.

Indicator	Acceptance range	Empirical results
CMIN/df	between [2;3]	2.440
CFI	>0.9	0.952
GFI	>0.9	0.935
AGFI	>0.9	0.883
RMSEA	<0.07	0.069
SRMR	<0.08	0.055
NFI	>0.9	0.935
NNFI (TLI)	>0.9	0.925

Source: Authors' own composition based on Hooper *et al.* (2008)

must be less than the square root of the AVE index of the given latent variable (reversing the criterion: the coefficient of determination between the latent variables of the model must be greater than the AVE index of the given latent variable) (Fornell and Larcker, 1981). Table 7 shows the latent variables of the studied model; for the sake of illustration, the names of the latent variables are indicated by letters (A, B and C) in the columns. The second column of the table contains the AVE index of the latent variables, while the third, fourth, and fifth columns contain the correlation coefficients between the latent variables, with the exception that the diagonal contains the square root of the AVE index of each latent variable. Based on the table and the tests, the difference validity can be determined, and the model is suitable for further tests based on the Fornell–Larcker criterion.

Market segmentation

To create market segments we applied cluster analysis, which resulted in four distinct clusters. Then, we analysed the clusters along each dimension (factor) by ANOVA (Figure 2). The values illustrate the distance from the mean for each factor by cluster. The significance level was $p < 0.001$ in all cases.

The first of these factors, the importance of product characteristics, appears in all segments except the second cluster, but is most marked in the fourth group. Emotional engagement is paramount only for the first group, while support for local producers and traders is essential for the first, second, and fourth clusters. The first cluster is the group that most professes ethnocentric values. Compared to the average, the perceived ingredients and the eco-friendly nature of the product are more important to them, but nostalgia and emotional influence are also important (Emotional). In the second segment, support for the local economy is dominant, the cluster is less identified with the other values, and, indeed, this group is more likely than average to reject these values (Local Patriots). The third group appears to be the most passive; they do not have a significant, above-average positive commitment to any factor (Passive). Members of the fourth cluster primarily make their purchases because of the positive qualities of local food and to support the local community. This group is closest to health-conscious and sustainable thinking (Conscious).

After studying the dimensions, each cluster was also examined along the background variables and a significant relationship was found with four demographic and one psychographic variables (Table 8).

The first cluster accounts for 36.48% of the sample. They are mostly characterized by a middle-income situation, live in the Northern and Southern Great Plain regions, and include one third of the pensioners. This also explains their sensitivity to nostalgia for local products. Those in the second cluster for the most part consider their income to be good, while most economically inactive people belong to this group (primarily expectant mothers). The segment has the highest proportion of those who are mostly uninterested in local products. Of the four clusters, this is the smallest segment (14.96%). The members of the third cluster (21.26%) typically live in Central Hungary and Transdanubia and mainly

Table 7: Examination of the difference validity.

Factors	AVE	A	B	C
External and internal product characteristics (A)	0.409	**0.640**		
Purchase Benefits from Emotional Commitment (B)	0.553	0.364	**0.744**	
Support for local producers, local traders (C)	0.752	0.404	0.331	**0.867**

Source: Authors' own composition

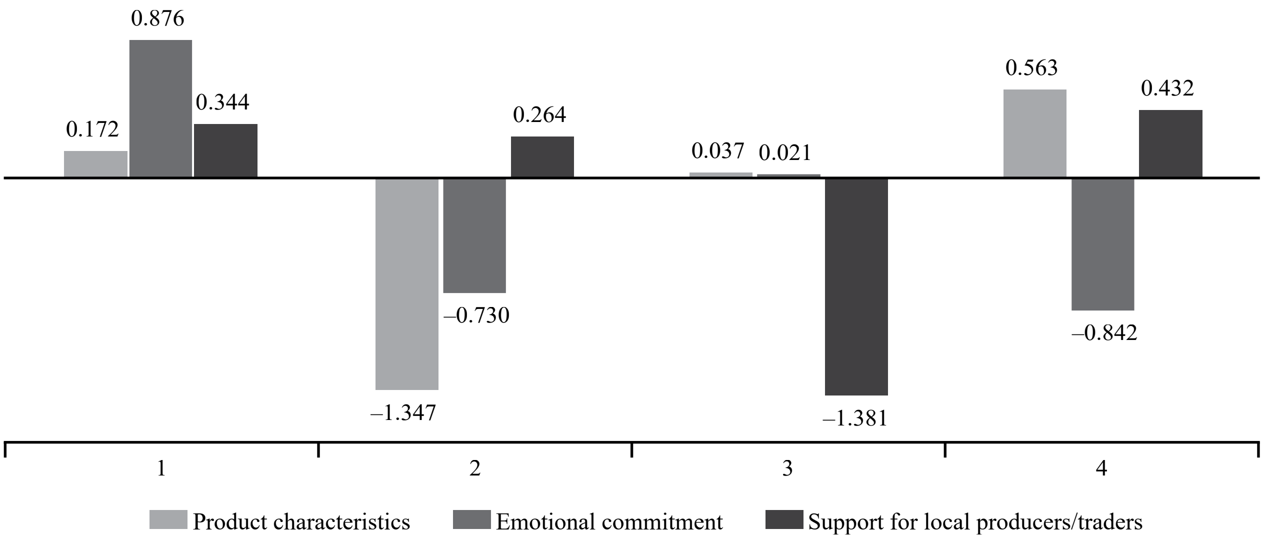

Figure 2: Presentation of each cluster based on differences according to factors.

Notes: Method: ANOVA, Sig: p<0.001.
Source: Authors' own composition

Table 8: Presentation of clusters alongside background variables (%).

Demographic background variables 1		Cluster Proportions				Total	Sig. (p)
		2	3	4			
Proportion of clusters in the sample		36.48	14.96	21.26	27.30	100	
Regions	Central Hungary	26.6	38.6	**39.5**	23.1	30.2	<0.001
	Central Transdanubia	8.6	7.0	**22.2**	9.6	11.5	
	Western Transdanubia	7.2	14.0	*1.2*	**14.4**	8.9	
	Southern Transdanubia	5.0	17.5	4.9	**15.4**	9.7	
	Northern Hungary	*7.9*	*3.5*	19.8	**21.2**	13.4	
	Northern Great Plain	**20.9**	14.0	*4.9*	12.5	14.2	
	Southern Great Plain	**23.7**	5.3	7.4	*3.8*	12.1	
Type of settlement	capital	15.1	22.8	18.5	14.4	16.8	0.004
	metropolitan county	28.1	22.8	22.2	*15.4*	22.6	
	City	30.9	36.8	42.0	26.9	33.1	
	village, small settlement	25.9	17.5	*17.3*	**43.3**	27.6	
Subjective income	He/she/they make(s) a very good living and can put some aside	7.5	9.3	5.2	10.9	8.2	0.005
	He/she/they make(s) a living but can only put a little aside	30.1	46.3	31.2	41.6	35.9	
	He/she/they make(s) just about enough to live on and cannot put anything aside	**60.2**	*35.2*	**62.3**	*39.6*	51.2	
	Sometimes there is not enough to live on	2.3	9.3	1.3%	7.9	4.7	
Current legal status, main occupation	active physical worker	38.8	33.3	39.5	39.4	38.3	0.026
	active mental worker	23.0	29.8	35.8	29.8	28.6	
	on maternity leave, otherwise inactive	2.2	**12.3**	2.5	9.6	5.8	
	pensioner	**30.2**	19.3	18.5	20.2	23.4	
	student	5.8	5.3	3.7	1.0	3.9	
Psychographic variable							
Commitment to buying Hungarian food	Mostly not committed	6.6	**21.1**	6.3	8.7	9.3	0.013
	Committed, but also not committed	26.3	22.8%	34.2	20.2	25.7	
	Mostly committed	52.6	43.9%	46.8	46.2	48.3	
	Very committed	14.6	12.3%	12.7	**25.0**	16.7	

Notes: In bold: adjusted residual > 2.00, italics: adjusted residual < -2.00.
Source: Authors' own composition

in towns; they are characterized by a better-than-average financial situation. Those in the fourth cluster make up just over a quarter of the sample (27.3%). Typically, the inhabitants of villages are over-represented as are those living in Western and Southern Transdanubia and Northern Hungary. They are the most committed to buying local produce, with nearly three-quarters belonging to this circle.

Discussion

According to our results, the three most supported reasons for choosing local products are origin identification, health, and support for local producers, which are in line with previously reported research results (Carrington *et al.,* 2010; Megicks *et al.,* 2012; Mirosa and Lawson, 2012). Among consumer expectations, when considering consumer decision-making regarding local products it is important to highlight the following keywords: quality, safety, trust, and ethics, and (local) sustainability (Megicks *et al.,* 2012; Giampietri *et al.,* 2018). The segments most committed to local products, both in terms of awareness and the purchase of local products, are middle-aged, well-off people.

We found some similarities with the results of Megicks *et al.* (2012), although there are also differences due to different survey dates and cultural differences. The segregation of factors shows similarities with Megicks *et al.* (2012), but the statements were arranged side by side differently. They were able to create a separate factor in their research along with the following ethical values: being environmentally friendly, supportive of the local community, social justice, and human and animal rights. In our study, however, intrinsic quality and ethical sustainability are not separated, i.e. in the case of the Hungarian population they are more closely related than in the survey conducted in the United Kingdom. Moreover, in contrast to the results of Megicks *et al.* (2012), for the consumers surveyed in Hungary, ethical behaviour was found to be a less relevant – although positive – factor when buying local food. These findings are not surprising, since ethical consumption studies show serious cultural differences between countries, i.e. various values and beliefs are prevalent, and different nations focus on different aspects in their consumer decisions (Kushwah *et al.,* 2019). As a result of the inseparability of intrinsic quality and ethical sustainability values in our study, it was necessary to name a new dimension, so the clusters based on the identified factors also show a different picture. Overall, however, the basic dimensions differentiate segments well along their attitudes toward local products. The emergence of both rational and emotional arguments and their usefulness as a basis for segmentation confirmed another similarity to be found between Megicks *et al.* (2012) and our research. A further difference between the two studies, however, is that we were unable to create factors along the grounds of non-choice. Nonetheless, we still obtained useful information, as the survey of non-customers of the local product revealed that most of them did not reject these products because of a single barrier which was known from the literature, such as price or availability (Henseleit *et al.,* 2007; Megicks *et al.,* 2012; Shahbandeh, 2020), but in a more complex way, with several factors together being responsible for the disinterest.

Conclusions

Based on our research results, it can be stated that the most decisive argument in favour of buying local products is the sense of security (local character) arising from the knowledge of origin, the belief in their health-protecting properties, and the support of the local community. After a thorough examination of the clusters formed, a group of emotionally committed individuals was identified, most of whom were members of the older age group. They were accompanied by supporters of the local economy and passive consumers, among whom there is no unambiguous commitment. The Conscious consider the role of both external and internal (perceived or real) characteristics of local products to be equally important, as well as the support the purchase provides for the local economy. Based on the above, it can be concluded that there are also two groups that can be effectively addressed with appropriate (emotional or rational) messages, and who can be potential consumers of local products. The proportion of the two groups makes up nearly half of the sample. However, it is also worth bearing in mind that the interest varies from region to region due to the different cultural customs of different geographical areas.

Trademarks and certifications can also help make local products more popular but creating them alone is not enough. Building trust and increasing sensitivity to local products requires adequate quality assurance, food safety, better quality, and today, certified environmentally friendly production, as well as compliance with animal welfare standards. These contribute most to the creation of a positive image, trust, and a well-communicable presentation (Szakály *et al.,* 2010). For non-buyers of local products, it is not the expenditure of time or energy, or possibly the scarcity of supply, that plays the main role in the rejection, but the high degree of disinterest in local products.

Recognising the attractiveness and perceived or real positive qualities and values of local products along consumer attitudes can help to shape the appropriate market strategy of state decision-making, community agricultural marketing organisations, and entrepreneurs.

As to the limitations, the survey was conducted in 2019, but many changes have taken place in consumer behaviour since then. Consumer behaviour was affected by the Covid-19 epidemic and has also been impacted significantly by the current war situation in our neighbour Ukraine, which led to an increase in prices. Interest in short supply chains has in any case increased, which has also affected the frequency and quantity of purchases of Hungarian products.

Abbreviations

AGFI Adjusted Goodness of Fit Index
AVE Average Variance Extracted
CMIN/DF minimum discrepancy, divided by its degrees of freedom
CFA Confirmatory Factor Analysis
CFI Comparative Fit Index
EFA Exploratory Factor Analysis
GFI Goodness of Fit Index
NFI Normed Fit Index
NNFI Non-Normed Fit Index
PCA Principal Component Analysis
RMSEA Root Mean Square Error of Approximation
SRMR Standardised Root Mean Square Residual
TLI Tucker–Lewis Index

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Anna FREUND*

Effects of digitalisation on food safety

This paper reviews food safety within the agri-food supply chain (AFSC) literature and presents a comprehensive framework for understanding how digitalisation has reshaped food safety practices within the AFSC. Its significant contribution lies in its identification of novel research streams in food safety that are underpinned by digitalisation techniques, a focus that can be expected to benefit both academic researchers and practitioners who are seeking solutions to pressing challenges related to the efficient achievement of food safety goals. In this paper, the powerful bibliometric analysis capabilities of Biblioshiny and VosViewer were utilised to conduct a comprehensive review of the relevant literature. Biblioshiny's strengths in data visualisation and network analysis were instrumental in identifying key trends and patterns in the research, while VosViewer's ability to create insightful maps of collaboration networks provided valuable insights into the relationships between researchers and institutions. The evolution of the published reviews from the past 10 years and the trending AFSC articles were thus revealed. The used databases were Web of Science and SCOPUS. Based on bibliometric coupling, the identified seven underlying research streams are (a) traceability challenges in AFSC, (b) quality management in AFSC, (c) Agri-food 4.0, (d) future trends of AFSC, (e) impact of the Blockchain, (f) smart packaging, and (g) circular economy. Results show that besides contributing to the efficiency and profitability of companies, digital developments also help to promote sustainable practices and mitigate environmental impacts, while ensuring traceability, proactive risk management and incident prevention.

Keywords: agri-food supply chain, food safety, digitalisation, bibliometric review

JEL classification: Q13

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Introduction

In November 2022, the world's population reached 8 billion people. Research highlights that this figure – albeit at a slowing pace – continues to grow and the current expectation is that the global population will exceed 8.5 billion in 2030 and 9.7 billion people by 2050 (UN Statistics, 2023). In this context, the issue of world food supply represents an ongoing challenge and it must be a unified goal for agri-food supply chain members to work on serving the increasing demand efficiently. This paper aims to provide a comprehensive review and identify recent research streams in the field of food safety, including the connection of food safety and digital solutions.

The paper examines the manifestations of Industry 4.0 and digitalisation in a sector that is not typically considered high-tech when viewed as a whole. Although automation has been present in many sub-sectors of the food industry for many decades, the changes being wrought by the Fourth Industrial Revolution tend most often to be studied by researchers and professionals whose interests lie in the automotive and electronics industries (Demeter and Losonci, 2020; Szász *et al.,* 2020). This paper points out that Industry 4.0 is also present in the food industry and offers a number of opportunities in two areas that are the particular focus of this sector: traceability and food safety (Luo *et al.*, 2018). In addition, the automation of manufacturing processes, intern, and extern logistics and even finances can be supported by Industry 4.0 solutions, which can be indirectly connected to traceability and food safety (Beltrami *et al.,* 2021). The goal of this paper is to uncover the existence of distinct research streams in connection with the triad of "industry 4.0" – "agri-food supply chain" – "food safety" solutions. This paper makes an original contribution to the literature by describing the emerging topics from a holistic perspective regarding their positive and risky effects for the AFSC members. The two research questions are as follows: (1) What are the emerging topics of AFSCM regarding food safety?; and (2) How has the topic of food safety in AFSCM worldwide evolved during the last 10 years?

There are literature reviews (Barbosa, 2021; da Silveira *et al.*, 2021) dealing with the topics above, but this paper aims to complement them in two important ways. On the one hand, the focus has been widened from the previously examined food supply chain to the agri-food supply chain because the author assumes this term is the most comprehensive research scope possible. The term "food" sometimes does not cover the total agri-food supply chain, because agriculture and similarly zootechnics, forestry and fishing are considered as primary activities (Manzini and Accorsi, 2013). On the other hand, this paper seeks to uncover the links between distinct technological concepts and offers a comprehensive framework for both academics and practitioners.

The results of the paper provide an overview of both the positive and the risk-signifying effects of the technologies highlighted here. The paper initially introduces a brief review of the theoretical background. Next, it introduces the review methodology used to analyse the literature. Outputs from the analysis based on software-generated data then follow, after which the results are presented and a discussion of the findings closes the review. The last section concludes.

Theoretical background

This paper aims to analyse the effects of digitalisation from the perspective of food safety solutions within the agri-food supply chain (AFSC). The AFSC sector remains a priority even now; it plays a major role in supplying food. In the previous decades, research in the food sector has tended to focus more on manufacturing and services, while the agricultural sector has been less prominent (Ganeshkumar *et al.,* 2017). Food safety contributes significantly to the resilience of AFSC. Suppliers may require information about the origin and quality of the products (to validate their originality and quality and to be financially accountable in the trading processes) and consumers receive trustworthy information thereby (Xiang, 2015). Food safety can be defined as an approach controlled and regulated by official authorities. The tools used to ensure these two functions can be nationally and internationally valid laws, but mostly international standards such as GHP (Good Hygiene Practices), GMP (Good Manufacturing Practices), ISO9001, ISO22000, or the HACCP (Hazard Analysis and Critical Control Point) system (Gomes-Neves *et al.,* 2007, Wu *et al.,* 2010, Xiang, 2015, Kittipanya-ngam and Tan, 2020). Food safety includes aspects such as preventing food fraud, foodborne outbreaks, and traceability processes to ensure quality assurance compliance (Ehuwa *et al.,* 2021). Recent studies have found that digitalisation can contribute to ensure food safety in various ways: digital solutions or complex management solutions, such as applications for farm management, can decrease risks, increase transparency, and avoid food waste (Jagtap and Rahimifard, 2019, Prause *et al.,* 2020, Barbosa, 2021).

The term traceability can be interpreted as a trade link between stakeholders of various agri-food supply chains (Dabbene *et al.,* 2014) and is a highlighted part of food safety which can be supported by digitalisation. Key stakeholders of the AFSC, like representatives of governments, corporations, and customers must be involved in implementing traceability to ensure its effectiveness (Qian *et al.,* 2020). Traceability as a trade link is not only a commercial link between partners, but also a financial commitment in form of a technological investment. This paper aims to complement the previous research with a special focus on the effects of digitalisation on food safety within the AFSC.

Methodology

The aim of this work is to provide an insight for agri-food supply chain researchers and professionals from the focal industry into the digitalisation-based support for food safety over the last 11 years (2011-2023). Another aim of this paper is to reveal a summary of the topic along the existing literature through identifying key themes building on previous practices (Apriliyanti and Alon, 2017; Maditati *et al.*, 2018). The aim of author was to find out which are the most researched areas in relation to food safety that have come to the fore in recent years, including the question which new research trends are emerging. The interpretation of the methodology of bibliometrics is that both statistical analysis as a part of quantitative research methodology and in-depth interpretation as a way of qualitative analysis may appear in literature review (Maditati *et al.*, 2018). Bibliometric literature review builds on statistical statements regarding the relationships and performance of scholars. It may lead to a better prepared searching process, while looking for the most impactful publications. Figure 1 illustrates the research methodology adopted in this paper.

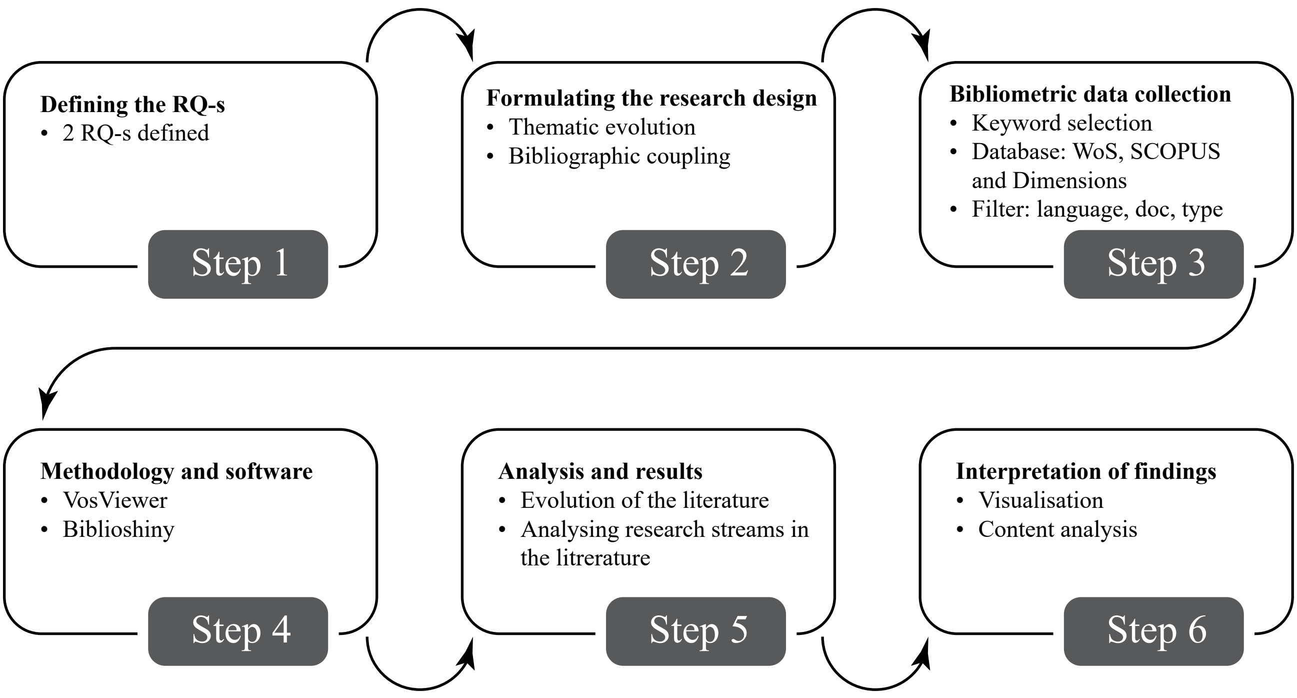

Figure 1: Steps of the methodology.
Source: Own composition

Table 1: Keyword search used on SCOPUS and WoS databases.

Keyword search	Number of articles (SCOPUS)	Number of articles (WoS)
Before filtering: (“agr* food supply chain” OR “food supply chain”) AND („food safety” OR trac*) AND “digi*” OR “*4.0” OR „blockchain” OR „big data” OR „internet of things” OR „robot*” OR „machine learning” OR „sensor” OR „cloud” OR „network”)	9,958	755
After filtering: TITLE-ABS-KEY ((„agr* food supply chain” OR „food supply chain”) AND („food safety” OR „trac*”) AND („digi*” OR „*4.0” OR „blockchain” OR „big data” OR „internet of things” OR „robot*” OR „machine learning” OR „sensor” OR „cloud” OR „network”)) AND LIMIT-TO (DOCTYPE , „re”)) AND (LIMIT-TO (LANGUAGE , „English”))	1,339	110

Source: Own composition

According to experts (Apriliyanti and Alon, 2017; Aria and Cuccurullo, 2017), thematic evolution can provide an answer for RQ-1 as it shows how the examined research topic changes over a period of time. Bibliographic coupling (BC) is a useful analysis tool to check how scholars are related to each other (Jose and Shanmugam, 2020). Bibliographic coupling “uses the number of references shared by two documents as a measure of the similarity between them” (Aria and Cuccurullo, 2017, p. 434). The author chose BC because of the intense development of technologies which may have an impact on AFSC. BC creates clusters from recent publications which cite previous ones. BC also allows to observe in which direction the field is evolving, as well as the emerging topics (Aria and Cuccurullo, 2017).

As Table 1 shows, SCOPUS listed more papers. All variations of keyword search were run on both websites and the table only contains the end searching combination. While managing the search engines based on the previously read literature topics, it turned out to be important that entering the keyword “blockchain” emerged the number of articles within the search. It may appear that the importance of blockchain will be shown within the scope of this paper. As similarly important keywords “internet of things” and “sensor” can be listed.

The following step was the examination of the titles and keywords of the articles. Researchers need to read all the abstracts to check whether the found results are relevant for the research. Reading the papers led to complementing the existing keyword list with new ones in addition. New keywords/topics appeared in the listed publications. The term “RFID” and “digital twin” appeared as new ones in contrast to the keywords from the original search. Bouzembrak *et al.* (2019) highlights RFID (radio frequency identification) as a facilitator in food traceability and product authenticity measures helping IoT (Internet of Things) systems enabling communication with other machines or humans and computing resources. The publication of Bhandal *et al.* (2022, p182.) presents the term of “digital twin” together with the term “cyber physical system” as “the most recent instalment of Industry 4.0 technologies that promises to further exacerbate the ongoing trend”. These terms completed the preconception of the author. Since none of the places showed direct reference to the combination “agri-food supply chain & food safety & digitalisation”, the publication was excluded from the database. Bibliometric research requires that the analysed papers are literature reviews. Other than this, a language limitation to English was applied. These two steps reduced the database (see in Table 1).

The observed dataset contained data from two important databases. Web of Science (WoS) and SCOPUS served as searching engines for this bibliometric literature review. The listed papers were manually checked in regard to the question, whether the scope is fulfilling the requirements. The author filtered out the biological papers because nanotechnology is not the focus of the current research. The author aims to provide a management related view and she assumes that nanotechnological developments would have changed the direction of the paper. After having checked the validity of the searched paper, 466 articles remained on the SCOPUS list and 78 articles on the WoS list. To reach an appropriate database without duplications, the merging function of R Studio’s bibliometrics package was used. As a result of the merging process, 499 documents form the dataset of the current literature review. The publications are all literature reviews. Conference proceedings, case studies and other empirical studies are excluded. The timespan is wide enough to examine the second research question (RQ-2). Papers that appear on the list were published between 2005-2023.

Results and Discussion

Results were generated using the bibliometric analysis software Biblioshiny and the network visualisation software VosViewer.. Biblioshiny was used to answer both RQ-1 and RQ-2 and VosViewer to present the interpretation for RQ-2.

Before applying the methodology, the author filtered the data through the search criterion “publication year”. 438 articles of the original 499 remained, after having set the year range between 2012 and 2023. Citation data from the year 2023 may not influence the result, but the aim was to take into account the recently published papers to interpret the evolution of this literature.

The annual scientific production indicator shows a huge increase from 2017 until the beginning of 2023. Figure 2 shows the average citations per year, so the graph visualises the results until the end of the year 2022 since the paper was conducted in spring 2023. The annual growth rate is 16.195% and a protrusion is seen in 2022 when the number of the published articles more than doubled compared to 2020. This exponential growth is followed from the year 2018. This might mean that the improvement of the technology (Rejeb *et al.*, 2022a) may have served as an inspiration of the authors. Articles in connection with the digital improvements regarding the agri-food supply chain management seem to appear as a consequence of this rapid technical development wave.

Besides this, the average cited data declares a significant decrease from 2020, which shows that due to their recent appearance of papers from the last 2 years, the citations could not be that high yet. The arrival of the Covid-19 pandemic cannot be disregarded. In spring 2020 (~March) European countries started to implement actions like lockdowns, which generated interest in digital technologies (European Comission, 2022). The agri-food industry is not a typical home office-capable industry, so the application of digital support must appear in another forms. Based on this, the sudden increase in publications might be tracked back to the general awareness about the application of digital technologies. It is also a possible that the shortage of human workforce (especially the migration wave in the direction of Western-European countries (e.g., Germany) might have led to the application of non-human resources within the AFSC as well (Mitaritonna and Ragot, 2020, Nagy *et al*., 2020). On the other hand, this increases the need for an IT-educated workforce (Demeter *et al*., 2020), something which also pushes academics in the direction of research areas which can contribute meaningfully to future workforce training.

The three-field plot can adequately represent the connection between the most important authors based on the number of papers they have publisheᴅ, their countries, and the research topics, which appear in their published papers. The size of the nodes represents frequency data, the bigger the node is the more dominant role publication has. Figure 3 shows which topic was the most dominant research topic in the respective year in the sample existing origin

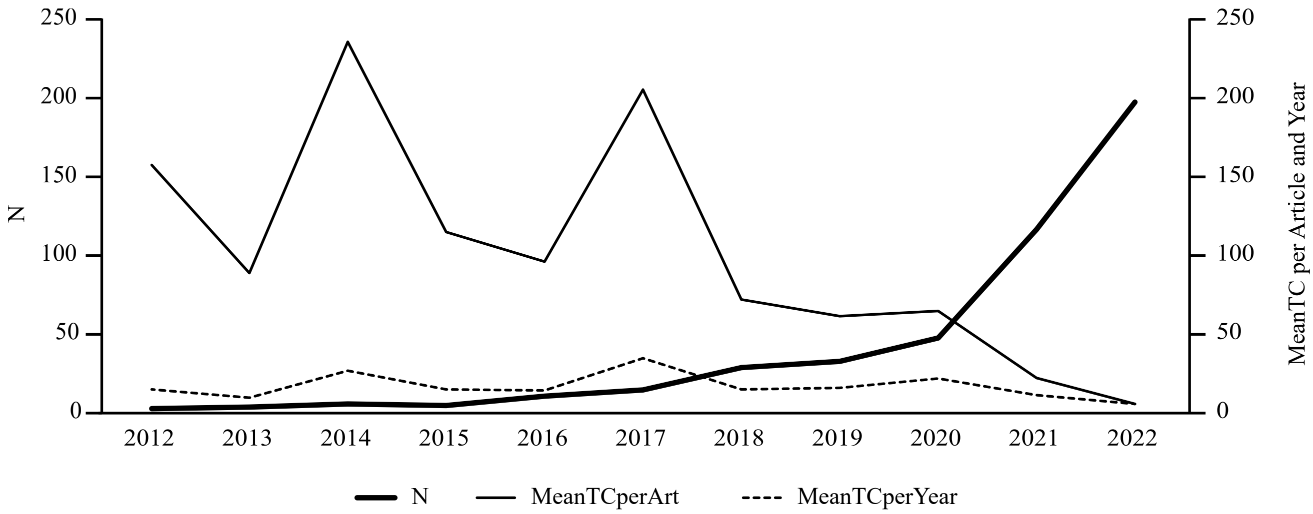

Figure 2: Annual citation per year.

Source: Own composition based on data generated from Biblioshiny (2023)

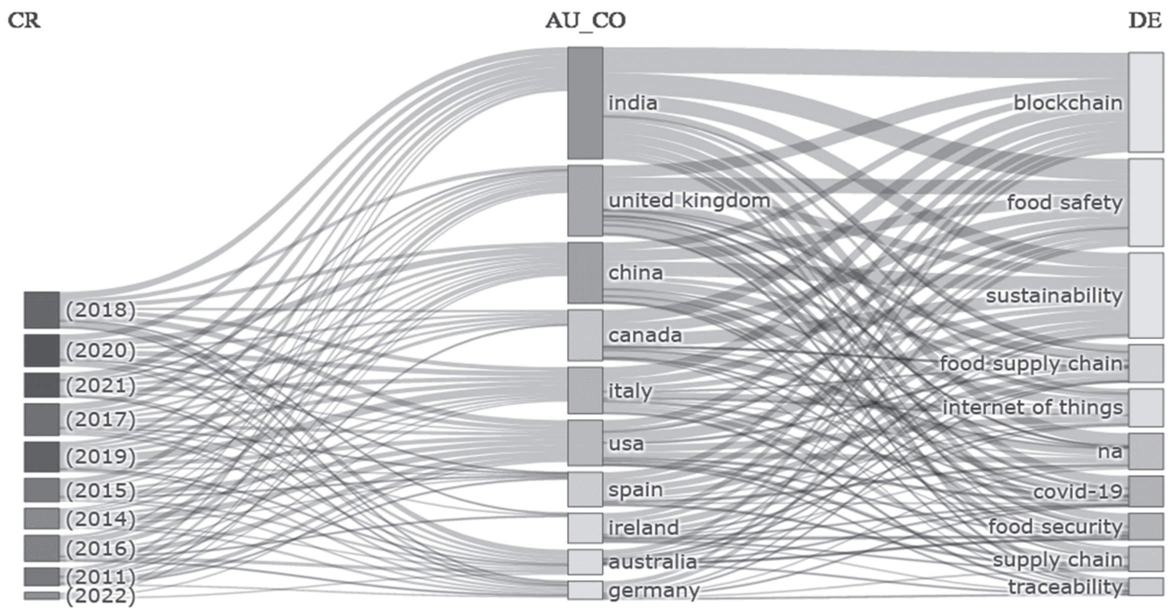

Figure 3: Three field plot.

Source: own composition based on data generated from Biblioshiny (2023) countries. India seems to be the most influential country due to its publication volume. This country is from where all kinds of topics are researched within the examined research frame. The food supply is a prominent issue in these regions of Asia (such as China and India). The parameters of the population justify a country's ongoing work on security of food supply. These developing countries must manage the problem of the large amount of necessary food supply.

In whole sample, blockchain counts as one of the dominant Industry 4.0 solutions (11.22% of the listed articles deal with blockchain), which support the establishment and maintenance of food safety (Lezoche *et al.*, 2020; Srivastava and Dashora, 2022). According to experts (Creydt and Fischer, 2019), blockchain is a technological solution to accomplish an efficient traceability on the entire way of the product.

Besides blockchain, Internet of Things appears as a tool for ensuring traceability during the food supply chain. IoT can be interpreted as a package of devices and technologies enabling sharing of data (Ben-Daya *et al.*, 2021). As an umbrella term, food safety is in the centre of this analysis as well. Food safety incorporates all standards and regulations, which regulate and control the transactions within the agri-food supply chain.

In addition, the importance of sustainability seems to have increased. 19% of the reviewed articles deal with the phenomenon of sustainability regarding food safety characteristics as well. This figure also reveals that the topic of sustainability is strongly connected to countries with a large population (e.g., India, China, Canada, USA). It may happen that organising food sector developments implementing a sustainable aspect is important for those countries that have to provide for a huge population. Furthermore, national, and international efforts of authorities (e.g., EU) can push scientific research in the direction of sustainability by applying funding and tender opportunities (European Commission, 2023).

As to topics of the published papers, Figure 4 demonstrates the evolution of these between 2012 and 2023. The author decided to cut the timeline into four as Figure 4 shows because the rapid growth of the annual citation data highlighted the importance of the period between 2017 and 2023.

This thematic evolution shows a huge wind-up of the topic after 2017: more and more Industry 4.0 solutions appear in the publications. As Figure 4 shows, blockchain is indisputably an emerging topic. Its dominance has not changed in recent years. However, it is interesting to observe that the factor "human" appears, and this is regularly connected with sustainability. The evolution of the topic shows a wide opening in which mostly the core definitions, like food supply chain and food safety and traceability, were in focus. Their existence is important for the future publications because they serve as the basis for recent theories about the technological solutions supporting food safety.

Regarding results made by VosViewer, Figure 5 presents the bibliographic coupling of the articles and the visual indicator of clusters by colour. The closer two articles are related the more references they share (Marchiori and Franco, 2020). This literature analysis states that two documents are bibliographically coupled if they both cite one or more documents in common (Aria and Cuccurullo, 2017). A minimum of five common citations were set. The nodes' size in Figure 5 represents the total number of citations of the 285 articles which met the threshold. It can be seen on Figure 5 that more than the half (285 out of 466) of the examined papers are bibliographically coupled.

Using the papers and meeting the threshold, seven clusters have been implemented by applying bibliographic coupling methodology with the VosViewer software. After reading and interpreting the articles, the author tried to name the clusters, with a view to starting the in-depth analysis. Table 2 contains the labels and the distribution of the seven clusters that were generated by the software.

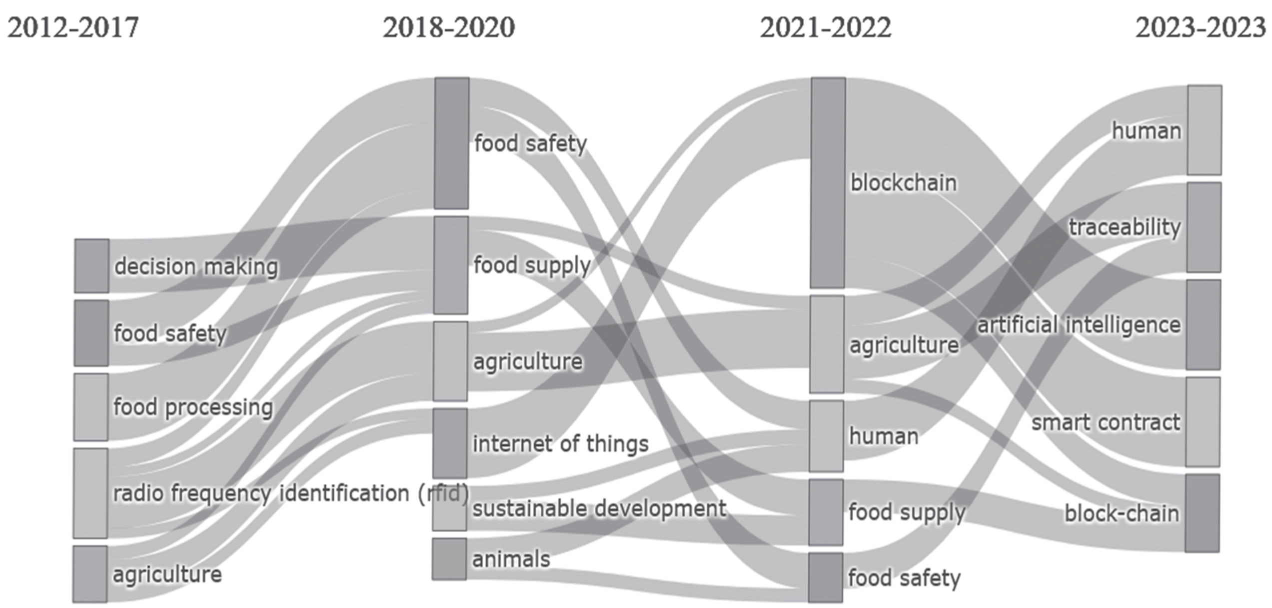

Figure 4: Thematic evolution of papers

Source: Own composition based on data generated from Biblioshiny (2023)

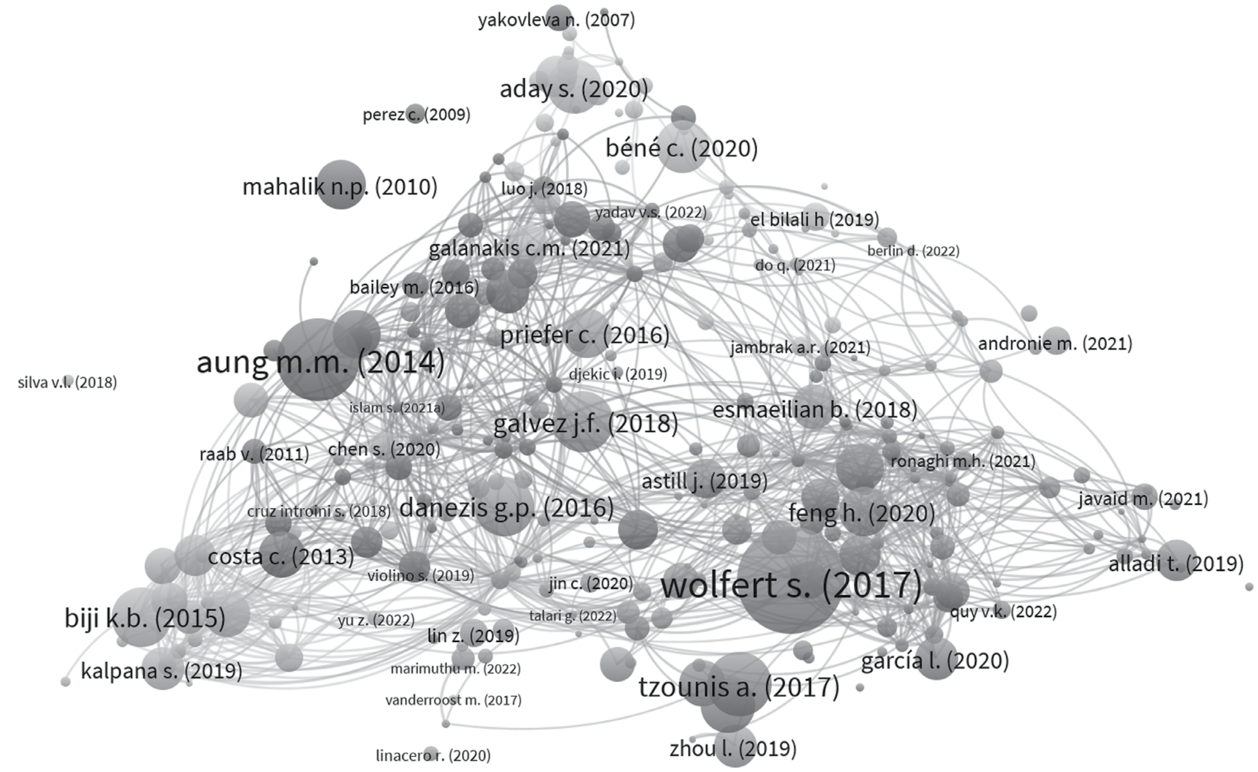

Figure 5: Bibliographic coupling of selected articles from SCOPUS.
Source: Own composition based on data generated from VosViewer (2023)

Table 2: Identification of clusters.

Cluster ID	Distribution of the analysed papers	Name of cluster given by the author
Cluster 1	20%	Traceability challenges in AFSC
Cluster 2	18%	Quality management in AFSC
Cluster 3	17%	Agri-food 4.0
Cluster 4	15%	Future trends of AFSC
Cluster 5	12%	Impact of the Blockchain
Cluster 6	10%	Smart packaging
Cluster 7	8%	Circular economy

Source: Source: own composition based on data generated from VosViewer (2023)

Traceability challenges in AFSC

Generally, agri-food supply chains face comprehensive traceability challenges. The biggest cluster contains literature reviews about possible traceability solutions. According to experts, there are drivers such as legislation, sustainability, consumer satisfaction, international standardisation or even food safety itself, which may contribute to define traceability (Islam and Cullen, 2021). As can be seen in the reviewed literature, technological improvements supported by digitalisation are seen as enablers for the traceability requirements of the 21st century (Magalhães *et al*., 2019; Violino *et al*., 2019).

Furthermore, technologically supported traceability within the AFSC ensures a high level of reliability. Technological solutions for traceability provide stakeholders of AFSCs a social, economic and environmental sustainability as well, with its characteristics of reducing food waste and food loss, building trust and creating transparency within the AFSC (Rahman *et al.*, 2021). Reducing food waste and loss can contribute to environmental sustainability by optimising consumption. On the one hand, society should learn how to avoid the production of food waste (traceability data can provide data to calculate it). On the other hand, harvesting and processing less food leads to a sustainable natural environment. A comprehensive view about the AFSC processes serves as a pillar for trust both from a social and financial (economic) perspective. Negative effects, like mislabelling products, can ruin trust processes. However, technology supported traceability (e.g. blockchain solutions) can lead to stability within food safety (Lo *et al*., 2019).

Quality management in AFSC

While traceability is a highlighted and specific area of food safety, there are also general factors of quality management in AFSC, in which digitalisation may be an important contributor. Quality management can be discussed from an enabler perspective with regard to its consequences. The *enablers* can be technological solutions or standardisation and regulation processes of decision makers. According to the reviewed studies, companies need to have special technological solutions if they wish to manage their agri-food supply chain successfully.

There are numerous software-provided methods supporting quality management systems. The main question of ensuring a stable quality management system is the ability to collect, store and analyse data. Data can be collected with the help of sensors (Hitabatuma *et al.*, 2022). To analyse and interpret the gained data, Big Data and IoT are suitable (Ben-Daya *et al.*, 2021; Rejeb *et al.*, 2021). Artificial Intelligence, Deep Learning and the creation of a Digital Twin serve as simulations for decision making, monitoring and maintenance (Mavani *et al.*, 2022; Verboven *et al.*, 2020; Zhou *et al.*, 2019). Cloud and smart storage represent the surfaces where these data can be responsibly stored for future usage (Nychas *et al.*, 2016). Blockchain is a technology which offers a comprehensive solution for producing, storing, and transferring data real time with full transparency and irreversibility (Galvez *et al.*, 2018).

An interesting fact is that the second cluster does not contain regulation specific papers, which the author will consider in the conclusion part of this paper. The consequences may appear in form of food frauds, food waste and food loss and they mean both financial and social quality managerial losses for corporations (Visciano and Schirone, 2021; Wu *et al.*, 2021).

Agri-food 4.0

The agri-food industry has obtained a dominant position in the literature recently. Terms such as Agriculture 4.0 and Agri-food 4.0 have appeared, generally referring to an interpretation of Industry 4.0 in this sector (da Silveira *et al.*, 2021; Lezoche *et al.*, 2020).

Table 3: Technological solutions characterising Agri-food 4.0.

Name of technological solution	Areas of usage	AFSC members meeting with it	Effects of technology on AFSC members
Artificial Intelligence (AI)	obtaining useful information, enables computers to interpret data	producers, software & hardware service providers (suppliers), distributors, consumers	Pros: quick “ready-to-go” information available, huge data processing capacity, no need of regular human interruption Risks: surface handling capability needed, misleading information/fraud based on non-human led processes, mistrust in given information
Big Data	food processing, food transportation, and food retail: data processing, obtaining useful information	producers, software & hardware service providers (suppliers), distributors	Pros: huge volume of data collectable, comprehensive, by human unmanageable dataset available Risks: data analytics capability needed, misunderstanding of data analysis, unsure decision-making input
Blockchain	“farm to fork” availability: tracks data, proves the originality (indirectly raises trust in food safety)	producers, software & hardware service providers (suppliers), distributors, consumers	Pros: theoretically proven trust in data, tracking solved if each member participates Risks: huge investment required within the whole AFSC to run it, possibility of being declined by users because of lack of understanding/trust
Cloud Computing	better cooperation between logistics and consumers with shared surfaces	producers, software & hardware service providers (suppliers), distributors	Pros: easy availability of real time data, available for all AFSC members in real time Risks: stable internet access must be ensured permanently, risk of cyber-attacks
Cyber Physical Systems (CPS)	farming, food processing: real-time integration of physical and computational algorithm and so facilitating to food safety and food waste reduction	producers, software & hardware service providers (suppliers), distributors	Pros: no need of human interruption, mainly maintenance and program setting are required by the human workforce Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks
Digital Twin	farming and food processing: real-time monitoring of physical world (farm) and updating the state of virtual world	producers, software & hardware service providers (suppliers), distributors	Pros: suitable for simulations (interruptions without endangering animals/plants/ manufacturing processes are possible) Risks: huge investment required, lack of real-life simulations can lead to doubts of users
Drones	farming: spreading pesticides, logistics: package delivery	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: quick transportation, high-quality observation, precise processing methods Risks: non-applicable at each sector, e.g., pesticides for grape yards (while corn can be sprayed from above, grape must be sprayed from the side between the lines), disturbing noises, doubts in people: feeling of being observed

Name of technological solution	Areas of usage	AFSC members meeting with it	Effects of technology on AFSC members
Flexible Wearables for plants	farming: gaining data from animal behaviour, performance management	farmers, software & hardware service providers (suppliers)	Pros: functioning can be controlled, suitable for moving animals (location change does not mean a problem) Risks: non-applicable for all AFSC members (mainly farmers), plants or even animals can suffer from being analysed on a real time basis
Information and Communication Technologies (ICT)	farming, food processing: monitoring conditions (e.g., temperature) and serving with real-time data to extend shelf life	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics), consumers	Pros: availability of communication and storage for all AFSC members, being connected Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks
Internet of Things (IoT)	whole AFSC: data analytics, operating drone farming, monitoring farm/processing operations	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: comprehensive service during the whole value creation Risks: investment into devices capable of communicating with each other is required, problems may occur because of instable electricity networks/internet access, doubts/misleading because of non-human interruptions are possible problems, risk of cyber-attacks
Machine Learning	Food processing, farming: substance of AI, interpretation of raw data	producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: advantages of cost-efficiency (based on enabling machines create algorithms instead of programmers) Risks: problems may occur because of instable electricity networks/internet access, failures may occur because of small human control
Precision Farming	Farming: farm management, from gaining to interpreting data and making decision-making offers to farmers	farmers, software & hardware service providers (suppliers)	Pros: comprehensive management tools are available for farmers mainly, decision-making support Risks: non-applicable for all AFSC members, IT infrastructure needed to be synchronised with by the authorities required IT software
Robotics and Autonomous Systems (RAS)	Farming, food processing, distribution: material handling, processing	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: fewer human resources are needed, capacity problems can be solved by RAS Risks: non-applicable at all AFSC members (mainly processing), human contribution: mainly programming, maintenance, higher value-adding jobs
Radio Frequency Identification (RFID)	Food processing, logistics: identification, serving data for tracking	producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: identification and data transfer available in connection with devices, materials, animals or even humans Risks: danger of radio frequency, non-readable situations may decelerate processes
Sensor	Food production: monitoring food safety and collecting data	farmers, producers, software & hardware service providers (suppliers), distributors (e.g., logistics)	Pros: investment is not too expensive any more, suitable for data collection within the whole AFSC Risks: positioning might cause difficulties (e.g., at a crop field)

Source: own composition based on the collection of Cluster 2

Table 3 demonstrates the technological trends appearing in literature reviews recently. Agri-food 4.0 can be interpreted as a merged technological solution building on data. As Table 3 shows, there are technological solutions which are responsible for gaining and transferring data or even taking special interventions. The hardware-intensive methods are mainly: Cyber Physical Systems (CPS) (Smetana *et al.*, 2021), drones (Rejeb *et al.*, 2022a), Radio Frequency Identification (RFID) (Gómez *et al.*, 2021), Flexible Wearables for plants (Qu *et al.*, 2021) and sensors (Tsolakis *et al.*, 2019). After having collected data, the surface of data storage, transfer and sharing follows as a next group of Agri-food 4.0 technologies. Big Data is suitable not only for storing data in a structured way, but it can also be used for analysis and decision-making processes (Wolfert *et al.*, 2017). Cloud computing (Mustapha *et al.*, 2021) can be a helpful tool for serving real time data for humans or even machines within processes and enable them to analyse or even intervene in processes observed.

IoT (Raj *et al.*, 2021; Sinha and Dhanalakshmi, 2022), Information and Communication Technologies (ICT), and Robotics and Autonomous Systems (RAS) contribute to managing agri-food operations automatically while reducing human interventions in the process. These are followed by Artificial Intelligence (AI) (Ben Ayed and Hanana, 2021), Machine learning (Raj *et al.*, 2021), Digital Twin (Nasirahmadi and Hensel, 2022), which are solutions for handling processes without human interruption to achieve the highest safety possible. AI can learn, interpret, and process huge amount of data coming from e.g., Big Data on its own (Zhou *et al.,* 2022). This capability can affect the AFSC both in a positive and a negative way. Technologies operating (quickly) without human interruption can avoid instability in the information flow but may also raise doubts in the mind of their users. AI can learn on its own and this also creates an uncontrolled sphere, in which rational interruptions can be hardly implemented. "Facts" that are wrongly interpreted but treated as data may have negative effects for AFSC members (e.g., financial consequences, or misinformed consumers) (Rana *et al.,* 2022). However, these technologies are suitable for simulating processes, testing the possible outcomes of interventions and they can make decisions based on their previous analysis.

Precision farming and Blockchain (Finger *et al.*, 2019; Rejeb *et al.*, 2022b) are comprehensive solutions for the stakeholders to track, record and manage changes within the agri-food processes. While precision farming is rather a collection of suitable technologies listed above for management tasks, blockchain is an enabler surface for both managerial and financial tasks. Table 3 includes also pros and risks connected to the prior effects of technologies introduced within this cluster. As observable, most of the listed solutions can replace human workforce, which is on one hand a great capacity enabler. On the other hand, risks as cyber-attacks appear in the results, because of relying on technologies hundred percent. All examined solutions need electricity and internet connection to function, and their ensuring process is paramount for AFSC members.

Future trends of AFSC

The cluster of future trends incorporate the reaction of the AFSC to signs from the changing world. First, it is important to state that food supply is a critical task of governments to be ensured for the citizens and is a part of food safety tasks too. The Covid-19 pandemic has played a dominant role in changing the food safety and especially food supply processes recently (Aday and Aday, 2020; Alabi and Ngwenyama, 2022). According to experts, the resilience of AFSCs should be strengthened, in order to be able to deal with coming crises (Béné, 2020; Derossi *et al.*, 2021). This empowerment can be connected to both national and international authorities and organisations with a special focus on sustainability within the agri-food sector (EU Green Deal, 2020). The necessity of these adjustments is paramount as a reaction to the challenges of climate change processes. The European Union has worked on strategies to achieve a sustainable condition from an economic, environmental, and also social aspect. Policy aims regarding AFSCs within the European Union can be described by CAP (Common Agricultural Policy) aims to achieve fair, healthy, and environmentally friendly food systems (Farm to Fork Strategy) while ensuring and maintaining biodiversity (EU Biodiversity) with a view to mitigating climate change effects (EU Green Deal, 2020).

There are various ways to establish resilience, which is a difficult task, especially within wide AFSCs. Resilience and sustainability goals can lead to one direction if using improved food safety methodologies (Agnusdei and Coluccia, 2022). On one hand, combined usage of Agri-food 4.0 solutions can lead to the maintenance and stabilisation of agri-food processes (Hassoun *et al.*, 2022). They contribute to establish digitalisation supported processes both within production and consumption (Musa and Basir, 2021). This cluster revealed an important method as an enabler of food supply challenges. According to experts, 3D food printing may contribute to deal with the effects of crises, like the Covid-19 pandemics (Derossi *et al.*, 2021). Derossi *et al.* (2021) state that 3D food printing is characterised by ensuring food safety (programmable production solutions without human interruption), producing only the required quantities (reducing food waste) and offering personalised food. 3D printing can also imply a food safety risk from the perspective of cleaning opportunities. Printers should have CIP (clean in place) systems to ensure the regular hygienic cleaning process during the production. On the other hand, applying 3D food printing could entail a limitation of the shelf-life of products because of the artificial changes of the structure of food. Thus, post-processing steps may be required because of customisation (Demei *et al.,* 2022).

Impact of the Blockchain

Coming from this cluster, blockchain can be interpreted as a platform, which stores blocks strung on a chain. Due to its characteristics blockchain is "a distributed ledger feature, every record in this ledger is secured by rules of cryptography which makes it more secure and tamper-free" (Gad *et al.*, 2022, p. 2). There are blocks, filled with data about transactions during the whole process (Ronaghi, 2021; Xu *et al.*, 2022).

From the perspective of members of the AFSC who have stable IT knowledge and infrastructure, blockchain technology can build trust because it provides a faster and more reliable traceability. Challenges of the food supply chain, like food safety, food fraud, fair trade, foodborne illness outbreaks, or even the environmental impact of food production can be supported by blockchain technology (Astill *et al.*, 2019). The stakeholder group of consumers or even smaller farmers and suppliers might have doubts related to the blockchain because of a lack of understanding of the technology. They might not even have a financial background that is stable enough to invest into this solution. The mechanism of blockchain is very complex. Theoretically, it relies on a mathematical basis which allows the technology to be handled in a tamper-proof manner (Gad *et al.*, 2022).

Experts claim that blockchain is a disruptive technology which can lead to changes of business and supply chain models (Ronaghi, 2021). Frizzo-Barker *et al.* (2020) add that this disruptive characteristic may appear not only with a financial focus (e.g., lower transaction costs), but that it has also several risk opportunities, such as unreliability of data provided first and being saved or that the lack of universal standardisation might lead to difficulties in its disruptive growth on the market (Frizzo-Barker *et al.,* 2020).

According to Zhang *et al.* (2022) both upstream and downstream supply chain members participate in information sharing and storage regarding traceability. They point to the characteristics of blockchain-enabled traceability models. They can ensure efficiency, trust, quality and resilience within the food supply chain (Zhang *et al.*, 2022). The impact of blockchain shows itself as an effective tool of traceability. Both the end consumer and the processor can require data about the food, so this is a two-way process. According to the literature blockchain is sufficiently accurate to serve these needs.

Smart packaging

The sixth cluster represent papers about a prominent operation within AFSC: smart packaging. Smart packaging is also a tool of food quality monitoring (Azeredo and Correa, 2021). Smart packaging can contribute to establish food safety, meet the customer requirements, and reduce food waste at the same time (Soltani Firouz *et al.*, 2021). Emerging packaging technologies have an impact on the protection of products, extending their shelf-life and informing all AFSC members, and even the consumers about the entire background of the products from farm to fork (Drago *et al.*, 2020; Nemes *et al.*, 2020). According to experts, smart packaging covers the areas of food safety and quality, traceability, managing food loss and waste and due to these characteristics, it contributes to the sustainability of food processing as well (Chen *et al.*, 2020; Yousefi *et al.*, 2019).

Circular economy

The sustainable development of AFSCs has already appeared within the results coming from Biblioshiny (see Figure 3 and 4). Experts point to the fact that there are links between circular economy, sustainability and digitalisation-supported developments (Ada *et al.*, 2021; Rejeb *et al.*, 2022c). Circular economy represents a perspective that can establish sustainable production and consumption with keeping resources in usage as long as possible (Ada *et al.*, 2021). On both of the sides (production and consumption) waste management represents a dominant part of the circular economy concept which may be supported by digitalisation providing prevention by the technological solutions introduced above in the clusters (Esmaeilian *et al.*, 2018; Oguntegbe *et al.*, 2022).

Discussion

This bibliometric analysis focuses on determining the research trends in terms of thematic evolution and bibliometric coupling. Based on the read and analysed references, a two-sided structure emerges. The literature lists both hardware (e.g. sensors, robots, etc.) and software (Big Data, cloud, etc.) solutions (Derossi *et al.*, 2021; Duong *et al.*, 2020; Lezoche *et al.*, 2020).

Figure 6 demonstrates the relevant pillars of traceability. Beside the two-sided approach (hardware and software), there are other technological solutions which require both sides to function efficiently (e.g., blockchain, IoT, etc.). The intersection of the triad of (1) agri-food industry, (2) digitalisation and (3) food safety depends primarily on the level of the data quality available, and the analyses derived from it. The results show that, in terms of the collection of adequate real-time data, the introduction of digital technologies such as Industry 4.0 solutions can be helpful. Considering the entire food supply chain, the key to implementing digitalisation technologies is the use of tools such as Big Data, IoT, or cloud-based communications (Astill *et al.*, 2019; Niknejad *et al.*, 2021). The implementation requires hardware that can collect data, and on the other hand, software that makes the system capable of handling data. For ensuring traceability cooperation of these two factors is indispensable. Reading the literature it turned out that some authors deal with the coherence of technological solutions

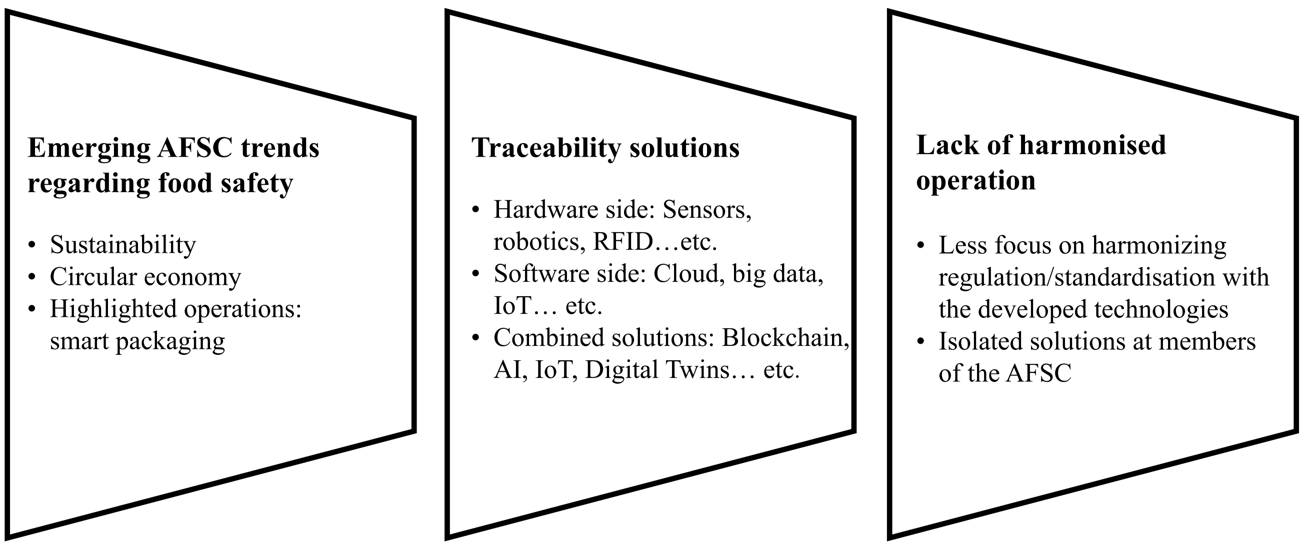

Figure 6: Interpretation of the results.
Source: Own composition

such as blockchain and IoT (Ben-Daya *et al.*, 2021; Kaur *et al.*, 2022), but only a few focus on the total harmonisation of advanced technologies. The requirement for implementing a well-functioning food traceability system consists of at least three fundamental areas. First, a network-capable device (sensor, RFID, etc.) is needed to transmit real-time data (Nasirahmadi and Hensel, 2022). Second, due to data collection big data is generated. Big Data analysis can contribute to decision making, tracking or even prevention processes (Astill *et al.*, 2019; da Silveira *et al.*, 2021). Third, the storage and sharing of a large amount of data is possible with the help of cloud-based repositories or IoT solutions (Kaur *et al.*, 2022). Nevertheless, the results also present that not only technological solutions are needed for ensuring traceability. After the clarification of the possible positive and risky effects of each digitalisation solution, AFSC members must ensure that both the workforce and management have an appropriate understanding of the possible developments.

Bibliographic coupling showed us 7 clusters based on the calculations of VosViewer. The analysed clusters represent an interesting situation about the emerging trends of AFSC's digitalisation regarding food safety. Cluster 1, 2, 3, and 4 describe comprehensive research areas in connection with the agri-food supply chain specifical, technological and quality managerial issues. Meanwhile, it can be observed that even though cluster 5, 6, and 7 would fit the first 4 clusters, they appear in the results highlighted separately – and this is an important new finding. Their importance and dominant role either within the technology or in the AFSC processes might be the reasons for this separated appearance. Incorporated in the clusters 6 and 7 (smart packaging and circular economy), social-environmental-economic impacts also appeared in the findings. Their less-than-dominant position within the findings of the literature search signifies that these effects of digitalisation have not been subjected to detailed academic research so far. The dominant pattern in the results instead relates to technological solutions.

Conclusions

The current paper aims to provide a bibliometric analysis of the publications on food safety supporting technologies applied in the agri-food supply chain. However, a considerable amount of literature is available in the observed research field, in which it can be observed that bibliometric analysis has not yet been commonly applied to the field. The usage of a workflow of bibliometric literature reviews generated a complex methodology relying on a statistical background. The trend of scientific review publications was investigated, and the author aimed to uncover recent research streams and define potential future directions within the field.

Two main research questions appeared in the paper. RQ-1 focused on the area: "Which are the emerging topics of AFSCM regarding food safety?" and RQ-2 dealt with the question: "How has the topic of food safety in AFSCM evolved during the last 10 years?". For accurately answering RQ-1 a bibliometric analysis in form of bibliographic coupling by using VosViewer was conducted and for answering RQ-2, a bibliometric analysis was carried out by using bibliometrix R-package (Biblioshiny platform).

The analysis highlights that there are some "popular" digital solutions such as blockchain or IoT which influence the literature (Astill *et al.*, 2019; Niknejad *et al.*, 2021). This dominance of the technological solutions leads the author to think about their role within the agri-food supply chain. It takes a long time to make the products flow from farm to fork and many members of the agri-food supply chain are involved in digitalisation-based development projects (Dadi *et al.*, 2021). The accurate cooperation of the members may serve a full line traceability which requires a huge financial and professional investment from each member. Due to this it is rarely seen that one or two technological solutions can appear during the whole supply chain. One of the main findings of this paper which is a new result is that not only the 4 previously expected topics (traceability challenges in AFSC, quality management in AFSC, Agri-food 4.0 solutions), but also the last 3 topics of the clusters (the impact of the Blockchain, smart packaging, and circular economy) are emerging and are gaining significance, which is also reflected in the bibliographic analysis results. Table 3 shows the characteristics of the examined technologies. It is seen that there are positive and sometimes risky effects, which have as well social (considering stakeholders), environmental (emissions, production, and functioning data), and economic (financial effects, as investments, maintenance, but also cost efficiency) effects.

Furthermore, there are unexplored topics which are suitable for further research. It has been showed that standardisation and regulation are the basics of food safety. Nevertheless, researchers have not really focused on combining the requirements of regulations with the emerged technological solutions. Cyber security appears as a second future research direction. It should be more researched and published from a managerial point of view. If professionals (e.g., managers or engineers or operators of a farm) do not start to deal with technology-based solutions that were introduced in this paper, it may lead to cyber-attacks or other negative consequences (Bayramova *et al.*, 2021). Limitations of the research are on one hand the broad scope of the research questions, and the lack of the appearance of the term cyber security during the searching steps. However, it is recommended to mix the software for the analysis, and VosViewer software cannot work with the merged database, something which also counts as a limitation of this research. A more detailed analysis can be conducted in the future examining co-citation or co-word relations with a view to obtaining a stronger overview of the pillars of the field. In addition, emphasising the social-economic-environmental effects during the search for the existing effects can widen the list of findings within the literature.

In general, traceability within a whole agri-food supply chain is difficult to implement due to the large number of AFSC members. This paper shows that recent technological solutions can support food safety. Research dealing with the consistency of technologies and regulation platforms can potentially pave the way for a yet more holistic understanding of the AFSC.

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