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Foreword

After the first shock of the global COVID-19 outbreak in early 2020, the virus has been with us for more than a year. Although most conferences in agricultural economics are going virtual this year, open-access journals like Studies in Agricultural Economics have been working continuously, without any disruptions. What is more, due to last year's Scopus listing, we are expecting our first Q value this year!

We have five papers in this issue. The first paper, written by Koester and Galaktionova, analysed the new proposal by the Food and Agriculture Organization of the United Nations (FAO) that aims at harmonising the methodology for food loss and waste research through the Food Loss Index (FLI). In particular, the paper assesses the FLI as a potential tool to inform policymaking. The authors would like to highlight that although studies play an important role both in raising awareness about the global problem of FLW and in encouraging further research, they do not solve such important issues as providing a unified definition of FLW, the problems caused by the aggregation of heterogeneous commodities within a single category, and the absence of a methodology and data necessary for policymaking. The objective of the article is to start a discussion about these issues.

The second paper, written by Mutua Ndue and Goda, investigates the multi-dimensional assessment of the European agricultural sector's adaptation to climate change. The paper argues that over the past decades, strong emphasis has been placed on how to mitigate the negative effects of climate change across the sector, resulting in countries making slow progress in terms of adaptation. Although adaptation is now part of the sector's development agenda, sectoral adaptation performance across member states remains low. In order to justify the need for an accelerated adaptation process across the sector, the paper develops a Relative Climate Change Adaption Index (RCCAI) for the sector based on Eurostat data. The analysis shows that there is no single member state across the EU whose agricultural sector can be considered as fully climate-adapted (resilient), thus validating the assumed need for adaption efforts to be scaled up sector-wide. To ensure continued improvement in the sector's adaptive capacity, the paper recommends coherent integration and accelerated implementation of adaptation practices and policies that serve both the private and public goods alongside the Common Agricultural Policy (CAP).

The third paper, written by Tosovic-Stevanovic, Ristanovic, Lalic, Zuza, Stepien and Borychowski, provides an overview and analysis of the status of farms in Serbia, with a special focus on finding factors influencing the sustain development of small-scale family farms. To develop simpler and more precise problem-solving and decision-making processes for improving the farms' operations, the analytic hierarchy process (AHP) model is used in this paper. This model is applied to the selection of key economic determinants for small farms' viability, illustrated through the results of the authors' own survey of 550 small farms in Serbia which refers to the economic, social and environmental aspects of small farms' operation. By applying the criteria for selecting key economic indicators of a small farm, the multi-criteria assessment results can be utilised to reach more effective business and policy decisions to improve the operation of small-scale family farms. The survey results have shown that the best-ranked determinant for the viability of small farms in Serbia is the price of agricultural products, followed by well-structured agricultural product distribution channels.

The fourth paper, written by Chanie and Yuan-Pei, analyses the impact of the supply of farmland, level of agricultural mechanisation, and supply of rural labour on grain yields in China. According to this paper, China has implemented various policies such as its farmland protection policies, rural-labour allocation to off-farm industries, and agricultural mechanisation subsidies to induce grain self-sufficiency. However, farmland loss is an increasing trend; surplus rural labour continues to exist; and agricultural mechanisation has not reached the required level of quality and quantity. With this in mind, this paper examines the long- and short-term impacts of farmland supply, rural-labour supply, and agricultural mechanisation development on grain-crop yields in China. The Autoregressive Distributed Lag (ARDL) approach to co-integration and error correction has been applied to data over the period 1978-2017. The results show that farmland supply and agricultural mechanisation developments are positively associated with the growth of grain-crop yields in both the short- and long-term. However, the impact of the rural labour supply on grain yield is insignificant. Strengthening farmland protection policies and promoting innovation-based agricultural mechanisation development both play an important role in sustainable food production. Moreover, China's efforts to enhance the multidimensional level of agricultural mechanisation should be encouraged.

The fifth paper, written by Djokoto, has used multilateral foreign divestment (FD) data covering 1991 to 2017 for 50 countries fitted to a model based on theory and optimisation from microeconomic foundations, in order to estimate the drivers of FD out of agriculture. Identifying the factors that determine FD would offer an opportunity for policymakers to know the policies that can discourage FD. Also, knowledge of the directional effect would offer a way to use the policy variables to appropriately influence FD. Market size, exchange rate, political regime characteristics and transitions as well as the level of development drive FD out of agriculture globally. Trade openness and land resource did not determine FD. The authors conclude that agricultural managers should work towards increasing the size of the agricultural economy, liaise with their respective country Central Banks with a view to minimising significant depreciation of their currencies, and their governments to improve their country's political regime characteristics and its handling of political transitions.

On the whole, I hope this issue provides again some new and useful insights to those studying the economics of European and Central Asian agriculture.

Attila JÁMBOR

Budapest, April 2021

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FAO Food Loss Index methodology and policy implications

In 2015, all 193 UN member countries agreed to halve global food losses and waste by the year 2030. In this article, we are going to explore why the first official study on food loss and waste (FLW) by Gustavsson *et al*. FAO, 2011 cannot be used as a reasonable basis for policymaking – even though it underlies Sustainable Development Goal (SDG) 12.3. Then we will look at the new proposal by the Food and Agriculture Organization of the United Nations (FAO), which aims to harmonise the methodology for FLW research employing the Food Loss Index (FLI). In particular, we are going to assess the suitability of the FLI as a tool for policymaking. We would like to highlight that although both papers have played an important role in raising awareness about the global problem of FLW and in encouraging further research, they do not solve such important issues as providing a unified definition of FLW, the aggregation of heterogeneous commodities within a single category, and the absence of a methodology and data, both of which are certainly needed for policymaking. The objective of the article is to start a discussion about those issues, as even the recent flagship FAO study (2019) openly presents such a dichotomy between on the one hand, the aggregated percentage number of the Food Loss Index and on the other hand, the call for specification and precision in shaping policy measures, based on cost/benefit analyses.

Keywords: food loss, waste, policy, methodology, SDG

JEL classification: Q18

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Introduction

The number of publications on the topic of food loss and waste (FLW) has increased significantly since the first groundbreaking study commissioned by the Food and Agriculture Organization of the United Nations (FAO) in 2011 (FAO, 2011). This study informed the world community that about one third of world food production intended for human consumption was lost or wasted. This finding created the hope that worldwide food security and resource efficiency should and could be improved significantly by reducing FLW.

The importance of this issue is reflected in the Sustainable Development Goals (SDGs). SDG Target 12.3 calls to halve per-capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, by 2030 (FAO, 2020). It is no surprise that the call was supported by all 193 member states of the UN.

The targeted reduction of FLW in SDG 12.3 is most likely based on the only figure, which was known at that time, namely, that one third of worldwide food production is lost or wasted. If policy makers on the national or international levels want to know whether their policy measures have contributed to achieving the defined target (to halve FLW by 2030), they have to be able to rely on clear and comparable information. This means that any new FLW-related study should use the same methodology as the first FAO study; if there is a convincing rationale for using a different methodology, it should be explained, or at least the question of whether the methodology of the first study would have led to a different finding should be discussed.

Moreover, policy recommendations should contain two necessary elements: first, the proposal, explaining how the objective may change due to a proposed policy; and second, the economic costs needed to achieve this objective. If a study only shows that the present situation could be improved but does not inform the reader what the costs might be, the benefit of introducing the recommendation is not proven. Of course, a necessary condition of a cost/benefit analysis is that the positive effect – the achievement of the objective – and the costs are measured in terms of the same metric.

The article is structured as follows: Section 2 highlights the existing disadvantages of the current FLW research overall, while Section 3 explores whether the first official FLW study (FAO, 2011) can be used as a reasonable source of information for policymaking. Section 4 reviews the new Food Loss Index (FLI) proposed by the FAO, which aims to harmonise the methodology used in research on FLW and the assessment thereof, while Section 5 argues that policies for reducing FLW effectively should target those spots within the supply chain where a cost/benefit analysis indicates a positive benefit. The last section concludes.

Issues with the Existing FLW-Research

The majority of available FLW-related studies focus on specific countries or regions and avoid presenting a worldwide picture. In this regard, the studies by the USDA Research Service and studies sponsored by the FAO stand out. However, their methodologies differ in many respects.

First, *the definition of FLW differs.* There are more than a hundred different definitions of 'food loss' and 'food waste' in the literature (Koester, 2014). Some studies include all stages of the supply chain in data collection, whereas others narrow their definition of the supply chain and neglect losses in production at the farm level. There might be good reasons to define FLW differently, but the findings are not comparable. For example, see the three definitions referred to by Parfitt *et al.* (2010, p3065):

'(1) Wholesome edible material intended for human consumption, arising at any point in the Food Supply Chain (FSC) that is instead discarded, lost, degraded or consumed by pests.
(2) As (1) but including edible material that is intentionally fed to animals or is a by-product of food processing diverted away from the human food.
(3) As definitions (1) and (2) but including over-nutrition – the gap between the energy value of consumed food per capita and the energy value of food needed per capita.'

Monier *et al.* (2010, p7) use only the term *food waste* and define it as the following: 'fractions of "food and inedible parts of food removed from the food supply chain" to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).' Buzby and Hyman (2012, p561) present the following definition: '... food loss is a subset of post-harvest losses (or post-production) and represents the edible amount of food available for human consumption but is not consumed. Food waste is a subset of food loss.'

On the one hand, this flexibility allows one to shape a definition which corresponds to the specific purposes and needs of one's particular research project. On the other hand, it makes it difficult to compare various papers, as the different authors' understanding of what constitutes FLW, what is included and what is not may vary drastically.

Second, most studies count as 'food' all items produced by farmers and *intended for human consumption*. Those product items which left the food chain due to rejection by customers or were used for feed due to low food prices, are considered as a loss. This also holds for food redistributed to food banks, even though it is a measure to fight hunger. Some studies calculate farm produce as a whole even if some parts of it are intended for non-food purposes.

Third, another very important problem is the *question of aggregation*. Products are defined in economic terms very narrowly. Products are only the same (i.e., they can be aggregated) if they have the same physical dimension (including quality), if they are at the same location and if they are evaluated at the same time. Grain at harvest time is not identical in economic terms to grain before the next harvest; a raw agricultural product such as potatoes cannot be aggregated with meat products in metric tons. Aggregation is also a problem when the FLW volumes are calculated in calories. The economic value of a product is not always only related to the calorie content. Many studies try to add up products along the supply chain and do not take into account that most food items are joint products, incorporating agricultural raw commodities, services added along the supply chain (e.g., transport, marketing, etc.), as well as by-products. Hence, aggregating different agricultural products as if they were comparable, or aggregating products with the same origin but at different stages of the supply chain, is not reasonable from an economic point of view.

Fourth, *valuation of FLW* is necessary to quantify the economic value. If instead a study just adds up the weights of individual lost food items, it does not inform its readers as to whether food loss reduction is an economic or a political problem. Moreover, to conduct a cost/benefit analysis, one needs to know the economic value of the loss. Very few FLW studies present such calculations. Some studies assume that the economic value of a discarded food item is identical to that of the food that is consumed. Such an assumption leads to an overestimation of FLW. Products discarded are, most of the time, inferior in quality or are leftovers on the plate because, for example, the consumer did not like parts of the meal, such as the fat of a steak.

Fifth, most studies convey the impression that reducing FLW depends only on goodwill, hence, *costs for FLW avoidance or reduction are not mentioned*. This also holds true for the FAO study (FAO, 2011). Furthermore, it is worth highlighting that SDG 12.3, which calls to halve FLW worldwide by 2030, does not even reflect avoidance costs. Actually, we have not seen any study on worldwide FLW that includes an assessment of avoidance costs. It is quite understandable that this information is not available as avoidance costs for each specific food item differ across countries, and these costs depend on whether the total loss and waste of each product can be avoided or whether only marginal changes can be made. In addition, it is important to know the aggregated avoidance costs across products within a country and across countries in order to learn what the net benefit would be if every country halved FLW by the year 2030.

To conclude this section, we advise policymakers to aim to obtain more specific data which may allow for the development of efficient policies for reducing FLW. It should be noted that each individual country should not aim at reducing FLW by the same percentage. The food production structure, the level of technologies, and the institutional frameworks, including domestic policies, differ significantly across countries. Therefore, the avoidance costs of FLW will likely differ across products and across countries. If the world community aims at reducing FLW efficiently, i.e., by taking into account avoidance costs, the percentage reduction of FLW should not be the same for each country but should be higher than the average for those countries where the expected net benefit is the highest.

There are some recent studies available, which assess the net benefit for specific focused policies; either on specific points of the supply chain or on specific products (e.g., see Sethi *et al.*, 2020). Such studies could contribute to an efficient reduction of specific FLW and of overall FLW.

FAO (2011) Report: Data Quality Issues

The FAO report of 2011 uses the definition of food loss and waste based on Parfitt *et al.* (2010): *'food losses'* refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. Food losses take place at production, postharvest and processing stages in the food supply chain. Food losses occurring at the end of the food chain (retail and final consumption) are rather called *'food waste'*, which relates to retailers' and consumers' behaviour. This definition also highlights that FLW 'is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible.' (FAO, 2011).

It is worth mentioning that the FAO report itself highlights that 'due to lack of sufficient data, many assumptions on food waste levels ... had to be made' and calls for interpreting the results with great caution (FAO, 2011, p15). However, its findings nevertheless became the cornerstone of the FLW reduction discussion. That is why we think it is necessary to look at its methodology in more detail.

The starting point for compiling the data set is the FAO Food/Balance/Sheets (FBS) Data from national/regional FBS, together with the weight percentages of FLW; they were used to quantify the volumes of FLW for each region and commodity group separately (FAO, 2011, p3). The FAO has the mandate to collect data about food production and consumption and food security. The information is available in metric tons and in calories. FBS are set up for 152 countries out of the 193 UN member countries worldwide. Thus, it is obvious that this data set does not allow conclusions to be made about FLW worldwide; moreover, the data included in the FBS are objectively not very reliable – as well as the figure presented for FLW of the individual food products. The reason is that FBS data include estimates on FLW for each specified product. These data can be considered as expert estimates that may have significant standard errors. FAO (2011) started with this information and tried to improve the estimates based on a literature review and information from individuals working in specific product supply chains. However, data reliability remains an issue, and the numbers can hardly be considered as accurate estimates of global FLW.

The reliability of the FBS data has been assessed by a comparison with the Global Dietary Database (GDD): the authors concluded that 'for most food groups, FAO estimates substantially overestimated individual-based dietary intakes by 74.5% (vegetables) and 270% (whole grains), while underestimating beans and legumes (-50%) and nuts and seeds (-29%) ($P < 0.05$ for each)'. Furthermore, 'for all food groups and total energy, FAO estimates substantially exceeded or underestimated individual-based national surveys of individual intakes with significant variation depending on age, sex, region, and time.' (Del Gobbo *et al.,* 2015, p1038).

The FAO study, moreover, did not include a reasonable estimate of the benefits and costs involved in reducing FLW. In actual fact, the methodology was not adequate for delivering data needed for a comprehensive cost/benefit analysis. Quantities were added up and considered as the potential benefit which could be achieved. The aggregation problem had been completely ignored, and possible costs incurred for reducing the FLW were not taken into account. Nevertheless, this study was of high importance as it created an awareness about the food loss problem in a world where hunger is still widespread. Furthermore, the study did important work in presenting the FLW as an economic and ethical problem. However, the study's findings do not seem to offer a sufficient basis for the UN to set a quantitative target for FLW reduction in 2030.

Consequently, we can infer that any empirical assessment for checking whether the UN countries are on track to achieve the FLW reduction target for 2030 can hardly be based on the methodology used by FAO (2011). Moreover, the current SDG target might need to be reconsidered.

Food Loss Index Discussion

In 2015 the UN agreed to halve global food loss and waste by 2030. Reviewing the actual performance of instituted policies needs a careful diagnosis of the performance both in individual countries and worldwide. Hence, there is a strong need for a publication that will aim at clarifying the importance of specific assumptions and proposing a new methodology for further research. Without a harmonised measurement of FLW in individual countries, the 2015 UN agreement cannot become effective. The FAO obviously accepted this challenge. The mission of the FAO is 'helping to build a food-secure world for present and future generations'. Hence, the FAO is in charge of submitting proposals for harmonising alternative approaches. Indeed, in its flagship publication, 'The State of Food and Agriculture 2019', the FAO presented a new approach to be considered as a blueprint for further work on this topic. The FAO's publication is timely and more than welcome. However, for the competence of the FAO and the many consultants of the organisation to be accepted, a discussion about the output in the wider research community needs to happen.

Definition

In order to fulfil SDG 12.3, the FAO presented a new definition of FLW in 2019. According to the FAO, this new definition is supposed to become the common denominator for the majority of research and data-collection activities. The distinction between food loss and food waste has an important impact on the measured quantity of food loss. Let us have a closer look at the definitions:

'*Food loss* is all the crop, livestock and fish human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter/catch supply chain by being discarded, incinerated or otherwise disposed of, and do not re-enter in any other utilisation (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transportation and processing, as well as imported products, are therefore all included. Loss includes the commodity as a whole with its inedible parts.' (FAO, 2019, p10).

'*Waste* occurs from retail to the final consumption/ demand stages. However, waste is not included in the FLI.' (FAO, 2019, p10).

As Figure 1 demonstrates, food products, like other tradable products, move along a specific supply chain. Loss of food can be found at all stages of the supply chain. The FAO definition of 2019 includes only losses that occur during stages 1-3, because food waste will be calculated separately as the Food Waste Index by UN Environment Programme (UNEP).

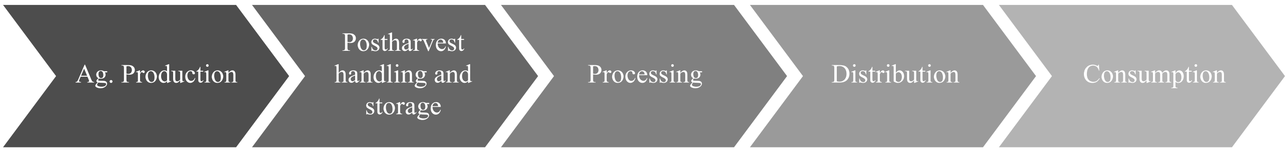

Figure 1: Example of a Food Supply Chain.
Source: Urutyan (2013, p4.)

Consequently, food loss is not identified along the whole supply chain; this marks a significant difference from other studies on food loss. Thus, the findings of the FAO study are not comparable to the findings of other studies. Moreover, this definition is not in line with the methodology used to define the UN target, which has been based on the actual food loss estimation of 30 percent of world production. Consequently, the use of the proposed definition in the first place would have resulted in a significantly lower estimation of food loss and, thus, the UN might have established a different number for the SDG 12.3.

The FAO considers only those products that leave the farm gate, although some other researchers take into account the losses in the fields due to inefficient use of inputs for increasing plant and animal production. It is known, for example, that there is a huge variance across farms in yields where generally large farms have higher crop yields than small farms. Hence, it may make sense to include this potential additional production in the calculation of food loss.

In addition, the FAO definition looks at the commodity as a whole with its edible and inedible parts. This raises the question whether it makes sense to include inedible parts of the commodity in FLW computations. If we take a pig as an example, according to the definition, we should consider it as a whole and ignore the fact that some parts of the animal may be used to produce non-food products, such as soap, concrete, or paint. (Koester *et al.,* 2013).

Food diverted to other economic uses, such as animal feed, biofuel, charity, etc., is no longer considered as food loss (FAO, 2019), which is a reasonable change. Although such diversion usually leads to the loss of resources anyway, it is an important measure to reduce FLW worldwide.

Methodology of the FLI

The FAO developed the FLI to monitor food losses to help meet the target set by SDG 12.3. The Index is supposed to provide information about food losses on a global level for a set of key commodities from harvest until retail and measures trends in percentage losses over time compared to the base period of 2015. Consequently, the FAO intends that the numerical value of the Index should urge the countries to develop policies to reduce losses at the national level and keep tracking the trends (FAO, 2019).

Any index is based on metric variables and their development over time. For simplicity's sake, any index shows the development of a specific basket over time. If there is more than one specific item in the basket, those items are aggregated. The Index can be explained in the following form: quantities are aggregated into an overall percentage at a national level (FAO, 2019). Hence, the FLI – contrary to the definition of food loss – does not provide information about the *quantity* of food loss and waste. Instead, it calculates the *value*. However, the value of loss is not necessarily equal to a certain share of food production. Sometimes, it is cheaper for a farmer to leave some crops in the field than try to sell it. Or, the price of some lost/discarded products, like small potatoes or spoiled apples, will be understandably lower than the price of the total production.

The commodities' economic value of loss is calculated in international dollars, meaning that the average country price in local currency is converted into international dollars using Purchasing Power Parity (PPP). The calculations are based on the assumption that 'markets operate efficiently in valuing the commodities' importance'. The FLI is based on the food loss percentages (FLP) for each commodity in the basket. Percentage points instead of physical quantities allow one to observe long-term trends and avoid year-to-year fluctuations (FAO, 2019).

The FLI can be calculated by the following formula (FAO, 2019, p125):

$$FLI_{it} = \frac{\sum_j l_{ijt} \cdot (q_{ijt_0} \cdot p_{jt_0})}{\sum_j l_{il0} \cdot (q_{ijt_0} \cdot p_{jt_0})} \cdot 100 \qquad (1)$$

In this formula:
l means losses
i means a country
t means a current period
t_0 means a base period
j means a basket of commodities
$(q_{ijt_0} \cdot p_{jt_0})$ means the value of production.

The Index changes over time if the value of the loss at constant prices changes. To calculate the FLI, individual countries had to choose top ten commodities by economic value within five commodity groups. Loss measured in physical terms of each food item had to be collected for the base year and the following years. These quantities were valued with a derived farm-gate price for 2015 in the base year and the following years.

Consequently, we can find the following weak points of the FLI:

a) The FLI assumes that the implicitly used value of the individual quantities is equal to the economic value of the loss. That can only be true if the economic value of discarded product items was equal to the economic value of produce at the farm gate. This assumption does not reflect reality.
b) Products moving along the supply chain change their economic value because other products and services

are added to the raw product. Using farm-gate prices for evaluation underestimates the economic value.

c) The quality of the discarded products is likely lower than the average quality of the consumed products. Consequently, the economic value of the discarded product may be overestimated.
d) It is misleading to assume that the FLI informs on the expected benefit of instituted policy measures. Reducing food loss needs resources in most cases. There is a gain on one side but resource costs or avoiding costs on the other side. These avoiding costs differ significantly from product to product.
e) The FAO uses international prices in US dollars for aggregation of the loss which implies that national farm-gate prices are related to world market prices. However, some of the farm products are not tradable due to high trading costs (transaction, transport and insurance costs). Moreover, the national exchange rate is not as assumed the real shadow price of the domestic currency. Hence, the estimated figure for the aggregate used in setting up the FLI provides no help for policy makers to find out what induced changes in selected products and stages of the supply chain might lead to the highest benefit.

Aggregation

Aggregation is the issue common to all indices. However, we would like to discuss it more in detail in relation to FLI as it has a potential to provide highly misleading data. In economics it is widely agreed that products can be aggregated only if they are identical from an economic point of view, namely quality, time and location. However, the FLI aggregates very dissimilar commodities. For instance, what information do we really get when yearly losses of meat, fish and vegetables are aggregated in the same percentage number on a national, international, or a global level? Individual commodities may also drastically change along the food supply chain, like wheat, flour and cake. Even moving from one stage to another on a supply chain leads to different products. The FAO itself claims that countries should disaggregate the FLI up to sub-national levels, points of the value chain, and even economic sectors (FAO, 2018).

However, overall, the FAO report does not deal explicitly with this problem. It mentions that the loss of individual products along the supply chain is aggregated by using producer prices. Using this procedure implies that the quality of a specific product does not change along the supply chain and that as a result, the discarded food has the same quality as the food item used for human consumption. This implicit assumption is not realistic. The quality of the food changes along the supply chain. The food leaving the farm gate is in most cases not ready for consumption. Therefore, the discarded food is often of lower quality than the food which has left the farm.

The FAO uses the same procedure for aggregating the loss of different products across different countries: it takes national farm-gate prices and converts them to world-market prices. The national average loss valued with national prices is transformed into International Dollars using the exchange rate. It implicitly assumes that the actual exchange rate in 2015 was the same throughout the year. One world-market price is used for each specific food item. This procedure does not accurately inform policymakers how to design a specific policy for improving food supply since it is based on flawed assumptions.

Currently there is no method that will make aggregation meaningful. Hence, it does not make sense to define policy objectives that aim to decrease the overall food loss by a certain percentage. The FAO seems to implicitly accept this reasoning. It calls for ‘the exact measurement of the problem targeted, as well as precise monitoring and evaluation of the interventions’ in policy measures (FAO, 2019).

Quality of Data

Another important issue related to the FLI calculation is, as the FAO itself points out, the scarcity of available country data. Its proportion ‘amounts to a mere 4 percent of observations. The remaining data cells ... are estimations’ (FAO, 2018, p36). In order to compensate for the lack of information, the FAO uses a two-sided approach (FAO, 2019):

1. The FAO has introduced guidelines concerning cost-effective methods countries can use to estimate food losses along the supply chain.
2. The FAO uses model-based loss estimates where data are not available in the short term.

The model is based on three sets of information (FAO, 2019):

1. officially reported loss data;
2. information obtained through a literature review of food losses; and
3. a dataset of possible explanatory variables taken from various international databases (International Energy Agency, the World Bank, FAO, etc.).

Let us take a closer look at a quick example. As mentioned above, the model is based on officially reported data; a literature review of food losses; and a list of variables. If we look at the Russian Federation, the official data about FLW here is provided by the Russian Federal State Statistics Service (Rosstat). Rosstat calculates the numbers based on the food balance method, which results in approximations considerably below real numbers. The drawbacks of the existing methodology are widely acknowledged; however, a better methodology does not exist. The literature shows that Russia lacks a comprehensive analysis of FLW along the food supply chain or an extensive country report. The only paper that provided some preliminary percentages of FLW was based on research carried out in 2019 by the Skolkovo Consumer Market Development Centre. However, the percentages are fully based on expert interviews and may only provide approximations and not concrete data. Thus, the only possibility left to build the model are explanatory variables.

Judging by this example, we can infer that the FAO model is unable to provide necessary information about concrete causes of food loss in specific countries or specific food supply chains (FAO, 2019), meaning that currently it is almost impossible to propose any political measures based upon the FLI. This also poses the question about the reliability of the Index itself. Certainly, when more countries start sending their food-loss-related information, the Index will become more accurate. However, currently the FLI may over- or underestimate the global food losses and thus cannot be used for policy decisions.

Policy Dimension

Purposes of the FLI

According to the FAO, the double purpose of the FLI is to monitor SDG Target 12.3 and to provide information for policy makers to create effective polices intended to reduce food loss and waste (FAO, 2018). In this section, we are going to take a closer look at whether the FLI meets these intended goals.

In order to outline the measures to reduce food loss, decision makers should carry out a cost/benefit analysis to make sure that the measures are economically sensible, identify all stakeholders and calculate the winners and losers of those measures.

The current global FLI states that 14 per cent of food is lost along the FSC between post-harvest and retail stages, excluding retail. This number aggregates various heterogeneous commodities without taking into account their economic value along the FSC. Moreover, it is based on scarce information and is mainly an estimation. Even when compared with the next years' FLI in the future, we will not be able to tell whether positive trends in some countries can outweigh negative trends in other countries, or even how those trends will be reflected in the aggregated Index. Again, the FLI does not provide any data concerning costs and benefits of food loss reduction, economic value of losses and opportunity costs. Thus, the FLI gives no information that will help to achieve the SDG Target 12.3.

Cattaneo *et al.* (2020) propose that the following questions should be answered to formulate a FLW-related policy:

- Do we know how much food is lost or wasted?
- What are the causes of FLW?
- What interventions are best suited to address FLW and how should we target them? Should policymakers focus on loss, waste or both?
- What is the rationale for public intervention? How ambitious should we be in setting reduction targets?
- Are there trade-offs and unintended consequences of reducing FLW?

The FLI does not provide specific data on any of these questions. The FAO discusses specific policy measures supposed to reduce food loss, like climate-friendly cold storage in Morocco, an innovative pricing technology in Spain, simplified legislation for food donations in the European Union and so on (FAO, 2019). These measures seem very reasonable. However, none of them use aggregated data as set up by the FAO. Hence, why do we really need the Index to propose a policy?

Furthermore, the Index does not tell us whether food losses are the result of a market failure or a policy failure. Consequently, disaggregation is needed to find out where changes in policies or human behaviour are required. The FAO calls for the exact measurement of the targeted problem, as well as precise monitoring and evaluation of the interventions. In the flagship report (FAO, 2019), FAO provides a number of specific case studies related to FLW reduction, and all of them were based on well-defined hotspots of specific supply chains. This information is crucial as in some cases the avoidance costs might be higher than the economic value of the saved food. Some food loss might be unavoidable, like some storage losses or spoiled vegetables in the field due to the weather conditions or to incorrect forecast demand. However, none of these variables are reflected in the Index.

The FLI does not make clear connections with the broader issues usually associated with FLW reduction, like the increase in efficiency of the food system, improvement of food security and nutrition and contribution towards environmental sustainability. The relations between FLW reduction and food security may be more complicated than it seems at first sight. For example, the greater observability of aflatoxin contamination of maize will lead to the removal of the unsafe food from the supply chain. While this will increase food safety, it may also result in more food losses (Cattaneo *et al.,* 2020).

The influence of the measures to reduce food loss on the environment depends on the specific situation as well. For example, failure to maintain a cold chain – one of the major causes of food losses – may place more pressure on other resources. For example, refrigerators installed in trucks at the transportation stage of the FSC demand much more gas or diesel for the same route, thereby imposing supplementary financial and environmental pressures. Such information may be crucial for shaping a specific policy; however, it is not provided by the Food Loss Index.

Policy implications

To our mind, the greatest problem with the Index is its aggregation of the data. There are no arguments in favour of aggregating various commodities in different countries and adding up the results in the form of the same percentage point. If we accept that different (in economic terms) products cannot be aggregated in a reasonable manner, then it will mean that the information from the FLI cannot be used as the basis for a rational policy decision. Even if the Index number changes on a year-by-year basis, the Index does not provide information about the causes of the change, and, thus, cannot be used for instituting a target-oriented policy decision.

The Index does not inform about the avoidance costs of FLW reduction either. In order to create targeted policies to reduce food loss, policy makers should first try to identify those spots in the FSC where policy measures would most likely lead to a positive economic benefit (avoidance costs are smaller than the benefit of having reduced the food loss). If this statement is accepted, the task of the government will be to improve the economic efficiency of the economy. Thus, data collection can be helpful to identify hot spots where policy intervention may lead to greater overall gains. Of course, inefficiency in production of raw food must also be targeted in the search for hot spots.

At the same time, in order to create effective policies for food loss reduction, decision-makers should know the overall costs and risks associated with reducing FLW. This statement is even supported by the FAO: 'Reducing food loss and waste generally entails costs, and suppliers and consumers will only undertake the necessary efforts if these are outweighed by the benefits.' (FAO, 2019, p17). Hence, the Index can only contribute to policy making if it informs about both the economic value of the losses and the economic value of the costs. It is obvious that both – the loss and the avoidance costs – have to be measured in the same metric. Moreover, as food losses are tightly connected to scarce resources, it is especially important to take into account the waste of those resources in other areas of the economy. In this case, the solution seems to be to identify specific spots of the supply chain where policymakers can contribute to resource savings (FAO, 2019).

The Index does not reflect the quality of the products along the FSC, as volume-based measures tend to ignore most of the services involved in delivering food to consumers, prices on different stages of the FSC, production costs or opportunity costs (Koester, 2020). The scarcity of information is another important issue, which leads to excessive estimations in the Index. Furthermore, the Index does not inform us whether food loss reduction will lead to a more efficient use of resources or whether more food will be available as a result.

The recommendation we have is to continue research about FLW along the FSC and collect as much detailed and disaggregated information as possible. This concerns all stakeholders from governmental organisations, to business, academia, NGOs etc. There are still whole regions where the FLW issue has not yet been taken into account, and consequently, there is no available data on food losses and waste from those parts of the world. However, calls for action should not be based on estimations only, as rigorous research and data collection will enable us to discover specific country-related issues. Consequently, we suggest – totally in line with the FAO – that policymaking on FLW reduction should be as specific and precise as possible. In this view, it is also important to remember that some food losses are unavoidable or make sense, as food loss reduction, in some cases, may demand more resources and cost more than the existing food losses.

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Multidimensional assessment of European agricultural sector adaptation to climate change

The agricultural sector and how it relates to climate change is today emerging as a central subject of debate and critique, because it is heavily impacted by, and at the same time, a primary contributor to, climate change. The intertwined, complex relationship between the sector and climate change is among the unprecedented challenges now facing the European Union (EU). The complexity of the relationship calls for the establishment of a sustainable, future climate-proof, adapted and resilient sector with strong adaptive capacity. This paper argues that over the past decades, strong emphasis has been placed on how to mitigate the negative effects of climate change across the sector, causing it to fall behind in terms of adaptation. Although adaptation is now part of the sector's development agenda, sectoral adaptation performance across member states remains low. In order to justify an accelerated adaptation process across the sector, the paper develops a Relative Climate Change Adaption Index (RCCAI) for the sector based on Eurostat data. The analysis shows that there is no single member state across the EU whose agricultural sector can be considered as fully climate-adapted (resilient), and thus validates the hypothesis that adaption efforts must be stepped up across the sector. To ensure continued sectoral adaptive capacity improvement, the paper recommends coherent integration and accelerated implementation of adaptation practices and policies alongside the Common Agricultural Policy (CAP) for the sake of both private and public interests.

Keywords: Climate change, adaptation, Relative Climate Change Adaptation Index, climate-proof agriculture, climate-adapted agriculture

JEL classification: Q15

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Introduction

Agriculture is one of the most dominant European land-use sectors, accounting for approximately half of the European Union (EU-28) area (EC, 2015; Schmidt, 2019). The European Environmental Agency (EEA) explains that the sector not only contributes to, but is also influenced by, climate change (EEA, 2020). The complexity of the sector has resulted in overemphasis during the past decade on mitigation as compared to adaptation (Garnett *et al.,* 2013; Ignaciuk and Croz, 2019; Moore *et al.,* 2017). Despite these controversies, the sector holds high potential for adaptation to climate change. At the EU level, the necessity for the accelerated sectoral adaptation to climate change is evident from the prioritisation of adaptation to the level of an objective in the new CAP (EEA, 2020; Lankoski *et al.,* 2018).

The European Commission (EC) acknowledges that sustainable food production, coupled with climate change, calls for a multi-stakeholder approach in order to ensure that farmers build strong adaptive capacity (a climate-proof future) to withstand the rapidly changing environmental conditions. The sector's adaptation to climate change has the potential to build strong resilience while increasing its competitiveness in food production and environmental conservation terms at both a regional and a global level (EEA, 2020).

In the pursuit of a climate-proof future, the EU, through the CAP, has established itself as a global leader in managing the effects of climate change. The EU has been in the front line, globally championing the best way to handle the uncertainties while making the agricultural sector and the rural areas adopt Green Growth. The EU Green Deal as a growth strategy is geared towards making the EU to be the first climate-neutral continent by 2050 (EC, 2019b). Green Growth in the agricultural sector is a product of the low carbon sector. Aiming for carbon neutrality is a mitigation strategy in the short term, but adopting and implementing the practices in the long run transpires to be adaptation (Attri and Rathore, 2010; Ignaciuk and Croz, 2019).

Currently, joint efforts towards zero emissions by 2050 across all member states are gaining high importance (EEA, 2020; Garnett *et al.,* 2013). European agriculture contributes approximately 10% of total EU greenhouse gas (GHG) emissions (Bellocchi *et al.,* 2017). The Macsur Knowledge hub recently concluded that the greatest challenge is not mitigating the emissions but determining the possible ways through which farmers can survive the net-zero emissions (Roggero, 2018). Although there exists great information on adaptation, execution and implementation remain the greatest challenges for farmers.

The European agricultural sector development is highly driven by multiple factors that are characterised by regional variation, thereby doubling its complexity (EEA, 2020). To establish a sustainable sector characterised with high adaptive capacity and strong resilience to climate change, its prerequisite is to ensure smooth integration of societal values and economic objectives (Lipper *et al.,* 2018).

The European agricultural sector vulnerability to climate change offers two different opposing scenarios based on geographical location and the attributable seasonal changes. The European Commission points out that production patterns are expected to alter due to climate change (EEA, 2020). They see the emergence of new diseases, and the occurrence of unprecedented catastrophic events as factors significantly contributing to these changes. The occurrence of such events will heavily influence farmers' income across the EU depending on their geographical location, in turn influencing

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farm income distribution. The implication of such changes can result in increased food insecurity or increased commodity production due to production zone migration, causing market price distortion.

Leveraging adaptation approaches to match mitigation efforts is essential (Long *et al.,* 2016; Nelson and Stroink, 2014). These studies explain how most of the adaptation measures and strategies in place employ "mainstreaming" adaptation approaches, which they criticise as problematic since they fail to address what can be adapted to by farmers. In their opinion, the adaptation process should be an integral part of societal development and not treated as a separate entity. As they see it, integrating adaptation to climate change into people's ordinary way of living should mean that the sector implements adaptation as a necessary part of its development and not as a driving force for fighting against climate *per se*.

This problem with mainstreaming adaptation can be addressed by shifting towards transformative adaptive measures (Fedele *et al.,* 2019). These scholars have outlined that transformative adaptation goes beyond understanding the impacts of climate change on the sector to the extent of developing site-specific real-time adaptation techniques. Upholding the importance of private goods or farm values in adaptation further differentiates the two approaches (Chambwera *et al.,* 2015; Pelling *et al.,* 2015). The establishment of strong knowledge hubs has the potential to increase the sectoral adaptive capacity (Perez Perdomo *et al.,* 2010). Establishing a multi-actor approach leads to knowledge cross-fertilisation and eventually a one stop-shop for solving farmers' problems (Edward *et al.,* 2019; Karlsson *et al.,* 2018; Mitter *et al.,* 2020; Reidsma, 2007).

The existence of insufficient investment in research and development in the European agricultural sector, coupled with weak Agricultural Knowledge and Information Systems (AKIS), contributed to slow sectoral growth (8%) as compared to over 11% in the previous decade (Klerkx *et al.,* 2019). According to Goda and Kis (2017) and Pardey *et al.* (2013), there may exist an inverse relationship between countries' development curve and investment in agricultural research, with highly developed economies being more likely to invest less in agricultural research and development, a situation that is attributable to a congruence effect.

Establishing a healthy co-existence between both the vertical and horizontal actors across the agricultural sector in the implementation of adaptation measures is a plausible pathway to setting up a food system that is resilient to climate change. Diversification of policy stakeholders compounds the complexity that arises due to the implementation of conflicting decisions; this necessitates the adoption of transformative policy change (Goldenberg and Meter, 2019; Jpi *et al.,* 2016).

Determinant factors for the agricultural sector adaptation to climate change

The future of European agriculture, coupled with climate change, represents one of the most debatable scenarios and issues to be addressed (Bozzola *et al.,* 2018; Reidsma, 2007). Temperature and rainfall variations are some of the evidence that has been held accountable for changes in agricultural zones across Europe (Ciscar *et al.,* 2019). Continuous temperature changes are projected to have a negative effect on Southern Europe, as opposed to Northern Europe agri-zones, where extension to growing seasons is predicted to occur (Ciscar *et al.,* 2019). Although temperature and precipitation contribute significantly, local weather conditions play a deterministic role in these changes (Bozzola *et al.,* 2018; Dixon *et al.,* 2015).

The pursuit of a climate-resilient agricultural sector is highly driven by multiple factors that are less costly if initiated and implemented now than in the future when defining sustainable food systems (Chaudhary *et al.,* 2018). An ideal scenario conducive to sustaining adaptation is more likely to come into existence through an identification of the trade-offs between the desired practices that ensures a win-win interaction (Lankoski *et al.,* 2018; Shrestha and Dhakal, 2019). In such a trade-off identification, irrespective of whether the complex systems are autonomous or semi-autonomous, the aim should be to establish a climate resilient sector (Holzkämper, 2017; Olde, 2017; Sacchelli *et al.,* 2017).

Agricultural water management

Water is a core issue in adaptation to climate change in the agricultural sector (OECD, 2014). There exists a complex interaction between water, climate change and agriculture, one that calls for a critical approach. Climate change-related risks are projected to intensify in those regions perceived as water scarce (Iglesias and Garrote, 2015). The OECD highlights the reduction in water availability through precipitation, the interference with the water quality through surface runoff, river flows, accumulation of nutrients and the occurrence of extreme disasters such as droughts as some of the eminent potential effects of climate change on agriculture and water (OECD, 2014). The associated impacts of the water resource change due to climate change varies across the sector causing destabilisation of markets, triggering food insecurity and imposing strain on non-agricultural water uses (Sordo-Ward *et al.,* 2019). Climate change has the potential to interfere not only with the availability of water but also with specific water requirements which vary from crop to crop, season to season and even farm to farm (Falloon and Betts, 2010; Mateo-Sagasta and Jacob, 2011). To protect against such negative effects, the European Commission advocates sound water management as being of decisive importance to the future of the agricultural sector (Kahil *et al.,* 2015). They propose adoption of increased efficient water use and effective land use practices in line with the Water Directive Framework (WFD) to increase sectoral adaptive capacity while continuing to maintain "good" water status (EC, 2008).

Compared to other sectors, European agriculture has huge potential to ensure sustainable water management. The sector, if well maintained, can improve the soil's water holding capacity and reduce the high levels of consumption of natural waters. The sector is responsible for 22.5% of water abstraction and 60% of freshwater abstraction, facts which make sustainability of water abstraction imperative.

To ensure the sustainability of this scarce resource, the EU has put in place instrumental policies that have highly supported the initiative. The Nitrate Directive (EC, 2020c) has had a measurable effect on water quality through the reduction of pollution. Moreover, the Sustainable Use of Pesticides Directive has recently served as an important instrument contributing towards the achievement of "good" water status (EC, 2009a, 2009b).

Agricultural biodiversity management

The use and application of agricultural biodiversity have been applauded as a plausible concept for climate smart agriculture (Abrams *et al.,* 2017; Dabkienė, 2016; Lipper *et al.,* 2018; Shortle and Uetake, 2015). According to this view, agricultural biodiversity can be perceived as an approach aimed at reorienting the way sectoral biodiversity is conceptualised, starting out from the genetic, species and ecosystem levels. Adoption of sectoral biodiversity has the capacity to transform both inter and intra-diversity at the farm level, leading to increased production, resilience and adaptation to climate change (Jones and Silcock, 2008; Lankoski, 2016). The outcome of such diversification, besides resilience and an increased adaptive capacity of the sector to climate change, is food security due to reduced deterioration of soil quality, reduced prevalence of pests and diseases and improvement of the farm wellbeing in general (Lin, 2011; Taguas *et al.,* 2015).

Across the EU agricultural sector, the importance of farm diversity is emphasised by the biodiversity strategy (European Commission, 2020) as an element essential to bringing back nature to the sector. The strategy outlines the measures that can be followed to ensure nature coexists with farm practices sustainably. In compliance with the Kyiv Resolution on Biodiversity, all EU member states agreed to identify all high nature value areas and have favourable management of substantial portions of them in order to conserve the environment (Paracchini *et al.,* 2008). Preservation of high nature value areas can potentially serve as biofilters and bioremediations, thereby improving the quality of soil, water, and air so as to create an enabling environment for agriculture.

One objective of the EU Biodiversity Strategy-2030 is to increase the contribution of the agricultural sector in the reduction of biodiversity loss. Under the CAP, the EU introduced "greening" measures to improve biodiversity within conventional agriculture and support traditional knowledge and practices in rural areas. The EEA pointed out the declining biodiversity trend across Europe that necessitated the development of the Biodiversity Strategy 2030 for post-2020 biodiversity control. The Biodiversity Strategy 2030 aims to put Europe's biodiversity on the path to recovery to ensure it is people-oriented, climate-, and planet-friendly (EC, 2020b; Garnett Tara, 2013).

Agricultural environmental management

The agricultural sector and the environment are inseparable entities characterised by a complex relationship. To reduce the complexity and promote coexistence, prioritising sound environmental management is crucial (Eichler *et al.,* 2018; OECD, 2017; Reidsma, 2007). One possible cause of the sectoral environmental degradation is waste generation. Agricultural waste and by-products across Europe are responsible for almost half of the total solid waste equivalent to 700 Mt annually (Pawełczyk, 2005). This implies that the agricultural sector is responsible for wastes other than food that need to be accounted for if one is to regulate environmental degradation. Over 88 million tonnes of food is wasted across the EU and is expected to go up to 120 million tonnes (Caldeira *et al.,* 2017; EC, 2018c).

Biodegradable waste, where agricultural waste lies, has been responsible for approximately 3% of methane emissions. Reducing agricultural waste and the promotion of more efficient agricultural systems through conversion of the waste into inputs for energy production is a plausible sectoral adaptation pathway that simultaneously implements the 1999 Landfill Directive that required member states to reduce their biodegradable waste by 35% by 2020 (EC, 2018a).

Agricultural soil management

A future involving healthy soils in Europe calls for better management of peatlands and wetlands, a goal that can be achieved by ensuring that Good Agricultural and Environmental Conditions (GAECs) are practised (EEA, 2020; Hatfield *et al.,* 2018; Thaler *et al.,* 2012). Under the GAECs, farmers are required to use the Farm Sustainability Tool (FaST) for developing their nutrient management plans (EC, 2019a). GAECS are linked to direct income. To promote voluntary health soil management practices, the CAP under the "eco-schemes" incentivises local practices directed towards managing healthy soils like agroforestry, organic farming, afforestation, and agroecology (EC, 2020b). In practice, advances in technology are setting the direction for soil health in the future; hence, due to precision farming, increasingly the right amount of nutrients and pesticides are being applied (Delgado *et al.,* 2019; EC, 2019b).

Agricultural energy management

One of the objectives set by the EU under the Green Deal is renewable energy. The agricultural sector has great potential to achieve these objectives. Despite the potential farms possesses, the sector still faces technological, social and economic barriers to transitioning to renewable energy (EIP-Agri, 2019). Some of the challenges can be overcome by the sector adopting energy efficient farm practices geared towards adapting to climate change (Troost, 2014). Moves towards greater agricultural energy efficiency have been highly driven by the desire for the sector to achieve the EU's clean energy transition objective by 2030 (Warren, 2019). The EU aims to ensure that Europe not only transitions towards green energy but in addition, adapts it. Achieving energy efficiency across the sector has been defined as a challenge faced by the sector. This is due to the nature of food production, as a function of perishable and non-perishable products with different energy demands along the value-chain. To address such a challenge, ensuring efficient energy utilisation across the sector has become crucial. Although more than two thirds of the renewable energy produced in Europe is derived from biomass, with the sector contributing immensely to production of the raw materials, the greatest obstacle is the paucity of hard data on biomass extraction coupled with the limitations placed on extractable biomass in order to avoid depletion of Soil Organic Carbon (SOC) (Henderson, 2011).

The European Commission describes the current agri-food chain as highly energy-dependent, highly reliant on fossil fuels and in need of a sustainable system of energy use (Monforti *et al.,* 2015). Increasing its share of bio-energy has the potential to reduce the impacts of climate change. The EU agricultural sector's energy consumption as a proportion of total energy consumption is estimated at 17 per cent, with over 70 percent of it occurring beyond the farm gate. Coupled with the amount of food wasted, the amount of energy used to produce the wasted food is also accounted for in the figure for the sector (Diakosavvas, 2017). This calls for increased circular production within the sector in order for the value-chain to have zero energy leakage.

Research and development, information, knowledge, and skills management

Although a great number of steps have been initiated across all member states to strengthen their research capacity and build resilience towards emerging and future challenges, the majority of these measures are being implemented at a national level, resulting in a fragmented system. System fragmentation can lead to impaired knowledge sharing and information exchange between farmers and relevant stakeholders (EIP-Agri, 2018). Moreover, the existence of fragmented knowledge and information systems has created a space for innovation brokers who are most likely to exploit farmers (Klerkx *et al.,* 2009; Malinovskyte *et al.,* 2014; The European Network for Rural Development, 2013). The involvement and participation of farmers in the research process has been criticised for its partial inclusion criteria (EIP-Agri, 2018). Establishing a strong, well connected and aligned agricultural research system with farmers at the centre requires high capital investment (Catalano *et al.,* 2020). To counter the climate change-related risks and threats to sector-wide knowledge dissemination and skills development, the European Commission is advocating for efforts to be intensified, involving the public, the corporate sector and individuals to scale-up research and development. All these efforts are geared towards increasing the sectoral adaptive capacity to climate change (The European Network for Rural Development, 2013).

Agricultural economic management

Performing cost-benefit analysis is essential to determining the economic efficiency of any desired practice (Bruin, 2011; Dixon *et al.,* 2015). Although desired practices vary from place to place based on endowments and resources, future benefits must outweigh the planning costs. Farmers tend to select those practices where they can pre-formulate the anticipated outcomes. Increasing farm efficiency in adaptation to climate change has the potential to increase farm output and reduce adaptation barriers (Kurukulasuriya and Rosenthal, 2003; Reinsborough, 2003).

The European Environmental Agency projects that a lack of escalated adaptation to climate change in the agricultural sector would result in a 16% loss of farm income by 2050. To preserve the economic value of these farms, enhancing social-economic aspects that will improve a farm's income while at the same time reducing negative impacts on the environment becomes essential (Attri and Rathore, 2010; EC, 2019b; Ignaciuk and Croz, 2019; Peyriere and Acosta, 2019).

Agricultural social integration

Behavioural change is an effective tool for bottom-up decision-making with a view to increasing society's adaptive capacity (Niamir *et al.,* 2020). The Drawdown Methodology formulates that reorienting societies' approach towards climate change from the larger community perspective to individual responsibility constitutes part of behavioural change (Williamson *et al.,* 2018). The Climate-ADAPT partnership highlights the importance of economic incentives for behavioural change as an important tool in policy-shaping in relation to climate change adaptation and mitigation measures and notes how they can spur accelerated behavioural change (Climate-ADAPT, 2019). Most adaptation incentives and disincentives originate from the government. Overreliance on government support can also be viewed as an obstacle limiting farmers from active involvement in eradicating social issues affecting climate change adaptation (Van Valkengoed and Steg, 2019). Establishing a strong community with the desire to change the ways farmers operate and to create a collaborative approach towards solving climate-related problems could help reduce overreliance on government support.

Methodology

Composite indices are an outcome of a long and elaborate sequential process involving steps that have to be followed keenly (Greco *et al.,* 2019; Hickel, 2020; Saisana, 2008). The authors of this paper, in keeping with composite index development principles, developed a stepwise approach towards creating an agricultural sector Relative Climate Change Adaptation Index (RCCAI). The methodological process was based on the conceptual framework (Table 1) below, involving a series of steps. After establishing the concept, data manipulation involved empirical application of statistical steps such as data selection, aggregation, normalisation, and visualisation. The conceptual framework was developed as a tool for indicator development and determinants development following the literature review. A similar approach was applied by Acosta *et al.* (2020) in formulating indicators for natural capital. The desirability of the chosen indicators was determined by the reviewed literature as presented in the determinants of adaptation section. According to Greco *et al.* (2019), the subjectivity of indicators formulation is one of its strengths when it is supported with well documented evidence (OECD, 2008).

The data for all the indicators was gathered from the Eurostat. Although questions may arise concerning the consistency and the robustness of their data, Acosta *et al.* (2020) and Peyriere and Acosta (2019) propose the engagement of stakeholders in the process in order to evaluate their key interests; this can play a significant role in weighting the indices. Stakeholder engagement was not part of this paper, a fact necessitating further research to validate the indices and updating of the subjective indicators. To ensure coherence and completeness of data from the indicators, simple imputation involving the omission of incomplete data was selected in preference to extrapolation and mean imputation due to the likelihood of the latter approaches involving implausible assumptions (Zhu *et al.,* 2012). The latter authors outlined the challenges of mean imputation in relation to the way it reduces variance thus changing the corelation between indicators.

Index formulation

When working with multidimensional indicators with different units and dimensions, its essential subject the data under normalization process (Pollesch and Dale, 2016). Normalisation in composite index development helps in indicator transformation into uniform scale and unitless numbers for easy comparison (OECD, 2008). The min-max normalisation method(rescaling method) as outlined by (Mazziotta and Pareto, 2013) was applied to align indicators with both positive and negative relationship to the index thus reducing the effect of extreme values on the index. Rescaling was chosen for its simplicity in application and the ability to eliminate extreme values therefore removing outliers partially.

The min-max transformation method rescales the different indicators (X_i) into an identical range (0-1) based on minimum (X_{min}) and maximum (X_{max}) as presented in Equation 1 below.

Table 1: Theoretical conceptual framework.

<table>
<tr><th>Indicators</th><th>Aggregate indicators</th><th>Determinants</th><th>Index</th></tr>
<tr><td>Irrigated utilised agricultural area as a percentage of total utilised agricultural area</td><td rowspan="2">Agricultural irrigation compliance</td><td rowspan="2">Agricultural Water Management</td><td rowspan="27">Relative Climate Change Adaptation Index (RCCAI)</td></tr>
<tr><td>Irrigable utilised agricultural area as a percentage of total utilised agricultural area</td></tr>
<tr><td>The agricultural area protected for Biodiversity</td><td>The agricultural area protected for Biodiversity</td><td rowspan="4">Agricultural Biodiversity Management</td></tr>
<tr><td>Common Farmland Bird index</td><td>Common Farmland Bird index</td></tr>
<tr><td>Agricultural area fully converted to Organic farming</td><td rowspan="2">Organic farming adoption</td></tr>
<tr><td>Agricultural area under conversion to Organic farming</td></tr>
<tr><td>Agricultural pollution tax (euro per ha)</td><td rowspan="2">Agricultural environmental awareness</td><td rowspan="3">Agricultural Environmental Management</td></tr>
<tr><td>Total agricultural tax (euro per ha)</td></tr>
<tr><td>Agricultural waste generation (Kg/capita)</td><td>Agricultural waste generation (Kg/capita)</td></tr>
<tr><td>High input farms as a percentage of utilisable agricultural area</td><td rowspan="2">Soil input dependency</td><td rowspan="5">Agricultural soil management</td></tr>
<tr><td>Low input farms as a percentage of utilisable agricultural area</td></tr>
<tr><td>Agricultural lands under severe soil erosion</td><td rowspan="2">Soil erosion risk</td></tr>
<tr><td>Agricultural lands under moderate soil erosion</td></tr>
<tr><td>Soil nitrogen gross nutrient balance</td><td>Soil nitrogen gross nutrient balance</td></tr>
<tr><td>Biomass extraction per capita</td><td>Renewable energy capacity</td><td rowspan="3">Agricultural energy management</td></tr>
<tr><td>Agricultural energy supply per hectare</td><td rowspan="2">Agricultural energy sustainability</td></tr>
<tr><td>Agricultural energy use per hectare</td></tr>
<tr><td>Agricultural Human Resource Employment in Science and Technology (HRST)</td><td rowspan="4">Research and Development, information, skills, and knowledge management</td><td rowspan="4">Agricultural Information, Knowledge and Skills, management</td></tr>
<tr><td>Research and Development expenditure as a percentage of GDP</td></tr>
<tr><td>Research and Development personnel as a percentage of the active population</td></tr>
<tr><td>Agricultural availability of labour</td></tr>
<tr><td>National Farm income (Standard output)</td><td rowspan="2">Agricultural economic efficiency</td><td rowspan="2">Agricultural Economic Management</td></tr>
<tr><td>Annual work unit (Total hours worked in the farm</td></tr>
<tr><td>Youth Agricultural farm income (SO/ha)</td><td rowspan="2">Agricultural Future attractiveness</td><td rowspan="3">Agricultural Social Integration</td></tr>
<tr><td>National agricultural farm income (SO/ha)</td></tr>
<tr><td>Waste recycling</td><td>Waste recycling</td></tr>
</table>

Source: own composition based on Eurostat (2020) data

$$x_{i\ Normalised} = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \quad (1)$$

Where:
$X_{i\ Normalised}$: Normalised i^{th} indicator
X_i: The value of the aspect/indicator under study
$X_{\min}$: The minimum value of the aspect under observation
$X_{\max}$: The maximum value of the aspect under observation

Post normalisation, differentiation between indicators was based on the literature review because of their subjectivity to determine their nature. To differentiate the indicators, $X_{i\ \mathrm{Normalised}}$ was expressed in two forms as presented in the two equations 2 and 3 below. Equation 2 was applied to the indicators that were considered optimal when their index is high while equation 3 was subjected the indicators that were defined as optimal when their index is optimal when low.

$$S_{D_{ij}} = \frac{x_{D_{ij}} - x_{D_{i\min}}}{x_{D_{i\max}} - x_{D_{i\min}}} \quad (2)$$

$$S_{D_{ij}} = 1 - \frac{x_{D_{ij}} - x_{D_{i\min}}}{x_{D_{i\max}} - x_{D_{i\min}}} \quad (3)$$

Where:
$S_{D_{ij}}$: The *j* sub-index of Dimension *i*
$x_{D_{ij}}$: Member states value in Dimension *i* in aspect *j*
$x_{D_{i\min}}$: Minimum value of aspect j in Dimension i across member states
$x_{D_{i\max}}$: Maximum value of aspect j in Dimension i across member states

The determinants' indices (D_i) were calculated by aggregating the arithmetic mean of the relative sub-indices of the aspects/indicators characterising the determinants as shown in equation 4 below:

$$D_i = \frac{\sum_{i=1}^{n} D\,i_j}{n} \quad (4)$$

Where:
D_i: The determinant index of a member state in Dimension *i*
$D\,i_j$: Sum of sub-indices of Dimension *i*
n: Number of sub-indices in Dimension *i*

The *RCCAI* was calculated as a composite of the different determinant indices using equation 5 below:

$$RCCAI = \sqrt[n]{D\,i_{j=1} \cdot D\,i_{j=2} \cdot \ldots \cdot D\,i_{jn}} \quad (5)$$

Where:
RCCAI: The Relative Climate Change Adaptation Index
n: Number of determinants indices of the all the dimensions.

To classify the member states the arithmetic mean, the upper and lower medians' values of the RCCAI were used as shown below. These constituted the upper and lower limits of the index.

$$\overline{X}RCCAI = \frac{\sum_{n=a}^{n} RCCAI_a + RCCAI_b + \ldots + RCCAI_n}{n} \quad (6)$$

Where:
$\overline{X}RCCAI$: The average of all the (*n*) member states *RCCAI*
$RCCAI_{a,\ldots,n}$: Member states *RCCAI*

$$Med_{upper}RCCAI = \frac{RCCAI_{\max} - \overline{X}RCCAI}{2} + \\ + \overline{X}RCCAI \quad (7)$$

$$Med_{lower}RCCAI = \frac{\overline{X}RCCAI - RCCAI_{\min}}{2} + \\ + RCCAI_{\min} \quad (8)$$

Where:
$Med_{upper}RCCAI$: Median of the *RCCAI* values greater than the $\overline{X}RCCAI$
$Med_{lower}RCCAI$: Median of the *RCCAI* values less than the $\overline{X}RCCAI$

All the member states *RCCAI* values were classified based equation 7 and 8 resulting into four groups which a member state sector could be considered to exist in as shown below:

If $RCCAI > Med_{upper}RCCAI$: High potential for adaptation
If $RCCAI > \overline{X}RCCAI < Med_{upper}RCCAI$: Potential for adaptation
If $RCCAI < \overline{X}RCCAI > Med_{lower}RCCAI$: Risky to climate change
If $RCCAI < Med_{lower}RCCAI$: High risky to climate change

Results and discussion

This section presents the outcomes of the different aggregation of member states' performance in different aspects that together form the key factors for adapting to climate change in agriculture, as presented above. When dealing with composite indices, their multidimensional nature results in a high level of subjectivity depending on how they are perceived and defined. To justify the need for accelerated adaptation efforts across the EU agricultural sector, this section presents the results for the member states' performance in terms of sectoral adaptation.

Agricultural water management

The irrigation compliance index shows how the different member states' agricultural sectors are exploiting their irrigation potential to compensate for variations in their crop or livestock water requirements. In terms of irrigation compliance, Malta (1.0), Portugal (0.94), Greece (0.84), Bulgaria (0.82), and Italy (0.7) have the highest share of irrigable lands under irrigation compliance (Table 1 and Table 2). This can be attributed to the increased prevalence of droughts in the Southern Europe regions (Falloon and Betts, 2010; Trnka *et al.,* 2012). Most the member states' agricultural sectors have complied with irrigation to counteract the negative effect of water scarcity. Even though the need for irrigation is present in all member states, there are over 9 member states whose agricultural sectors' irrigation compliance is still very low. The index was lowest in Finland (0.00), the Netherlands (0.23), Sweden (0.27), Belgium (0.31) United Kingdom (0.32), Austria (0.37), Poland (0.48), and France which had 0.49. For the Nordic countries, it can be concluded that the low indices are due to increased precipitation or increased thawing of frozen waters due to increasing temperatures and longevity of seasons (Ray *et al.,* 2019). Increasing the area under irrigation is a plausible pathway towards adaptation to climate change. However, the increase must be guided by the desire for highly water-efficient irrigation systems, technologies and practices to ensure that water quality and quantity are not affected. Research has predicted that the European agricultural sector will continue to experience water demand competition from increased biomass and energy production; thus there is a need to ensure high efficiency in utilisation and management of the available resource (IIASA, 2014). Coupled with advances in technology, increasing efficiency – so as to ensure any irrigation technique aimed at having a less negative effect on both soil quality and quantity while increasing the conditionality of eco-schemes across the European agriculture – holds huge potential for ensuring good water irrigation practices (Kahil *et al.,* 2015). However, these practices on their own are not sufficient to ensure sustainable water management, as outlined under the sustainable use directive. Implementation of sound water management practices under cross-compliance and conditionality for smart techniques for agricultural water use is therefore a plausible pathway for the sector's adaptation to climate change's effects on water.

Table 2: European agricultural relative climate change adaptation aspects sub-indices.

Country	Irrigation compliance	Agricultural area protected for biodiversity	Common Farmland Bird Index	Organic farming adoption	Agricultural environmental awareness	Agricultural waste generation (Kg/capita)	Soil input dependency	Soil erosion risk	Soil nitrogen gross nutrient balance	Agricultural energy sustainability	Renewable energy capacity	Agricultural human resource employment in science and technology	Research and development expenditure as a percentage of GDP	Research and development personnel as a percentage of the active population	Agricultural availability of labour	Economic efficiency	Social acceptance
Austria	0.37	0.12	n/a	1.00	1.00	0.95	0.97	n/a	0.84	0.94	0.52	0.56	0.96	0.73	0.71	0.26	0.52
Belgium	0.31	0.01	0.04	0.25	0.91	0.91	0.61	0.99	0.33	0.19	0.36	0.16	0.72	0.67	0.63	0.82	0.96
Bulgaria	0.82	0.02	n/a	0.08	1.00	0.65	1.00	1.00	0.87	0.47	0.46	0.64	0.14	0.20	0.00	0.04	0.44
Croatia	0.54	0.13	n/a	0.23	1.00	0.70	0.96	1.00	0.74	0.77	0.43	0.73	0.14	0.15	0.59	0.03	0.43
Cyprus	0.65	0.15	0.87	0.19	n/a	0.92	0.97	0.98	0.00	0.04	0.05	0.24	0.02	0.00	0.45	0.10	0.38
Czechia	0.51	0.03	0.27	0.67	1.00	0.96	0.96	1.00	0.61	0.41	0.42	0.56	0.51	0.51	0.76	0.21	0.31
Denmark	0.60	0.01	0.47	0.33	0.52	0.91	0.86	0.85	0.60	0.25	0.81	0.28	0.94	1.00	0.88	1.00	0.56
Estonia	0.69	0.22	0.42	0.81	0.98	0.69	1.00	0.85	0.91	0.41	0.88	0.70	0.34	0.31	0.39	0.16	0.47
Finland	0.00	1.00	0.76	0.48	0.99	1.00	0.96	0.56	0.77	0.84	1.00	0.59	0.90	0.87	0.54	0.27	0.48
France	0.49	0.08	0.33	0.21	0.71	0.93	0.86	0.99	0.79	0.31	0.48	0.36	0.65	0.62	0.71	0.41	0.39
Germany	0.62	0.13	0.46	0.31	n/a	0.97	0.77	1.00	0.63	0.41	0.41	0.26	0.90	0.66	0.72	0.54	0.52
Greece	0.84	0.02	0.44	0.33	n/a	0.98	0.96	1.00	0.71	0.30	0.21	0.42	0.17	0.34	0.95	0.06	0.00
Hungary	0.53	0.09	0.36	0.12	0.99	0.82	0.99	1.00	0.85	0.53	0.56	0.58	0.31	0.27	0.87	0.04	0.28
Ireland	n/a	0.00	0.96	0.06	0.99	0.93	0.96	1.00	0.81	0.13	0.90	0.44	0.30	0.60	0.81	0.15	0.42
Italy	0.70	0.19	0.44	0.59	0.98	0.98	0.98	1.00	0.67	0.29	0.19	0.21	0.33	0.41	0.75	0.22	0.51
Latvia	n/a	0.13	1.00	0.59	0.99	0.80	1.00	0.80	0.87	0.31	0.90	0.87	0.05	0.14	0.58	0.04	0.57
Lithuania	0.69	0.04	0.33	0.32	0.99	0.61	1.00	1.00	0.89	0.42	0.95	0.83	0.19	0.25	0.98	0.03	0.28
Luxembourg	n/a	0.01	0.41	0.16	n/a	0.94	0.88	n/a	0.34	0.30	0.31	0.00	0.31	0.90	0.70	0.51	0.59
Malta	1.00	0.00	n/a	0.00	0.00	0.96	0.86	1.00	0.25	0.00	0.00	0.17	0.08	0.21	0.96	0.07	0.50
Netherlands	0.23	0.02	0.20	0.12	0.84	0.00	0.00	0.00	0.11	0.05	0.28	0.28	0.56	0.63	0.77	0.79	0.76
Poland	0.48	0.01	0.52	0.19	0.92	0.95	0.99	0.96	0.79	0.19	0.58	0.97	0.19	0.18	0.77	0.03	0.51
Portugal	0.94	0.19	n/a	0.30	1.00	0.98	1.00	1.00	0.80	0.38	0.31	0.30	0.30	0.36	0.42	0.07	0.47
Romania	n/a	0.02	n/a	0.08	1.00	0.91	1.00	1.00	1.00	0.77	0.44	1.00	0.00	0.03	0.56	0.00	0.40
Slovakia	0.24	0.02	0.70	0.46	0.98	0.57	1.00	0.99	0.88	0.34	0.49	0.53	0.18	0.18	0.59	0.20	0.37
Slovenia	0.61	0.25	0.31	0.43	0.99	0.86	0.98	1.00	0.79	1.00	0.41	0.49	0.63	0.63	1.00	0.03	0.48
Spain	0.60	0.15	0.28	0.39	1.00	0.55	0.99	1.00	0.82	0.19	0.32	0.37	0.28	0.31	0.45	0.21	0.49
Sweden	0.27	0.46	0.30	0.85	0.91	0.74	0.96	1.00	0.86	0.27	0.85	0.27	1.00	0.75	0.63	0.44	0.48
United Kingdom	0.32	0.01	0.43	0.13	0.96	0.97	0.97	1.00	0.58	0.20	0.24	0.35	0.44	0.53	0.88	0.41	0.22

Source: Own calculations based on Eurostat (2020) data

Agricultural biodiversity management

Agricultural biodiversity management across European agriculture is one of the climate change adaptation areas that calls for accelerated action; indeed, this is explicit in the EU biodiversity Strategy 2030 where nature is recognised as an important ally in fighting against climate change (EC, 2020b). This and ecosystem management must be viewed as complementary activities and not in competition with one another, as both challenges are interlinked. As presented in Table 2 above, only four member states have a biodiversity management index above 0.5 with Finland (0.75), Latvia (0.57), Austria 0.56, and Sweden (0.54). Specifically, and taking a keen interest in the area protected for biodiversity, only Finland has an index above 0.5, with all the other countries having low indices. In terms of organic farming adoption, which is an ecosystem-friendly agricultural practice, Austria (1.0), Sweden (0.85) and Estonia (0.81) had the highest sub-indices while Romania (0.08), Bulgaria (0.08), and Ireland (0.06) have the lowest indices for organic farming adoption. Birds contribute significantly to the agricultural area and the protection of birds across Europe is significantly higher in Latvia (1.0), Ireland (0.96), Cyprus (0.87) and Finland (0.75).

The adoption of results-based eco-schemes as proposed under the Biodiversity strategy – in line with the Farm to Fork Strategy under the new CAP – is a plausible pathway for establishing a connection between nature preservation and the agricultural sector. The EU Pollinators initiative is a good indicator of the importance attached to birds and how they can positively influence the sectoral adaptation to climate change (EC, 2018b). Similarly, the EU Biodiversity strategy-2030 proposes that the agricultural sector must convert at least 25 percent of its land to organic production. All these initiatives are geared towards improving soil quality and biodiversity, while at the same time reducing the sectoral footprint of food production. The establishment of an enabling policy environment and knowledge transfer mechanisms to farmers with regard to how to implement these strategies is essential. Improved farm performance is more likely to occur when there is continued empowerment instead of sanctions on failure to amend. Sanctions on environmental protection have the potential to discourage farmers who may perceive good agricultural and environmental conservation practices as detrimental to their economic activities and livelihoods. One significant example of the problems faced here is the planned reduction of the size of Ecological Focus Areas (EFA) from their current 15 ha. This became necessary because in some countries, e.g., Romania, the average farm size is below 15 ha, a fact that exempts them from the intended incentive and therefore renders the EFA conditionality inefficient (Wiréhn, 2017; Zinngrebe *et al.,* 2017). Although protection is still a good measure, the EU-Nature restoration plan advocates restoration as being the most plausible way to align the interests of agriculture with the preservation of nature (EC, 2020b).

Agricultural environmental management

An environmentally aware agricultural sector will emit less pollution and pay less environmental pollution tax. In terms of their pollution and environmental tax liability, most of the European member states have impressive indices for environmental awareness with indices above 0.8 as shown in Table 2. In terms of waste generation per capita across the agricultural sector, only the Netherlands had an index below 0.5 followed by Spain (0.55) and Slovakia (0.57). In general, environmental management performance across European agriculture is a strength and all the member states are performing well. The strong environmental performance can be attributed to the strong pace set up globally by the EU for environmental management through the establishment of the world's leading environmentally friendly policies and implementing them at both national regional and farm levels (EC, 2019b).

Agricultural soil management

The soil management index was developed as a composite of input dependency, erosion risk, and nitrogen gross nutrient balance. High input dependency and nitrogen gross nutrient balance are key challenges for healthy soil management across the European agricultural sector (Table 1 and Table 2). Similar findings were reported by Thaler *et al.* (2012) and Vanschoenwinkel *et al.* (2016) in their analyses of whether both Eastern and western Europe are exposed to similar climate shocks. According to recent analysis, Romania has the highest index for healthy soils due to less dependency on inputs and low gross nutrient balance (Zinngrebe *et al.,* 2017). Soils are repositories for GHGs and excess carbon from the atmosphere and ensuring that less reliance on inputs is essential to maintain their healthy status (EC, 2020c). The Netherlands had the lowest soil management index due to its high input dependency, high erosion risk, and high gross nutrient balance (Panagos *et al.,* 2014). The geographical location of the Netherlands defines most of its soils as man-made, subjecting them to high fertility and the presence of peat soils coupled with high nitrates, phosphorous and heavy metals accumulation (Jones *et al.,* 2012).

Belgium and Luxembourg had low indices due to high nitrogen gross nutrient balance. High dependency on nitrogenous fertilisers increases soil degradation through increased emission of ammonia which increases soil GHG concentration and acidification of the soil and in turn having a negative effect on the water bodies (EC, 2020c). Bulgaria (0.96), Slovakia (0.95), Hungary (0.95) and Slovakia (0.95) presents another group of countries whose soils can be categorised as healthy. These countries are covered by food production zones for Europe and require precision and efficient soil and land management to ensure that their soil qualities remain healthy (Panagos *et al.,* 2014). The geographical location of these countries has immensely contributed to their lower soil management levels; consequently, their governments should promote land-use practices that are conducive to lower levels of soil degradation (EC, 2020c).

Agricultural energy management

The paper analysed European agricultural energy sustainability, as defined by the sector's energy supply per ha to the energy use per ha and the countries' renewable energy production per capita (national biomass production per capita).

Finland had the highest energy management index (0.92). Finland has high national biomass production per capita in comparison with the rest of Europe, but at the same time has a low energy sustainability index, a fact necessitating the exploitation of energy-efficient production mechanisms. Austria (0.71), Lithuania (0.69), Estonia (0.64) and Latvia (0.61) have high national biomass production per capita but low energy sustainability indices. Across Europe, Energy sustainability per ha is weak, with only Slovenia and Austria having higher indices. Cyprus (0.04) and the Netherlands (0.17) had the lowest energy management indices. The Netherlands' low index can be attributed to its low energy sustainability due to high levels of mechanisation and a highly intensive agricultural sector with high energy consumption per ha as compared to output per ha. Similarly, the Netherlands has low national biomass per capita, due again to the intensiveness of its agricultural practices; it has only a small portion of its lands dedicated to biomass production. With an energy management index of 0.52, Ireland has one of the highest per capita levels of biomass production and a low energy sustainability index (0.13).

Adopting energy-efficient agricultural production systems – characterised by high energy efficiency while at the same time increasing the share of renewable energy production in comparison to food production – is a plausible path to sector-wide climate change adaptation. Although biomass is not the only source of renewable energy, across Europe it accounts for more than two-thirds of renewable energy with the majority of biomass production occurring in agriculture. Irregular bioenergy management practices can lead to indirect land use change which can cause adverse effects to the sector (Valin *et al.,* 2014). Exploring sectoral energy production by converting agricultural production waste into energy through increased circular production methods and the use of renewable energy can accelerate sectoral adaptation to climate change (Viaggi, 2015).

Agricultural information, knowledge, and skills management

The agricultural knowledge, skills, and knowledge management across European agriculture, had no member state with an index above 0.8. Denmark (0.77), Austria (0.74) and Finland (0.72) had the highest information, skills, and knowledge management index. These findings correlate to those of PRO-AKIS report by the EIP-agri where European member states were categorised based on the nature of the AKIS structure; Denmark, Austria and Ireland were classified as having a strongly integrated system (EIP-Agri, 2018). Denmark had the highest index overall, but had a low index

Table 3: Determinants of Relative Climate Change Adaptation Index by EU countries.

Country	Water management index	Biodiversity Management Index	Environmental management Index	Agricultural soil management index	Energy management Index	Agricultural information, knowledge and skills, management Index	Economic efficiency Index	Social acceptance Index
Austria	0.37	0.56	0.97	0.90	0.73	0.74	0.26	0.52
Belgium	0.31	0.10	0.91	0.64	0.27	0.55	0.82	0.96
Bulgaria	0.82	0.05	0.83	0.96	0.46	0.25	0.04	0.44
Croatia	0.54	0.18	0.85	0.90	0.60	0.40	0.03	0.43
Cyprus	0.65	0.40	0.92	0.65	0.04	0.18	0.10	0.38
Czechia	0.51	0.32	0.98	0.86	0.42	0.59	0.21	0.31
Denmark	0.60	0.27	0.71	0.77	0.53	0.77	1.00	0.56
Estonia	0.69	0.48	0.84	0.92	0.64	0.43	0.16	0.47
Finland	n/a	0.75	1.00	0.76	0.92	0.72	0.27	0.48
France	0.49	0.21	0.82	0.88	0.39	0.59	0.41	0.39
Germany	0.62	0.30	0.97	0.80	0.41	0.63	0.54	0.52
Greece	0.84	0.27	0.98	0.89	0.26	0.47	0.06	n/a
Hungary	0.53	0.19	0.91	0.95	0.55	0.51	0.04	0.28
Ireland	n/a	0.34	0.96	0.92	0.52	0.54	0.15	0.42
Italy	0.70	0.41	0.98	0.88	0.24	0.42	0.22	0.51
Latvia	n/a	0.57	0.90	0.89	0.61	0.41	0.04	0.57
Lithuania	0.69	0.23	0.80	0.96	0.69	0.56	0.03	0.28
Luxembourg	n/a	0.19	0.94	0.61	0.30	0.48	0.51	0.59
Malta	1.00	n/a	0.48	0.70	n/a	0.36	0.07	0.50
Netherlands	0.23	0.12	0.42	0.04	0.17	0.56	0.79	0.76
Poland	0.48	0.24	0.94	0.91	0.38	0.53	0.03	0.51
Portugal	0.94	0.25	0.99	0.93	0.34	0.34	0.07	0.47
Romania	n/a	0.05	0.95	1.00	0.60	0.40	0.00	0.40
Slovakia	0.24	0.39	0.78	0.95	0.42	0.37	0.20	0.37
Slovenia	0.61	0.33	0.93	0.92	0.71	0.69	0.03	0.48
Spain	0.60	0.27	0.78	0.93	0.26	0.35	0.21	0.49
Sweden	0.27	0.54	0.83	0.94	0.56	0.66	0.44	0.48
United Kingdom	0.32	0.19	0.96	0.85	0.22	0.55	0.41	0.22

Source: Own calculations based on Eurostat (2020) data in agricultural human resource employment in science and technology (0.28). Cyprus (0.18) and Bulgaria (0.25) had the lowest indices (Table 1 and Table 2). These countries had low sub-indices for research and development as a share of the GDP and for research and development personnel as a percentage of the active working population. It can therefore be concluded that increasing the share of research and development relative to GDP and creating more opportunities for employment in research and development positively correlates with knowledge discovery and dissemination and relevant skills management.

Agricultural social integration

To assess the level of societal change in relation to climate change adaptation, the paper outlined social acceptance as a measure of how society is adapting. Societal acceptance of a new way of living was measured by assessing the communities' waste recycling and the ability to involve youth in agricultural activities. Waste recycling as part of the 3-R principles of circular economy to establish Green Growth holds the potential to be an indication of environmentally aware society. In terms of waste recycling, Belgium had the highest index (1.0) followed by the Netherlands (0.66) with the rest of the member states having a sub-index below 0.5 (Table 1 and Table 3*).* This is an indication that waste recycling is still low in most of the member states. The low sub-indices correlate with the findings of the BIOREGIO that presented the food waste figures for selected member states based on the findings of the project (BIOREGIO, 2019). High figures of food waste are an indication of low recycling capacity.

In order to assess the future attractiveness of agriculture, young people's income from agriculture as a share of national farm income was examined across member states. The higher the share of youth income per ha, the higher was the possibility of a higher level of involvement in farm activities. Higher indices were recorded across all the member states except for the UK and the Czech Republic. Farmers' aging is a general challenge across European agriculture. Low future attractive indices are more likely to imply that fewer youths are highly involved in agriculture. Therefore, incorporating more youths in the sector by making it more favourable is more likely to improve sectoral adaptation capacity. High involvement of youths in the agricultural sector is a promising strategy that offers a potential solution not only for climate change adaptation but also for an ageing society. Strong social integration promotes cohesion among farmers, as those who are socially organised are more likely to take adaptive measures than their less organised counterparts.

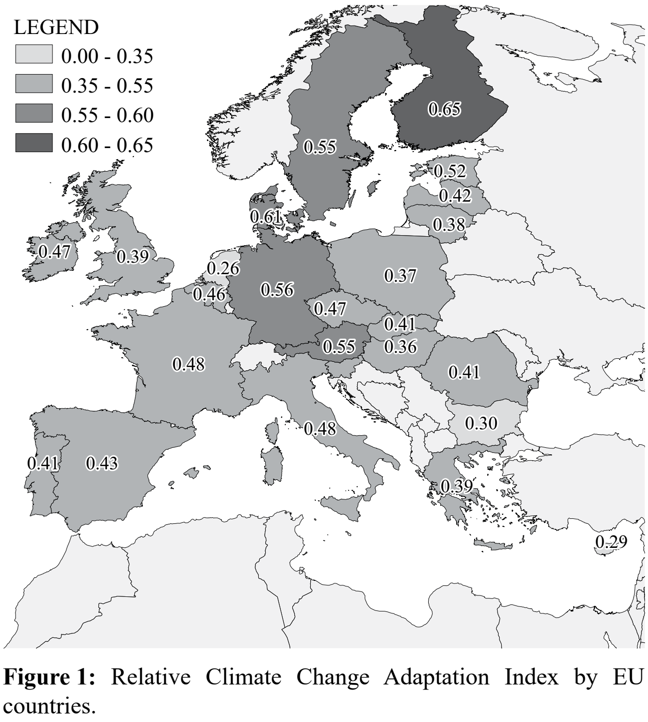

Figure 1: Relative Climate Change Adaptation Index by EU countries.

Source: Authors' own calculation

Agricultural economic management

In terms of farm economic efficiency, Denmark had the highest index (1.0), Belgium (0.82) and the Netherlands (0.79) and Germany (0.54). All the other member states had an index below 0.5, which is an indication of low farm efficiency. Increasing farm income efficiency by increasing the farm income and farmers' welfare through reduced working hours while adapting to the negative impacts of climate change is a plausible adaptation pathway. Every farmer wishes to run their operations profitably. Ensuring that green growth is viewed as the roadmap for farmers is a promising route for farmers to take with a view to maximising their incomes in a sector facing potentially drastic climate change (Acosta *et al.,* 2020).

Relative Climate Change Adaptation Index (RCCAI)

Finland had the highest agricultural RCCAI of 0.65 followed by Denmark (0.61). Based on the adaptation classification criterion developed in 3.2 above (step 4), Finland and Denmark were classified as those countries with the highest potential for adaptation to climate change in their agricultural sector. Germany (0.56), Austria (0.55), and Sweden (0.55) were categorised as having the potential for adaptation to climate change. Taken together, this group of countries were considered to have strong potential to adapt to climate change.

The remaining 23 member states were defined as having weak potential for climate change adaptation and thereby, as being at risk of climate change. They were further regrouped in two classes as presented in Figure 1. The spatial presentation of the indices shows that Southern European member states fall under the risky category. These results are similar to the findings of JRC/EEA which classifies Southern Europe as under high risk of climate change (EEA, 2020; Merino *et al.,* 2020); this can be strongly attributed to their increased exposure to climate change over the past decade.

Discussion and Conclusion

Making a concerted effort to increase the European agricultural sector's adaptive capacity to climate change remains a priority. Although there is no concrete framework for adaptation such as exists with mitigation, evidence can be drawn from New CAP 2021-2027 where climate action as a priority was elevated to a level of importance above the environment. Similarly, increased investment in advanced technology coupled with smart and circular agribusiness models is now dominating the entire sector. All these efforts are in line with the Paris Agreement's commitment to keeping the global temperature rise below 2 degrees Celsius and the European Green Deal aimed at carbon neutrality. The European Green Deal anticipates a green, digital, inclusive and resilient economy for the 21st century (EC, 2019b, 2020b). All these efforts together strive to make the sector resilient and climate-proof, and in so doing adopt green growth in the sector.

Globally, the EU is a leader in climate solutions offering the best policies to fight climate change. Unfortunately, variation at the sectoral level has been subject to sharp criticism (Mosnier and Leclere, 2015; Schmidt, 2019). For example, the energy sector has several major climate-related objectives, whereas agriculture does not (Adelle and Russel, 2013). The CAP as the most distinctive EU agricultural policy tool for responding to climate change is regulated at higher levels of government, in marked contrast to the effects of climate change, which are experienced locally.

The special case status accorded to the agriculture sector on account of its basic role in food production has been characterised by a strong connection between farmers and the political class, as evidenced by the sector's 34.5% share of the EU budget for 2020. Scholars are now criticising this, and are predicting a loss of that status due to the application of an increasingly multidimensional approach in respect of environmental issues affecting the sector (EC, 2019c). They further allude that the environmental efforts that have so far been attributed to the multidimensionality approach are insignificant. Improved environmental performances and climate action have been addressed by specific greening measures within the EU since 2013. However, the European Court of Auditors in 2017 challenged the effectiveness of the greening measures which it noted had only had a positive impact of about 5%, suggesting that the measures taken will not have a great impact on agricultural policymaking (European Court of Auditors, 2017).

To increase the sectoral performance against climate change, the new CAP places climate action above the environment. Although the top objective of the CAP remains to guarantee a fair income to farmers, the introduction of climate change combative actions into the CAP offers a brighter path for the sector to prepare to adapt and respond fully to climate change (Maréchal *et al.,* 2020). Although all these objectives are geared towards climate neutrality, there is a lack of a clear framework for adaptation, a problem that underlines the need properly to integrate the EU adaptation strategy and the different policy frameworks aligned to the CAP. The continued lack of differentiation between mitigation and adaptation in EU funded policies and programmes has accentuated the need to enhance adaptation by ensuring that funded programmes and policies predefine adaptation prior to their implementation (European Court of Auditors, 2014). The auditors' 2014 report further suggested that over 50% of the climate-related funded projects for adaptation under the direct payments scheme do not actually qualify under the category of climate adaptation. Defining the adaptation programmes before funding is an appropriate tool that can be used under the Rural Development Focus and can result in increased investment in adaptation measures and increased biodiversity protection (EC, 2020a). Increased investment through the greening programmes across the sector with a view to ensuring that the number of GAEC programmes is doubled is likely to increase the level of sectoral adaptation.

The paper calls for joint effort to ensure that the new climate adaptation strategy defines the eligible measures that can be funded under the CAP, so as to avoid misinterpretation of mitigation as adaptation. There needs to be established a community of farmers who are more environmentally aware and ready to adjust their actions to adapt to climate change by establishing a strong knowledge and information hub run by for farmers by farmers. A strong linkage between the farmers, agricultural stakeholders and policy actors needs to be guided by an appropriate policy framework and not political will. A coherent policy approach to promote strong coordination among the different players will serve to increase preparedness across all capacities of the sector. Capacity building needs to be guided by strong value addition derived from the adoption of problem-oriented measures rather than purely technology-oriented solutions. Unfortunately, conflicting policies have resulted in a less effective CAP. This is evident when the Court of Auditors highlights that the predominance of Ecological Focus Areas coupled with insufficient management requirements has the potential to reduce the benefits of greening for biodiversity. Similarly, where genetic and species diversity are concerned, rotational programmes in the crop sector are better than diversification (European Court of Auditors, 2020). Post farm production, the Farm to Fork strategy, which advocates efficiency right across the Agri value-chain, needs to be implemented.

To conclude, this paper predicts that with the continuous implementation of cross-compliance measures, specific greening measures and rural development programmes will have a positive effect on the sector's adaptive capacity. The wide array of funding possibilities, coupled with generation renewal and further guided by the Farm to Fork strategy so as to attain the EU Green Deal objectives, are more likely to induce farmers to implement the defined measures and thereby aid adaptation. To promote the local sustainability of adaptation programmes, its necessary to increase the share of private investment at the farm level.

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Determinants for the viability of small-scale family farms in Serbia: an example of the use of a multi-criteria assessment tool

Agriculture is a pillar of Serbia's economic development. Consequently, this paper provides an overview and analysis of the status of farms in Serbia, with a special focus on finding factors influencing the sustainable development of small-scale family farms. To facilitate simpler and more precise problem-solving and decision-making processes for improving the farms' operations, the analytic hierarchy process (AHP) model is used in this paper. This model is applied to the selection of key economic determinants for small farms' viability, illustrated through the results of the authors' own survey of 550 small farms in Serbia, which refers to the economic, social and environmental aspects of small farms' operation. By applying the criteria for selecting key economic indicators of a small farm, the multi-criteria assessment results can be utilised to inform more effective business and policy decisions directed at improving the operation of small-scale family farms. The survey results show that the best-ranked determinants for the viability of small farms in Serbia are first, the price of agricultural products, and next, well-structured agricultural product distribution channels.

Keywords: small family farms, economic indicators, multicriteria assessment, analytic hierarchy process, Serbia

JEL classifications: D81, Q12, Q13, Q18

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Introduction

The issue of economic efficiency in the case of small-scale[1] and large-scale farms is not clear-cut. When comparing the economic results, the productivity per 1 ha of arable land is often taken into account. When this approach is taken, small farms lose to large farms, because the latter usually use monoculture systems with a high degree of mechanisation. Moreover, large farms generally achieve better labour productivity indicators, which result from so-called scale effects (Błażejczyk-Majka *et al.,* 2012; Duffy, 2009). However, when comparing the effectiveness of two different types of farms, one should really consider the overall productivity of factors of production, a figure which takes into account the consumption of land, labour and capital. The productivity of small-scale farms calculated in this way turns out to be higher on account of better organisation of production factors (e.g. Barret, 1993; Binswanger *et al.,* 1995; Galluzzo, 2016). Family farming offers a means to guarantee agricultural production, based on small holdings managed by a family. In small farms, much of the labour comes from the household. Thus, it is characterised by self-supervision, the motivation to work with care and flexibility so as to accommodate the unpredictable timing of some farm operations (Wiggins *et al.,* 2010).

However, a full comparative analysis should consider other aspects as well, including social and environmental contexts. Family farms play a crucial role in the supply chain of agricultural products, and they combine production and consumption functions (Tilman *et al.*, 2002). By providing food and other goods, they are the basis of the family's livelihood. Their multifunctional nature manifests itself in actions taken to maintain the sustainability of rural areas. The functioning of small farms determines the development of the local environment. They ensure that continued biodiversity, ecological balance, higher quality and tastier food are all guaranteed. They constitute a buffer against poverty in the countryside, shape the rural landscape, and pass on intangible cultural and historical values. The experience of the 20th century has shown that it is a major challenge to implement agricultural policies that support small farmers in a way that ensures both their viability and their fulfilment of 'public goods' functions (Birner and Resnick, 2010). Such activities are particularly important in those parts of the world where small-scale family farming dominates. As far as Europe is concerned, this mainly concerns the central-eastern regions, including post-communist countries. These economies have been subjected to a historic attempt at transforming the system from a socialist economy into a market economy and are currently characterised by a fragmented agrarian structure, as is the case in Serbia.

Agriculture constitutes a relatively big share of the structure of Serbia's economy as indicated by GDP (more than 6%). This places Serbia among other 'agricultural economies' in the region, similar to Bosnia and Herzegovina, Georgia, Kosovo, Montenegro and Turkey, according to data from World Bank (2020). The result for Serbia is comparable to countries in the 'upper middle income' group, but much higher than for Central Europe and the Baltics (2.7%). Because of this, agriculture is a very impor-

[1] "Small-scale farms" and "small farms" are used interchangeably in the article.

tant sector for Serbia, with a significant influence on the entire economy (Pavlović, Knežević and Bojičić, 2019). Despite the fact that Serbia has favourable factorial and commercial conditions for developing intense and competitive agriculture, it is characterised by a fragmented agrarian structure, just like other countries of Central and Eastern Europe (Fritz *et al.*, 2010). The average physical size of a farm in 2018 was about 6.1 ha per farm, and it is only 40% as big as the average farm in the 28 states of the European Union (EU28). The largest proportion of farms (27.7%) is classified as being of the lowest economic size, with standard output below €2000/year, although back in 2012, the figure for this was over 45% (Statistical Office of the Republic of Serbia, 2013; 2018). Thus, data indicate that a slow land consolidation process is taking place (the average area of individual farms was 15% more than in 2012), which results in a decrease in the overall share of the weakest farms that is mainly due to the adverse demographics in Serbia, the ageing of villages, migration, globalisation and intensified capital concentration in agriculture (Paraušić and Cvijanović, 2014). At the same time, the problems faced by small farms in Serbia include lack of one's own capital, difficulty obtaining favourable loans, market fluctuations and low prices for agricultural products (Kočović *et al.,* 2016). Nevertheless, it can be assumed that small farms will represent the future of sustainable Serbian agriculture. They provide multiple benefits for society, including food and nutrition security, high-quality agricultural products, employment and family income, environmental protection and adaptation to local resources, while at the same time preserving tradition and cultural heritage (FAO, 2020). However, besides their social and environmental relevance, it is also important to consider their economic aspects. According to the estimates, family farms in Serbia, usually occupying a small area, produce about 70% of food, but only 20% of profit is directed to them (the other 80% goes to big corporations, according to the Statistical Office of the Republic of Serbia, 2018). It is evident that changes are necessary.

With the current competitive environment and demographics trends in both Serbia and other countries, the survival of farms is threatened. The inferior status of the agricultural sector is characterised by a lack of regular income, decades-long downward trends in prices for agricultural products, an ageing population, outdated machines, unresolved problems of agricultural pensions, and inaccessible sources of borrowing. Combined with institutional problems, such as closed agricultural cooperatives, lack of collection points and a small level of state support (only some animal producers can count on production premiums, and even then not all of them due to the minimum limits of production value or animal pieces), it is clear why the number of people staying in rural areas and living solely on agriculture has been decreasing. In fact, cultivated areas have not grown and the rural population and the number of agricultural producers has dropped. As a result, the production volume and share of agriculture in Serbia's GDP has remained unchanged for several decades. Even the selection of crops has not changed significantly (Tošović-Stevanović *et al.*, 2020). Therefore, it is crucial for farmers to restructure assets and to increase investment outlays, using state incentives (subsidies) as well as finding additional sources of income both on-farm and off-farm. The aim of the current article is to find an answer to the question as to which factors can contribute to strengthening the economic condition of small-scale family farms in order to increase their viability, which is the overriding goal for the agricultural sector in Serbia.

Paraušić and Cvijanović (2014) have noted that efficient management of small farms starts with identifying potential determinants for successful management of agricultural activity and food supply chain. For aims assessment, this paper proposes criteria for selecting factors influencing the viability of small family farms in Serbia using the analytic hierarchy process (AHP). Our analysis is based on a survey conducted at 550 small farms in Serbia between June and September 2019. Generally, the survey focused on economic, social and environmental aspects of small farm operation, but this work refers to a specific aspect related to the assessment of variables that determine the economic position of the analysed units (social and environmental issues are not an interest of this study). From among many variables, selected are those which, according to the authors, are of key importance for the improvement of viability of farms – the top goal of the APH analysis. Assessing economic position and its determinants is crucial for understanding the foundations of resilience and sustainable development of this kind of household.

Understanding these effects is also of relevance for the state, as creators of economic policy must have a clear insight into improving the performance of the agricultural sector, and thus, the development of small farms. Taking into account the previously mentioned agrarian structure in Serbia and the problems of the agricultural sector on the one hand, and care for multifunctional rural development on the other hand, our analysis may assist the development of strategic plans for the functioning of family farms in the country. Hence, we have created a policy recommendations list, which we present at the end of the paper. The additional aim of the study is to define simpler and more precise problem-solving and decision-making procedures for improving small family farm operation. Using AHP for operational problem-solving is a rather unusual approach, but it is a suitable tool for implementing various business solutions and decision-making procedures. In this paper's case, the results of the analysis – namely, identified key determinants of the viability of farms – can be used in decision-making by agricultural producers or as an aid to the process of planning agricultural policy objectives. In addition to selecting factors, the analysis can be used both for determining the relevance of the criteria weightings and for ranking priority indicators. The prioritisation method we apply in the analysis of small-farm economic indicators is the method of own values. The advantage of such an approach is that the selection of indicators is based on objective and verifiable values. Moreover, the decision is not based on one criterion, but on a combination of multiple criteria. In this context, the decision-making process includes applying the AHP model.

Materials and Methods

Spatial scope of the study

Family farms with a small utilised area and a small scale of production constitute the foundations of the agricultural sector in Serbia. Historically, they have been subjected to attempts to transform their systems from a socialist economy to a market economy. Within one decade (the 1990s), thousands of farms had to reorganise in recognition of a new market reality. As a result, a dual structure of agriculture has developed, with industrial food companies operating alongside small-scale but multifunctional farms. Although still family farms are the basic economic-production units in a Serbian village (Prodanović *et al.*, 2017), their total number is continuously decreasing as a result of the disagrarisation of rural areas and a process of agricultural land concentration. In the years 2012-2018, the total number of farms dwindled by ten percent and in 2018, amounted to almost 570 thousand (Statistical Office of the Republic of Serbia, 2020). The majority of farms are low-area units with low economic strength. The proportion of farms below 10 ha of utilised agricultural area (UAA) and €15,000 of standard output accounts for almost 90% of the total number of farms. They cultivate an area of just over 60% of the total arable land in Serbia (see Table 1).

Definition of a small-scale family farm

There is no general definition of a family farm, small farm or small-scale farm (Davidova and Thomson, 2014). It depends on what criteria have been adopted by researchers and what issues investigated (different regions and countries, farms with different production types etc.). In the literature, the term 'small farm' is often used synonymously with terms such as 'subsistence farm', 'semi-subsistence farm', 'resource-poor farm', 'low-sales farm', 'non-commercial farm', 'low-input farm' or 'family farm'. However, these terms may differ in their meanings, especially for the last one, and should not be used interchangeably in each case. Mainly, family farms are treated as entities where the majority of labour resources (for example 50% or 75%) and farm management comes from the farm (farmer's head and family members). In turn, small farms are defined according to such criteria as structural size (e.g. farmland area, number of animals, number of labour force), economic size (standard output, gross cash farm income or farm revenue, annual sales or turnover, etc.) and market participation (e.g. purchased inputs, foodstuff sales) (European Commission, 2011; Guiomar *et al.*, 2018). In this context, very small farms could be defined as those with an agricultural area less than 2 ha or 5 ha (Lowder *et al.,* 2016), while small farms are those with the area up to 10-20 ha. The criterion of the economic size is applied in the European Union, where a threshold of €8,000 of standard output is used to define a very small farm, and €25,000 for small farms (FADN, 2018).

Table 1: Basic statistics for agricultural sector in Serbia (2018).

Total number of farms (thousand)	569.3
– including smaller than 10 ha	501.0 (88%)
Average farm size (ha of UAA)	6.1
Number of farms below EUR 4 thousand of SO*	289.1 (51%)
Number of farms with EUR 4-15 thousand of SO	213.2 (37%)
Number of farms more than EUR 15 thousand of SO	67.0 (12%)
Total utilised agricultural area (thousand ha)	3,486.9
– in farms smaller than 10 ha	2,162.0 (62%)

*SO – Standard Output, the average five-year production of the crop or animal expressed in thousands of euro per one year in the region's average production conditions.
Source: Statistical Office of the Republic of Serbia (2018)

Dataset

Small-scale family farms in Serbia were analysed due to the role they play in the agricultural sector and their importance in shaping the sustainable development of rural areas. The study is based on surveys conducted in 2019 (June-September), the sample numbered 550 farms covered all regions in the country. We used purposeful random sampling. Data were collected in the form of direct interviews by agricultural advisors. A structured questionnaire concerned four areas: general farm features, economic and social sustainability, environmental sustainability and connections with the market. Pilot studies on a group of several farms were carried out before the main study to avoid the possibility of misunderstandings arising during the actual survey. Finally, after eliminating questionnaires that were incomplete, incorrectly completed or that contained outliers, 527 farms were analysed. To define a small farm as well as take into account farm structure in Serbia, the following criteria were adopted for this research: up to 15 ha of utilised agricultural area and €15,000 of standard output. At the same time, in order to meet the criterion of a family farm, the share of family members' own work was taken into account – it had to be at least 75% of the labour inputs of farm members. The latter criterion resulted from earlier studies by authors (surveys as part of a scientific project) among a group of small-scale farms in Poland. As previous research has indicated, adopting a lower limit, e.g. 50% or even slightly more, means that the greater part of the household budget comes from non-agricultural activities. Setting the threshold up to 75% involves only 'real' farmers. The same method of qualifying units for research was used in the other works, including, *inter alia*, Stępień *et al.* (2021) and Poczta-Wajda *et al.* (2020). In Table 2, there are some basic descriptive statistics for the analysed group, including those elements involved into AHP analysis.

Modelling Decision-making Problems by the AHP

The idea of the analytic hierarchy process was developed by Thomas Saaty (1980). In the past four decades, this concept has become one of the most used methods for solving various multicriteria decision-making tasks. The key features of AHP are that it supports individual and group decision-making and that it includes classification of decision-making problems in a multi-level hierarchy. Initially, a problem structure is defined, followed by a comparison of all elements at the same hierarchy level against higher-level elements. The defined goal – selecting the most relevant eco-

Table 2: Basic descriptive statistics for the analysed small-scale family farms in Serbia.

Specification	Average	Stand. dev.	Median
Production value (EUR/year/farm)	5,715	3,637	5,063
Average farm area (UAA in ha)	3.86	2.41	3.50
Family Work Unit* (FWU/farm)	1.65	0.84	1.63
Capital assets value (EUR/farm)	25,978	25,301	15,570
Household income (EUR/month/farm)	737	707	608
Subsidies (% in agricultural income)	2.26	8.62	1.20
Manager age	54.4	13.2	54.0

Education (% of the analysed population)				
no educ./primary	secondary	vocational	general	higher
22.1	31.0	35.5	7.0	4.4

Number of household members (% of the analysed population)					
1	2	3	4	5	6 and more
13.4	26.2	16.8	22.8	12.0	17.8

Production type (% of the analysed population)**		
Crop production	Animal production	Mixed production
40.1	8.6	51.3

Quality (fertility) of agricultural land* (% of farms' land in a specified class)**				
I	II	III	IV	V
15.4	36.7	27.3	14.0	6.6

* FWU - is the full-time equivalent employment; one family work unit corresponds to the work performed by the member of a farm family who is occupied on an agricultural holding on a full-time basis.
** Production type – for crop or animal production at least 2/3 of total production comes from the specified production. If not, there is mixed production.
*** Quality of land on a five-point scale, where class I - the best quality, class V - the worst.
Source: own calculations based on the survey data

Table 3: Criteria for the AHP analysis influencing the economic situation of farm.

Criterion	Justification
Total farm income	Total farm income shapes the economic situation of a farm and affects its viability and development capacity in the long term
State support	State support for small-scale farms is crucial due to the low level of income and capital necessary for current production and investment activities
Distribution channel	Shortening the supply chain and strengthening the level of market integration increase the economic surplus of a farm
Agricultural prices	The higher the selling prices of agricultural products, the higher the farm's revenue
Arable area of farm	The increase in the area of small-scale farms most often leads to an increase in the scale of production and positive effects for agricultural income
Number of household members	The greater the number of family members involved in agricultural activities, the lower capital resources needed for production - the effect of capital-labour substitution typical for small farms - which reduces capital expenditure and improves income situation
Quality of agricultural land	Higher quality of land increases its productivity and income per hectare

Source: own composition

nomic determinants for the viability of small family farms in Serbia – is at the highest level. In line with the defined goal, four criteria were assessed: C_1 – total farm income, C_2 – state support, C_3 – agricultural products distribution channels and C_4 – agricultural products price. The alternatives are A_1 – the arable area of a farm, A_2 – the number of household members and A_3 – the quality of the arable land of a farm.

The process of selecting elements for the AHP analysis was carried out in two stages. In the first stage, 28 variables determining the economic condition and market position of small farms were adopted, including income, assets, liabilities, labour inputs, land area and quality, access to financial market, type of production, support instruments, distribution channels, market prices, promotional channels, production risk, etc. It was a selection based both on the earlier work of the co-authors and a literature review (e.g. Bowman and Zilberman, 2013; Safa, 2005; Mutimura *et al.*, 2018). Then, using the brainstorming method, the final list of criteria and alternatives was determined. The authors, invited experts in the field of agricultural economics, agro-policy and rural development (mainly academic staff members with minimum 10-years working experience in a managerial position), representatives of local authorities and regional advisory centres took part in the brainstorming session. The closing choice was also limited by the availability of data from a survey.

After defining the goal and establishing the criteria and alternatives, in the next phase of the AHP method, the decision-maker compares the criteria to the goal. The comparisons are made in pairs, using Saaty's scale of relative importance, comprising the following:

Table 4: Saaty's scale of relative importance in an analytic hierarchy process model.

Scale of importance	Definition
1	Equally important
3	Weak importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

Source: Saaty (1980)

The next step, the selection of economic indicators by applying the AHP method, is to create a problem hierarchy. Then the criteria are evaluated (based on Saaty's nine-degree scale), to define the weight coefficients required to assess and select small farm economic indicators. In the fifth phase, alternatives are evaluated against each criterion. Each alternative is given a value. In the final phase, the decision is made, and the alternatives are selected. The economic indicator with the highest value rate is the most favourable small farm solution.

Saaty's scale of relative importance is useful for making decisions because paired analysis compensates for any uncertainty caused by small changes in decision-makers' assessments. All results of the comparison of elements are positioned in adequate comparison matrices. Thus, when we compare *n* elements against a corresponding element on the next higher level of the hierarchy, the indicator of the importance of the element *i* (*i = 1, 2, ..., n*) against the element *j* (*j = 1, 2, ..., n*) upon Saaty's scale is marked as a_{ij}, and it is positioned adequately in the comparison matrix *A*.

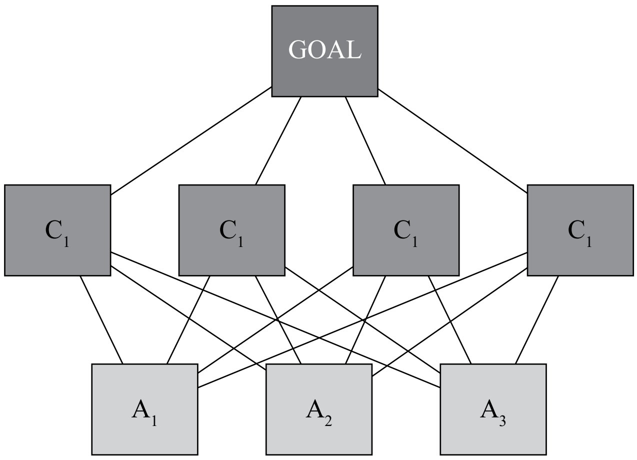

Figure 1: Saaty's hierarchy of criteria (C) and alternatives (A) in the analytic hierarchy process model.

Source: Saaty (1980)

Methodologically observed, AHP is a hierarchically structured decision model, comprising goal, criteria and alternatives (Figure 1). A goal is always at the top of the hierarchical structure, and it is not compared with other elements. The first level of the structure comprises criteria which are mutually compared in pairs against the first element on the next higher level. When the criteria are defined, alternatives are assessed by comparing pairs against each of them. Thus, a hierarchical or network problem presentation is created for determining solutions to the defined goal. All numerical values are entered into the matrix, in a sequence matching the matrix order in mathematics. The matrix diagonal has a value of 1. Values are entered in the upper matrix triangle, while their reciprocal values are entered in the lower matrix triangle. The method of own values is used for comparing elements in pairs, with vectors of the element weight defined using the linear system:

$$A\omega = \lambda\omega, e^T = 1 \quad (1)$$

where *A* is the matrix of comparison of dimensions $n \times n$, ω is the vector of own values (eigenvector), λ is the own value and *e* is the unit vector. Using the distributive aggregation model, weight vectors are synthesised, followed by assessing the consistency rate (CR) and consistency index (CI).

$$CI = \frac{\lambda \max - n}{n - 1} \quad (2)$$

$$CR = CI/RI \quad (3)$$

where *RI* is the random index (matrix consistency index of *n* randomly generated pair comparisons). Calculated values of the random index are presented in Table 5.

Table 5: The values of the random index (RI) for the analysed AHP model.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R.I.	0.00	0.00	0.58	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.48	1.56	1.57

Source: own calculations based on the survey data

In order to assess the consistency of results, it is necessary first to calculate a maximum own value of the comparison matrix (λmax). The upper limit for assessing the consistency index is 0.1. If the consistency index is higher than 0.1, the evaluation in the matrix should be corrected. That is, the comparison of rules by using the method of own values should be repeated.

The analytic hierarchy process method was widely documented in a variety of problem areas, including agricultural economics. Broad research on using AHP adopted to various fields (mainly in agriculture) was conducted by Garcia *et al.* (2014). Alphonce (1997) presented the use of AHP in different decision areas in developing countries, including (1) determination of the choice of agricultural production; (2) resource allocation to agricultural activities; (3) the best location for a village store; (4) choice between subsistence and cash crops production; (5) determination of the crop production technology. According to Optiz *et al.* (2019), consumer-producer interactions (CPI) may be considered as key factor in community-supported agriculture farm economic stability. Farmers should take into account the consumer needs concerning qualities and quantities of production especially. Besides, some authors addressed the AHP to the agriculture in Central and Eastern European countries. Bogdanović and Hadzic (2019) used Net Present Value and AHP when investigating Serbian farms to prove that choosing the perennial plantations is a better long-term investment strategy than the typical crop production. Huehner *et al.* (2016) claimed that organic fruit, wine and horticultural production seem to be the most important agri-environmental measures in Slovenian agriculture. Therefore, our analysis supplements the scope of the AHP method application with further evaluation criteria.

Results

During the study, authors selected the criteria, compared them in pairs against the goal (using Saaty's scale), and then performed the paired comparison of alternatives against each criterion. Table 6 shows that the most relevant criterion, based on weight, was agricultural products price, followed by agricultural products distribution channels. Total farm income and state support reached much lower weights. To avoid mistakes while formulating conclusions and determining the value of criteria in the paired comparison matrix, the rate of deviation from consistency was assessed. First, the maximum own value of the comparison matrix was calculated (λmax = 4.16), then the consistency index (CI = 0.06) and consistency rate (CR = 0.05) were defined. As the value of the consistency index is lower than 0.1, it means that the comparison matrix is well defined.

The next step in the AHP concept was to evaluate the alternatives against each criterion separately. Table 7 shows comparison matrices of alternatives against the four criteria and related weight factors.

After the priorities of criteria against the goal and priorities of alternatives regarding the criteria are calculated, priorities against the goal were determined. This was done by multiplying weights. At the end of the procedure, a synthesis of the whole selection problem was executed. At this point, it was possible to rank economic indicators for a small farm (Table 8). Making a final decision (selecting an optimal economic indicator) was identified as the alternative with the highest rank in value with the highest total weight.

In Table 8, if the sum of all values for alternatives (last column), namely criteria (last row) is equal to 1, it confirms that the procedure is precise and accurate. The final decision indicates that the size of arable land is dominant and vital for small farms, with the number of household members and land quality playing a less significant role. Among the criteria, the impact of the price of agricultural products and distribution channels dominates.

Table 6: Matrix of comparison for criteria and computed weights for the analysed AHP model.

GOAL	C_1	C_2	C_3	C_4	WI
C_1	1	3	¼	1/3	0.14
C_2	1/3	1	1/5	1/5	0.07
C_3	4	5	1	1/2	0.34
C_4	3	5	2	1	0.45

C_1 – Total farm income, C_2 – State support, C_3 – Agricultural products distribution channels, C_4 – Agricultural products price. W – weight.
Source: own calculations based on the survey data

Table 7: Decision making matrices with respect to criteria and computed weights for the analysed AHP model.

C_1	A_1	A_2	A_3	W_i	C_3	A_1	A_2	A_3	W_i
A_1	1	1/7	1/7	0.07	A_1	1	1/5	3	0.30
A_2	7	1	1/7	0.23	A_2	5	1	1/3	0.37
A_3	7	7	1	0.70	A_3	1/3	3	1	0.33
C_2	A_1	A_2	A_3	W_i	C_4	A_1	A_2	A_3	W_i
A_1	1	3	3	0.55	A_1	1	3	2	0.52
A_2	1/3	1	1/5	0.12	A_2	1/3	1	3	0.30
A_3	1/3	5	1	0.33	A_3	½	1/3	1	0.17

C_1 – Total farm income, C_2 – State support, C_3 – Agricultural products distribution channels, C_4 – Agricultural products price. The alternatives are A_1 – Farm arable area, A_2 – Number of household members, and A_3 – Arable land quality. W – weight.
Source: own calculations based on the survey data

Table 8: Total weight and rank of variants for the analysed AHP model.

GOAL	C_1	C_2	C_3	C_4	Rank
A_1	0.02	0.04	0.113	0.26	**0.433**
A_2	0.04	0.01	0.113	0.13	0.293
A_3	0.08	0.02	0.113	0.06	0.273
Total	0.14	0.07	0.34	0.45	1

Source: own calculations based on the survey data

Discussion and policy recommendations

This illustrative example provides a realistic picture of Serbian agriculture. The structure of farms is dominated by small-scale farms with a low degree of marketisation, although the food and beverage sector is the largest export sector in Serbia (12% out of the total export). The main export commodity are raspberries, which constitute approx. 60% of foreign sales, and Serbia is one of the largest European producers of raspberries (apart from plums, quinces and peppers). Nevertheless, this does not mean that the supply chain in this sector is well-structured; in actual fact, there is still much space to increase commercialisation and supply chain extension. The problem of the sector is an extremely low concentration of producers (Herfindahl-Hirschman index of only 62), low diversification of sale (almost only frozen fruits), obsolete technical infrastructure, and a lack of investment capital or low quality of human resources (Stojanović and Radosavljević, 2020; Stojanović *et al.,* 2018). A particularly low level of market integration exists in the milk and meat sector. In the first case, natural consumption and the informal market have a combined share of almost 50% of the total amount of skimmed raw milk, only every second letter is purchased by the dairy. In the case of meat, the number of animals slaughtered outside slaughterhouses ranges between 40% and 60%, depending on the type of meat (Center for Advanced Economic Studies – CEVES, 2017). As a result, the influence of small-scale producers on shaping the terms of transactions in the food supply chain is slight. In such conditions, the economic surplus escapes to middlemen, processors, wholesalers and retailers, and finally consumers. Agricultural producers play a negligible part in the final price of the product.

On the other hand, small farms in Serbia have a very significant role in agricultural production, self-employment and provision of family income, adjustment to local resources and preservation of tradition. Therefore, one should strive to maintain their viability by identifying those areas that largely shape the economic condition. The conducted AHP analysis shows that the key factors for improving the efficiency of farming are the prices of agricultural products and the level of market integration. In general, these results can be confirmed by other studies. Firstly, market prices, by shaping the production value, are the main determinant of the economic situation of farms (Gupta, 1980; Beckman and Schimmelpfennig, 2015; Madre and Devuyst, 2016; Czyżewski and Kryszak, 2017). Secondly, the level of prices obtained by the agricultural producers depends on their position in the food supply chain. Basically, small farms have lower bargaining power and lower selling prices compared to large agricultural enterprises. Smaller players participate in the distribution of the added value to an inadequate degree (Mulligan and Berti, 2016; de Schutter, 2010; le Vay, 2008). These negative – from the point of view of a small-scale farm – effects of the market mechanism may be limited by a coordinated integration system (long-term contracts, vertical and horizontal integration, participation in cooperatives and producer groups, etc.), which would not only improve the farmer's position in input-output flows, but also reduce the risk of activity and improves labour and capital productivity and decision efficiency through access to information (Bachev, 2017; Galdeano-Gómez *et al.*, 2006; Ray *et al.,* 1997). Simultaneously, it is important to limit the number of intermediaries and create shorter distribution channels, which would make it possible to increase the margin at the level of the agricultural producer (Palmioli *et al.*, 2020; Yaméogo *et al.*, 2018). In turn, the positive impact of the farm's physical size on the economic results and development abilities of family farms was confirmed, among others, by Galdeano-Gómez *et al.* (2017), Ren *et al.* (2019) and Therond *et al.* (2017).

Taking into account the above considerations, the vitality of small family farms and improving their economic operation have created the need for more significant state influence on the development of small farms. However, Serbia's agricultural policy has not defined clear and adequate measures of incentives for small farms. According to the Law on Incentives in Agriculture and Rural Development (Government of the Republic of Serbia, 2013, 2014, 2015 and 2016), 'beneficiaries of state support for agriculture and rural development can be agricultural holdings and family agricultural holdings registered in the farm register, units of local self-government, and other persons and organizations', with an agricultural land area above 0.5 ha. Out of all the support, only some programmes can be treated as targeting small-scale family farms.

One of the priorities of the Serbian Strategy of Agriculture and Rural Development for 2014–2024 is to strengthen the social structure and social capital in rural areas, which could be taken to refer to small-scale family farming. The operational goals within this priority include, *inter alia*, reducing rural poverty and improving the status of the deprived rural population, improving the social status of agricultural labour and access to state support for small agricultural holdings (FAO, 2020). Due to the fact that the funds for this purpose in the entire support pool are insignificant, one could legitimately state that the aid for this group of entities is insufficient. Such a situation may lead to irregularities in the distribution of support observed in the European Union countries. As the beneficiaries of direct payments can be all farms registered in the system with an area of more than 1 ha, a large part of the funding goes to the largest units (80% of support: 20% of the biggest farms) (European Commission, 2018).

To avoid the problem, and taking into consideration the reality that the economic efficiency of agricultural production on small farms in Serbia is not satisfactory compared to the resources at its disposal, our study, using an AHP procedure for multicriteria decision-making, enables the ranking by relevance of selected criteria for pinpointing small farm economic performance based on decision-makers' opinions. The results obtained thereby also have an application dimension and may constitute the basis for formulating the specific goals of agricultural support policy in Serbia and other countries with a similar agrarian structure. It can be concluded that the support policy for this part of the agricultural sector should be directed towards guaranteeing profitable and stable prices for agricultural products. However, it is not about direct price regulation by the state, because such instruments are included in the WTO's 'amber box' of measures considered to distort production and trade (World Trade Organization, 2021), but rather about policy exerting an indirect influence on the shape of the food supply chain. The proposed solution is to introduce greater transparency of contracts between farmers and intermediaries, with the price element included. It might be a good idea to create a standardised template for a contract at national or regional level. Additionally, it is recommended that policymakers introduce an obligation to report on the market situation in a given agricultural sector, so that it is easier to determine the price conditions of contracts.

The other aim should focus on strengthening the farmer's position in the food supply chain, making it possible to take over the greater part of the margin generated in the food processing process, even in the relatively competitive fruit and vegetable sub-sectors. Farmers could strengthen their position by conquering new phases of added value within the established traditional chain (retail packaging and deeper processing), by developing new chains – fresh consumed products, organic food, hot processing (jams, juices) and also through diversification to other sub-sectors (e.g. blueberries and strawberries). An example of stimulating these processes is financing the activities of agricultural producer groups and industry organisations, creating an infrastructure for the development of short sales channels, such as local bazaars. Due to the low awareness of the benefits of market integration and the lack of knowledge of solutions, the education of farm managers through participation in training, courses, training, etc. becomes crucial. Such events could be organised by agricultural advisory centres, agricultural unions, representatives of academic environment etc. It is also suggested that mechanisms be implemented to facilitate increase in the area of farms, e.g. land consolidation support programmes, structural pensions for older farmers transferring the farm, preferential lending to young farmers and land allocation from state ownership.

When assessing the development potential of Serbian agriculture, and of Serbian family farms in particular, it is necessary to take into account the perspective of including the country within the structures of the European Union and the implementation of the mechanisms of the common agricultural policy (CAP). Opinions on the effectiveness of CAP instruments vary from positive (Galanopoulos *et al.,* 2011; Pechrová, 2015; Guth *et al.,* 2020), through moderate

(Latruffe *et al.,* 2017), to negative (Zbranek, 2014; Bojnec and Latruffe, 2008). In the field of environmental support and so-called greening, the low efficiency of CAP was indicated by the European Court of Auditors (2017). Appropriate institutional solutions should therefore be prepared in advance so as not to repeat the mistakes of the EU countries. In the case of Serbian agriculture, area payments, which are the main source of support under EU agricultural policy, have a positive impact on the economic efficiency of farms. Therefore, they can become the engine of rural development in Serbia, provided that their proper distribution is ensured (the point is to avoid the aforementioned problem of unequal allocation of funds between small and large farms). The same research shows that investment subsidies were found to have an insignificant impact on farm technical efficiency. Yet they will be an important part of the rural development program (II pillar of CAP). It is therefore important to adapt these programs to the needs of Serbian agriculture. Taking into account the fact that it is dominated by semi-subsistence family farms with small capital, some of the funds should be in the form of grants, without the need to involve one's own expenditure.

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The impact of the supply of farmland, level of agricultural mechanisation, and supply of rural labour on grain yields in China

In order to provide food security for a growing population, abundant crop production is necessary. Globally, unpredictable natural and human factors are the result of the unforeseen consequences of agricultural productivity. Appropriate land tenure, proper labour allocation, and higher agricultural mechanisation levels are the fuel to boost agricultural productivity. China has implemented various policies such as its farmland protection policies, rural-labour allocation to off-farm industries, and agricultural mechanisation subsidies to induce grain self-sufficiency. However, farmland loss is an increasing trend; surplus rural labour continues to exist; and agricultural mechanisation has not reached the required level of quality and quantity. With this in mind, this study examines the long- and short-term impacts of farmland supply, rural-labour supply, and agricultural mechanisation development on grain-crop yields in China. The Autoregressive Distributed Lag (ARDL) approach to co-integration and error correction was applied to data over the period 1978-2017. The results show that farmland supply and agricultural mechanisation developments are positively associated with the growth of grain-crop yields in both the short- and long-term. However, the impact of the rural labour supply on grain yield is insignificant. Strengthening farmland protection policies and promoting innovation-based agricultural mechanisation development plays an important role in sustainable food production. Future research should focus on improving the quality of farmland, agricultural mechanisation, and finding effective strategies to protect farmland for sustainable food production. Moreover, China's efforts to enhance the multidimensional level of agricultural mechanisation should be encouraged.

Keywords: farmland; agricultural mechanisation; rural labour; grain yield

JEL classification: Q11, Q14, Q1

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Introduction

Currently, one of the most prominent objectives for worldwide food security is to optimise accessible land and water resources to cope with the growth of the world's population. The allocation of labour and technological innovation is used as a route to sustainable agricultural productivity (Adenle *et al.,* 2019; East, 2018; He *et al.,* 2019). In most cases, hunger, malnutrition, and undernourishment occurs owing to the failure in land, labour, and technology allotments in agrarian societies (Santos *et al*., 2014). Researchers have revealed that the efficient allocation of these agricultural production factors thorough various policy incentives can be used as a driving force for sustainable agricultural productivity and rural development.

In 1978, China adopted the basic rural reform and policy measures to feed 20 percent of the world's population with 10 percent of its arable land (Gong, 2017). The reform prioritised the improvement of grain yield as a key to attaining self-sufficiency in food. The government has since developed and implemented various agrarian support policies. For instance, the household responsibility system enables households to cultivate and manage their own farmland (Krusekopf*,* 2002). The system also encourages farmers to grow crops according to their own interest. In China, farmland loss is one of the biggest challenges now inducing a reduction in grain output. It is largely a result of land degradation (Rozelle *et al.*, 1997), farmland transfer (Liu *et al.*, 2018), land-use change, urbanisation, and the expansion of non-agricultural industries. Land protection policies and the forces of urbanisation have become antagonistic due to the pace of China's desire for socioeconomic development. Nonetheless, we claim that, to sustain grain yields, grain farmland protection mechanisms must be prioritised in order to maintain the national food security demand of the growing population. The population of China is forecast to peak within 10 years and to start shrinking quite rapidly afterwards. This suggests that increasing population is not much of a long-term concern. Perhaps the greater concern is that people want to consume more, rather than that there are more people to feed.

The socioeconomic shift also has also caused a shift in land-use from grain crop farmland to urban-based industrial expansion (Wang *et al.*, 2018b). The government developed strategies and policies to address the transformation of the nation's cropland. The prevention mechanism has included implementing farmland protection policies (Lichtenberg *et al.,* 2008; Huang *et al.,* 2019) and land reclamation (Xin *et al.,* 2018). Researchers have assessed the effectiveness of these farmland loss-prevention mechanisms. Chen *et al.* (2003) stated that a rise in the supply of farmland will play a significant role in boosting the growth in grain yields. Analysing the costs and benefits, Liu *et al*. (2019) for example recently concluded that the reclamation effort must focus on high-quality farmland in order to reduce the economic cost of reclaiming less productive farmland.

Rapid economic growth and a decreasing trend in its share of world agricultural production pushed China to subsidise farmers in order to buy agricultural machinery, thereby seeking to increase grain yields (Lopez *et al.,* 2017; Yi *et al.,* 2015). Moreover, the government has promulgated a grain subsidy policy to enhance grain yields. However, since the reform period, it is unclear whether these measures have had an important impact on the growth of grain yields in China, and to what extent the policies have been responsible for what growth there has been. The accumulation of surplus labour has been preventing China from developing medium- and large-scale agriculture. Nonetheless, China has met the demand for grain with small-scale agriculture. When the urban and rural industries surpassed the growth of agriculture, the off-farm real wage growth attracted rural labours. The government has also introduced surplus rural labour allocation policies (Bowlus *et al.,* 2003). Consequently, the question arises as to whether the transfer of rural labour has influenced grain yields.

China produces grain in excess of that required for domestic consumption (Johnson, 1994). The grain yield increased from 304.7 million tons in 1978 to 661.5 million tons in 2017, nearly doubling in four decades (NBSC, 2017). According to a report from the Ministry of Agriculture in 2017, the grain output remained above 600 million tons for five successive years, making China the world's foremost grain producer. However, as explained by Lin *et al.* (1997), grain-yield growth instability was found in various periods, and spatial and temporal shifts were observed (Yu *et al.,* 2019).

Researchers have indicated different reasons for the rise and decline in the rate of growth in grain yield. The increase in the rate of growth rate, for instance, was in part due to changes in institutional structure (Zhang and Carter, 1997), research-induced technical change (Fan *et al.*, 1997), and chemical fertiliser application (Zhang *et al.,* 2013). Wang *et al.* (2018a) revealed that the spatial and temporal shift of grain yield occurred as a result of farmer-protecting grain subsidies and drastic improvements in agricultural infrastructure. On the other hand, factors such as environmental degradation (Huang and Rozelle, 1995), climate change, and land-use change induced by urbanisation (Lu *et al.*, 2017) caused a reduction in the rate of grain yield growth. Porkka *et al.* (2013) suggest that China's national demand for grain can be fulfilled by adjusting trade policies and importing more grain from foreign markets. However, relying on imported grain cannot be a sustainable solution for the growing population due to global trade uncertainty. Thus, the adequate allocation of resources such as farmland, labour, and technology can provide a long-term solution for achieving the sustainable production of grain.

To the best of our knowledge, no study has determined the short- and long-term impacts of farmland supply, the agricultural mechanisation level, and rural-labour supply on grain yield since the major economic reform and opening up policy began in 1978. Few studies conduct related analyses over short periods of time (Rozelle *et al.,* 1997). He *et al.* (2019), for example, revealed that farmland supply preservation policies can play a substantial role in reducing arable land loss, which in turn helps to maintain grain output. Yao and Zinan (1998) revealed that the technical elements (agricultural mechanisation) of the farming scheme remain the basic way forward for long-term sustainable grain production. They advocate yield-enhancing inputs such as fertilisers and irrigation to increase grain yield in the short-term. Li *et al.* (2017) also found that agricultural mechanisation was a critical requirement for allowing farm size increases, as well as for enabling the growth of grain yields. Researchers are in two minds concerning the impact of rural labour supply dynamics on grain production in China. On the one hand, rural labour migration causes a decline in agricultural productivity owing to the loss of skilled farmers (Bowlus *et al.,* 2003; Dazhuan *et al.,* 2018). On the other hand, the rural labour flow due to off-farm rural and urban employment opportunities facilitates land-leasing and leads to the emergence of large-scale farmland and operations that improve grain-yield (Den *et al.,* 2007).

The purpose of this study is to provide insights into the long- and short-term impacts of farmland supply, the level of agricultural mechanisation, and the rural-labour supply on grain yield in China. We have used the ARDL bounds test for co-integration and error correction approach adopted by Pesaran *et al.* (2001). The findings enabled us to evaluate the influence of the supply of grain-crop farmland, the agricultural mechanisation level, and the rural labour supply on grain yield. This benefits policy makers in formulating effective policies and productivity incentive measures to strengthen sustainable grain productivity for the increasing population. In addition, the findings obtained provide a window on China's efforts to realize modern agriculture and revitalise rural areas.

The article is organized as follows: Section 2 explains the conceptual framework and hypotheses; Section 3 discusses the data and methodology; Section 4 describes the empirical outcomes and discussion; and Section 5 illustrates the conclusion and policy implications.

Conceptual framework

One of the basic inputs for grain production is the supply of adequate farmland. Fluctuation in the supply of farmland has an enormous impact on grain crop production. In China, one of the primary purposes of the rural reform undertaken in 1978 was to increase the efficiency of agriculture and to improve farmers' income by dismantling the People's Commune system and allocating farmland to households using the household responsibility system as the nation's land tenure scheme. Since then, grain yield and the per capita income of farmers has increased, showing a dynamic growth trend. The supply of grain farmland has been affected by numerous challenges such as urbanisation, industrial expansion, and land degradation, which has caused farmland losses. Specific farmland protection policies and farmland reclamation measures have been introduced in the face of these difficulties.

Hypothesis 1. Total supply of grain-crop farmland has had a significant positive impact on grain-yield since the period of rural reform starting in 1978.

Agricultural mechanisation promotes agricultural production from farmland to the processing stage. The level of mechanisation of agriculture is a measure of a nation's level of agricultural modernisation. There are factors that have a negative impact on the development of agricultural mechanisation. For instance, farmland fragmentation, farmers' income, and topography are the most important challenges hindering the development of agricultural mechanisation, especially in nations such as China where the majority of farmers are smallholders. China has provided numerous subsidies as an incentive to encourage sustainable grain production and to increase farmers' income. These have included subsidies for agricultural machinery.

Hypothesis 2. The development of agricultural mechanisation has had a significant and positive impact on grain yield growth over the last four decades.

Agricultural production in China is labour-intensive, which places huge cultivation pressure on, and reduces the quality of, farmland. The major economic reform and opening up policy have fostered industrial growth and facilitated nationwide urbanisation. The development of urban sectors has created employment opportunities for rural surplus labour and resulted in huge rural-to-urban migration. Researchers have found both positive and negative impacts of rural-to-urban migration on the allocation of labour in both areas. Reducing excess rural labour, for instance, facilitates farmland transfer through farmland leasing and renting between farmers. As a result, large-scale farmland that is appropriate for agricultural mechanisation is emerging.

Hypothesis 3. The decrease of surplus rural labour has a beneficial impact on China's grain-yield productivity growth.

The real-wage rise due to rural off-farm and urban industries growth causes the transfer of rural labour. This reduces the accumulation of surplus rural power in the agriculture sector and promotes farmland consolidation. Moreover, the reduction of surplus labour reduces the pressure of overcultivation of farmland caused by excessive farm labour. Consequently, the decline in surplus rural labour induces growth in grain yields.

Therefore, based on the above hypotheses, we lay out the following conceptual framework:

Data and Methodology

Data Source and Descriptive Statistics

The annual data used in this article are the output of grain crops (OGC), the total power of agricultural machinery (TPAM), the total sown area of grain crops (TSAGC), and the total number of employed rural labourers (TNREL). The data were collected from the National Bureau of Statistics of China (NBSC) over the period 1978-2017. We relied on data from 1978 onwards because the economic reforms were launched in that year, and almost all of the agricultural production indicators, including grain-yield, show an overarching change driven by these policies and incentives. The NBSC defines the variables as follows:

Output of Grain Crops (tons): this includes the total output of grain produced by farmers and other agricultural production actors in the whole year. The output of grain crops includes all cereals including rice, wheat, corn, millet, jowar, barley, beans. The unit of the measurement for the grain crop is tons.

Total power of agricultural machinery (Kilowatt): this refers to the total rated capacity of all agricultural machinery used for activities such as ploughing, planting, weeding, harvesting and construction of farmland infrastructure.

Total sown area of grain crops (Hectares): this includes

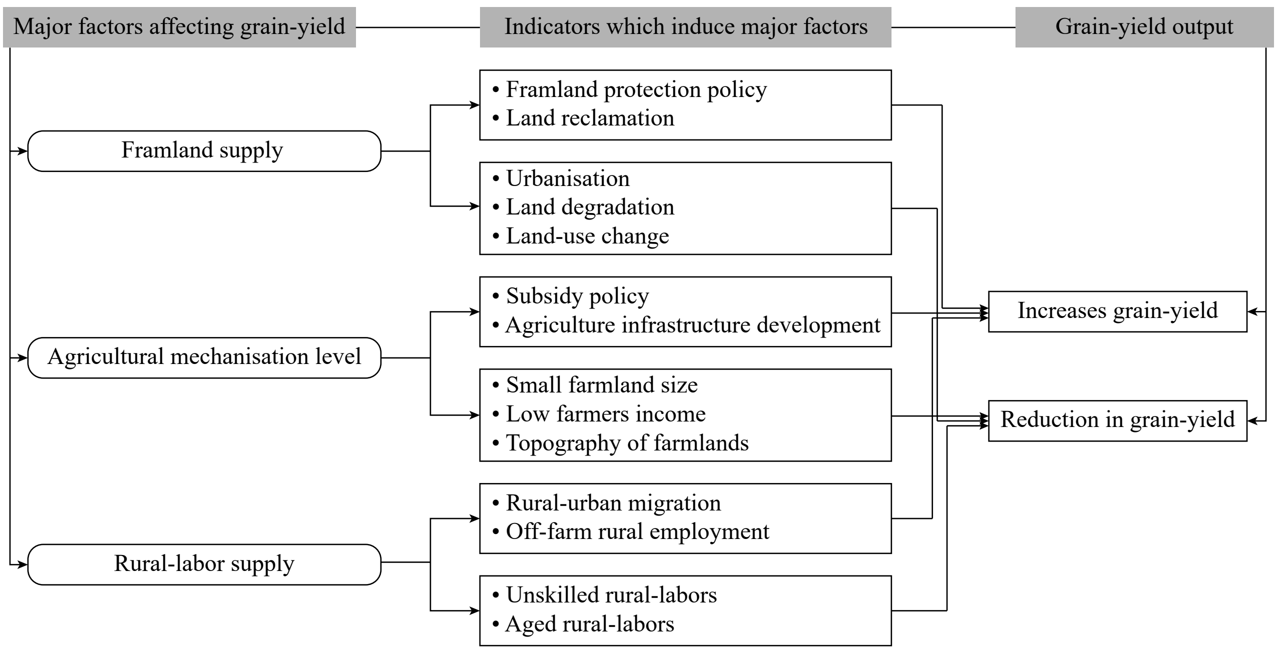

Figure 1: Conceptual framework for determining the presence and extent of the impact of farmland supply, the level of agricultural mechanisation, and the supply of the rural labour supply on grain yields in China.

Source: Own composition.

both arable and non-arable land on which farmers and other agricultural producers harvest grain crops. Grain crops sown in the previous year, but harvested this year, are considered as the current year.

Total number of rural employed labourers (people): all rural people 16 and over who are involved in on- and off-farm employment.

Model Specification

The article aims to examine the impact of farmland availability, agricultural mechanisation level, and rural-labour supply on grain yield. Thus, based on previous study of basic economic theory and the data availability we specify the following model:

$$\ln GY_t = \alpha + \beta_1 \ln REL_t + \\ + \beta_2 \ln AGC_t + \beta_3 \ln AM_t + \mu_t \quad (1)$$

where ln*GY*, ln*REL*, ln*AGC* and ln*AM* denote grain yield, number of employed rural labourers, sown area of grain crops, and total power of agricultural machinery, respectively. According to the standard economic model, β_1>0, β_2>0, β_3>0 and the disturbance term is adopted as normally distributed. The coefficients β_1, β_2 and β_3 are the elasticity of grain yields with respect to ln*REL*, ln*AGC*, and ln*AM* respectively. The basic economic model is as follows:

$$LNOGC = \alpha_0 LNTNREL + \\ + \alpha_1 LNAGC + \alpha_2 LNTPAM + \mu_i \quad (2)$$

where:
LNOGC = Natural logarithm of Output of Grain Crops
LNTNREL = Natural logarithm of Total Number of Employed Rural Labour
LNAGC = Natural Logarithm of Total Sown Area of Grain Crops
LNTPAM = Natural Logarithm of Total Power of Agricultural Machinery

In our analysis, *LNOGC* is a dependent variable, whereas *LNTNREL*, *LNAGC* and *LNTPAM* are independent variables. Since the major economic reform period, the Communist Party of China has used these four core agricultural indicators to guide policy, and incentive tools to drive the growth of agricultural productivity. Thus, the growth of grain yields has been induced by the formulation and implementation of land, labour, agricultural mechanisation, and subsidy policies in rural areas of China.

Method of Empirical Analysis

We investigate the long- and short-term impact of farmland availability, agricultural mechanisation level, and rural labour supply on grain yield in China. We employed the autoregressive distributed lag (ARDL) modelling approach to cointegration analysis. Engle and Granger (1987) formulated a cointegration analysis that could not be applied to variables which are integrated in different orders (such as in the first difference I(1)). However, Johansen and Juselius (1990) created a cointegration approach for variables which are integrated in different orders. However, their cointegration analysis is only applicable to small samples, and only able to determine long-term relationships between variables. To fill these gaps, we employed the ARDL modelling approach to cointegration analysis (Pesaran *et al.,* 2001). We

Table 1: Latent variables and indicators.

Latent variables	Observable/measured Variables	Codes	Measurement unit
Farmland supply	Total sown area of grain crops	TSAGC	Hectares (Ha)
Agricultural mechanisation level	Total power of agricultural machinery	TPAM	Kilowatt (KW)
Rural-labour supply	Total number of rural employed labour	TNREL	Peoples
Grain-yield	Output of Grain Crops	OGC	Tons

Source: own composition

Table 2: Descriptive statistics table.

Variables	LNOGC	LNTNREL	LNAGC	LNTPAM
Med.	19.95	19.57	18.54	19.89
Max.	20.31	19.78	18.61	20.83
Min.	19.54	19.16	18.41	18.58
S.D.	0.21	0.17	0.04	0.68
Obs.	40	40	40	40
LNOGC	1	-	-	-
LNTNREL	-0.54	1	-	-
LNTSAGC	0.44	-0.27	1	-
LNTPAM	-0.54	0.10	-0.04	1

Source: own composition

clearly adopted a step-by-step ARDL modelling approach to cointegration analysis as follows:

Step 1. The level of the stationarity of all variables included in the analysis was tested. The variables must be stationary only at level I(0) or at first difference I(1). This test was necessary because some time series variables may show divergence in their means. This causes the production of spurious regression and consequently, inaccurate outcomes. Thus, we applied an augmented Dickey–Fuller test (ADF) unit root test, developed by (Dicky and Fuller, 1979; Perron and Vogelsang, 1992). These unit root tests have been employed by econometric researchers to detect unit roots, which could originate from time-varying mean or variance (or both) (Harris, 1992). To determine these two unit-root tests, lag length must be determined.

Step 2. We specified the ARDL model, adopted and based on the available data and variables as follows:

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_{1i}\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_{2i}\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_{3i}\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_{4i}\Delta LNTPAM_{t-1} + \\ &+\beta_1(LNOGC_{t-1}) + \beta_2(LNTNREL_{t-1}) + \\ &+\beta_3(LNAGC_{t-1}) + \beta_4(LNTPAM_{t-1}) + \mu_t\end{aligned} \tag{3}$$

where:
$P1$ - $P4$ = represents optimal lag length of the variable
D = first difference operator
α_0 = intercept
α_1-α_4 = Short-run coefficients
β_1-β_4 = long-run coefficients
μ_t = white-noise disturbance term

Step 3. We conducted a cointegration bounds test to check for the existence of a long-term cointegration between variables. Thus, we applied the approach developed by Pesaran *et al.* (2001), assuming that errors in all the variables must be serially independent. The selection of the maximum lags for each variable may be affected by this assumption. Here is the equation for bounds test:

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_1\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_2\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_3\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_4\Delta LNTPAM_{t-1} + \upsilon_t\end{aligned} \tag{4}$$

To elucidate the presence of a long-term equilibrium among variables, we performed F-test. The hypothesis is:
H_0: $\alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ (Null hypothesis)
H_1: $\alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq 0$ (Alternative hypothesis).
The rejection of the null hypothesis shows the existence of long-term co-integration among variables.

Step 4. We drew an unrestricted error-correction model (ECM_{t-1}), which is a modified ARDL model. The main objective of the re-expression of ARDL model in error correction form is to isolate short-term linkage of variables from the long-term equilibrium relationship (Mills, 2019; Ericsson, 1995).

$$\begin{aligned}\Delta LNOGC_t &= \alpha_0 + \sum(i=1)\ p1\ \alpha_1\Delta LNOGC_{t-1} + \\ &+\sum(i=1)\ p2\ \alpha_2\Delta 1LNTNREL_{t-1} + \\ &+\sum(i=1)\ p3\ \alpha_3\Delta LNAGC_{t-1} + \\ &+\sum(i=1)\ p4\ \alpha_4\Delta LNTPAM_{t-1} + \lambda ECT_{t-1} + \upsilon_t\end{aligned} \tag{5}$$

The definition of the variables explained in Step 2 are:
α_0 = intercept
α_1-α_4 = Short-run coefficients
υ_t = error term
l = the speed of adjustment parameter to a long-term equilibrium.
ECT_{t-1} = the error correction term

Step 5. In this step, we conducted two major tests to check the appropriateness and strength of the model. Firstly, we tested the sensitivity of the model through an estimating normality test, serial correlation test, and heteroscedasticity test. Secondly, we tested the stability of the model by applying a Cumulative Sum Control Chart (CUSUM) and Cumulative Sum Square Estimation (CUSUMQ). The CUSUM and CUSUMQ tests can help the researcher detect changes among the variables over time (Grigg *et al.,* 2003). The data analysis was conducted using Stata 14.

Results and Discussion

Since the 1978 economic reform and opening-up policy, China's agrarian society has witnessed multi-directional development in areas such as growth of grain yield, improvement in agricultural infrastructure, and growth of farmers' income. The growing national demand for food has also been supported by the government's devotion to food self-sufficiency strategies at every level of the nation's Communist Party. Thus, post-reform agricultural policy prioritises grain-yield growth as a key instrument to improve food accessibility and affordability for millions of undernourished people. The grain-producing sector is driven by land policy reforms, subsidies, and allocation of rural labour triggered by urban industrial development. This article examines the short- and long-term impacts of the supply of farmland, the level of agricultural mechanisation, and the supply of rural labour on grain yields in China over the period 1978-2017.

In the ARDL bounds test of co-integration analysis, all of the variables must be co-integrated at level I(0) or at first difference I(1). A mixture of I(0) and I (1) variables are also accepted. As indicated in Table 3, the ADF and the PP unit root test reveal that all the variables are significantly (1%) integrated at the first difference I(1). Akaike Information Criterion (AIC) as used as a criterion for appropriate lag length selection (Cheung *et al.,* 1995). The ADF and PP tests provide evidence about the existence of stationarity (co-integration) between the variables used in the analysis.

Disclosing the existence of long- and short-term relationships between this study's variables has been the primary goal of many econometric researchers because the results would be a valuable input for future economic policymakers. In this article, the bounds test co-integration analysis, based on F-statistics or Wald statistics described in Table 4, demonstrates the existence of a strong long-term relationship between the supply of farmland, the level of agricultural mechanisation, and the supply of rural labour with grain-yield in China since 1978. The estimated F statistic is 5.949, which is significant and greater than the lower bound I(0) and upper bound I(1) at 1%, 2.5%, 5% and 10% based on the level specified by (Pesaran *et al.,* 2001). The result obtained in the bounds test of co-integration suggests the possibility of conducting long- and short-term impact assessments between the variables.

The ARDL bounds test approach employed in this study is appropriate. Diagnostic tests play an important role in the application of the ARDL model. As indicated in Table 5, the results from the Breusch-Godfrey Serial Correlation LM test indicates that our model is free of any serial correlation error term. The model employed is also free of conditional heteroscedasticity. In Table 6, all the diagnostic data disclosed that the model is properly employed and well-fitted.

In addition, the cumulative sum control chart (CUSUM) and cumulative sum square estimation (CUSUMQ) help to interpret the model's stability in econometrics research. Typically, it enables us to identify changes among the variables within a given time span (Grigg *et al.,* 2003). The CUSUM and the CUSUMQ tests in Figures 2 and 3 show the model's stability. The middle line in both graphs lies between the two straight boundary lines. Thus, the model is appropriate and properly utilised in the overall estimations.

The impact of farmland supply on grain-yield in China

The question of feeding future generations with the available land resources puts huge pressure on stakeholders in food security. For populous nations like China, this challenge is more stressful. The nation has made huge efforts to supply food for 20% of the world's population with only 10% of farmland resources. Given that the other inputs for grain production are constant, it follows that the more farmland is sown with grain, the higher the grain yield. One of the key elements of rural reform in 1978 was the dismantling of the People's Commune system. Because farmers did not have the right to complete ownership for deciding how to use their farmland, the household responsibility system (HRS) was launched in the land management law of 1978. In the first six years, it was introduced only on a trial basis in a few provinces, but in 1986 it had already covered almost 90 percent of the country. Since then, there has been a sharp increase in grain yields. The HRS provided farmers

Table 3: Unit root test results.

Variables	ADF		PP	
	Level	1st Difference	Level	1st Difference
LNOGC	-2.399	-6.290***	-2.505	-6.289***
LNAGC	-1.847	-4.283***	-1.545	-4.311***
LNTPAM	0.187	-4.717***	-0.218	-4.774***
LNTNREL	-0.795	-4.332***	-0.385	-4.312***

Note: *, ** and *** stand for significance at 10%, 5% and 1% levels, respectively.
Source: own composition

Table 4: Bounds test result.

Critical Value	Lower Bound Value (I(0))	Upper Bound Value (I(1))
1.0%	4.29	5.61
2.5%	3.69	4.89
5.0%	3.32	4.35
10.0%	2.72	3.77
F-Statistics = 5.949	The number of regressors (K) = 3.0	

Note: *LNOGC*, *LNTNREL*, *LNAGC* and *LNTPAM* (1, 0, 1, 2), where *LNOGC* is a dependent variable. The decision of the bound test result is based on the rule specified by Pesaran *et al.,* (2001). The rule states that if the estimated F statistics is significant and greater than the lower bound I(0) and upper bound I(I) values, there is long and short term relationship between the variables.
Source: own composition

Table 5: Model diagnostic test results.

Test	Diagnostic Check	P-value
Breusch-Godfrey Serial Correlation LM test	0.04	0.9804
White's test	36.85	0.3832
Heteroskedasticity	36.85	0.3832
R^2	0.98	
DW statistic	1.84	
Cusum Test	Stable at 5% level	
Cusum of Squares Test	Stable at 5% level	

Source: own composition

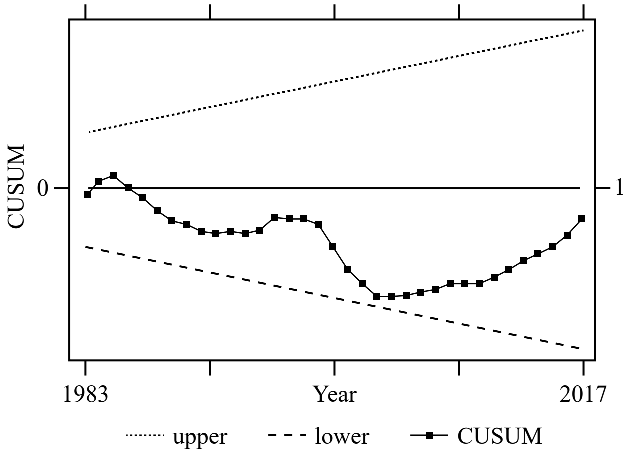

Figure 2: CUSUM test of recursive residuals.
Source: own composition

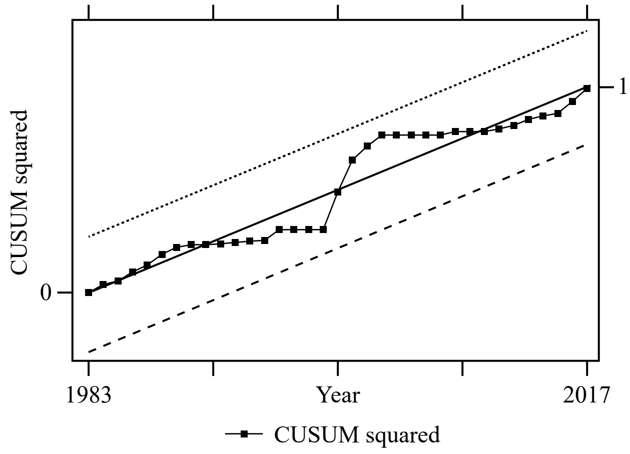

Figure 3: CUSUM square stability test of recursive residuals.
Source: own composition

Table 6: The result of long-run ARDL co-integration model

Variables	Coefficient	Std. Error	t-Statistics
LNTNREL	0.1794	0.1152	1.5600
LNAGC	1.3884	0.4371	3.1800***
LNTPAM	0.2278	0.0381	5.9700***

Note: *, ** and *** stand for significance levels of 10%, 5%, and 1% levels, respectively. LNOGC, LNTNREL, LNAGC and LNTPAM (1, 0, 1, 2), where LNOGC is a dependent variable.
Source: own composition

Table 7: The result of ARDL co-integrating short-run restricted error–correction model

Variables	Coefficient	t-statistics	P-value
ΔLNTNREL	0.0644	1.3700	0.1790
ΔLNAGC	2.1092	7.7200	0.0000***
ΔLNTPAM	-0.0486	-0.3400	0.7360
$\Delta LNTPAM_{t-1}$	-0.2090	-1.0000	0.3250
$\Delta LNTPAM_{t-2}$	0.3393	2.5400	0.0160**
Constant	-4.9156	-1.1600	0.2560
ECT_{t-1}	0.3592	-3.5900	0.0010***
R^2	0.9853	-	-
Adjusted R^2	0.9819	-	-
Durbin-Watson(D-W)	1.8414	-	-

Note: *, ** and *** stand for significance levels at 10%, 5%, and 1% levels, respectively. ΔLNOGC, ΔLNTNREL, ΔLNAGC and ΔLNTPAM (1, 0, 1, 2), where ΔLNOGC is a dependent variable.
Source: own composition

with the right to land transfers for their farmland. In addition, the scheme stabilised and mobilised farmers to grow grain. The supply of farmland, however, entered a vibrant phase that induced fluctuations in the grown of grain yields. Our research, therefore, elucidates the impact of a farmland supply variability on grain yields. Our findings in Table 6 show that the supply of farmland has positive and significant impact on the grain yield in the long run at a 1% significance level. The coefficient of grain crop sown area (LNAGC) is positive and significant at the 1% level. This shows that a 1% increase in the supply of farmland creates a 1.38% rise in the output of grain, and a 1% decline in the supply of farmland creates a 1.38% decrease in the grain yield in the long run. Furthermore, the findings in Table 7 also show the significant and positive impact of supply of farmland on grain yields in the short term at a 1% level of significance. A 1% increase in farmland supply leads to 2.1% growth of total grain crop yield in the short term.

Our findings are clear on how these prevention mechanisms have helped China to maintain farmland for attaining the increase in grain yields since the major reform and opening up policy, in both the short- and long-run. Contrary to these claims, Lichtenberg *et al.* (2008) earlier concluded that the reduction in the supply of farmland and the farmland protection policy had not had any significant influence on grain production, arguing that farmland losses can be compensated for by other factors such as fertilisers and agricultural machinery. In the short term, their claims may be true, but reduction in the supply of farmland does not provide sustainability for the increased population of the future. Thus, we highly recommend that the government safeguards grain farmlands from losses with a view to sustainable grain production in China.

The impact of agricultural mechanisation level on grain yield in China

Agricultural mechanisation is a fundamental agricultural input that helps improve the productivity of labour, the level of land output, and the quality of agricultural products. Promoting the level of agricultural mechanisation has a substantial role in enhancing the technical elements of grain production and boosting grain yields (Chen *et al.,* 2003). Agricultural mechanisation in China is one of the targets and former tools of rural reform aimed at transforming the agrarian economy in a sustainable manner. The government promoted agricultural mechanisation through direct agricultural machinery subsidies and the subsidies were aimed at increasing grain yields.

Our research shows that the development of agricultural mechanisation has had a positive and significant impact on grain yields in the long run at a 1% significant level. As seen in Table 6, an increase of 1% in the power of agricultural machinery causes an increase in the output of grain crops of 0.22%. The short-term analysis in Table 6 also demonstrates a positive and significant impact on grain yield at a 5% significance level. A 1% increase in the total power of agricultural machinery has led to a 0.33% increase in the total grain yield in the short term. Our findings show that the achievement of grain production in China has been strongly supported by the government since the major reform period by promoting the use of agricultural machinery through direct subsidy policies, specific strategies, and research and development. According to the National Statistical Bureau of China (NSBC), agricultural machinery subsidies rose from 70 million yuan in 2004 to 30 billion yuan in 2017, while aggregate grain yield increased from 469 million tons in 2004 to 661 million tons in 2017. This figure indicates a positive correlation between growing agriculture machinery subsidies and China's growing grain yields. Supporting our findings, Chen *et al.* (2008) earlier reported that agricultural mechanisation development had had a positive effect on the grain farming system. In addition, Yao and Zinan (1998), revealed that long-term grain yield growth can be accomplished by enhancing agricultural mechanisation.

However, agriculture mechanisation now faces various challenges such as land fragmentation, land-use change, low-income farmers, and inadequate and unwanted farm machinery production. Consequently, these factors are complicating government efforts to implement large-scale farm machinery and management operations in the sector. Thus, our findings remind us that these are all variables that hinder the development of agricultural mechanisation, cause declining grain yield growth in the nation, and play a significant role in holding back sustainable grain productivity. Moreover, in the context of China's most recent pursuit of rural revitalisation and modern agriculture in rural areas, our study reinforces the relevance of incorporating agricultural mechanisation development for sustainable food security and rural development.

The impact of rural labour supply on grain yields in China

Rural labour is one of the most important inputs of grain-production. Rural labour in China has shown a declining trend since the major reform and opening up policy, standing at 70% of the population in 1978 and anticipated to be 10% in 2030 (Johnson, 2000). This happened in two ways. Firstly, owing to fast industrial growth in urban regions, rural-labour migration to urban areas occurred as labourers sought to take advantage of urban employment opportunities. The release of labour from agriculture causes the government to invest in other factors of production (Wang *et al.*, 2019). Second, emerging rural industries attracted rural labour to participate in rural off-farm employment opportunities. Thus, we will now examine whether this displacement of rural labour has had an effect on grain yields. Our findings demonstrate that the dynamic rural labour supply has had no significant impact on grain yield in China. This is contrary to our expectations and counters Hypothesis 3. Our findings are compatible with Yang *et al.* (2016) who likewise conclude that rural labour migration has had no impact on grain yield in China. Moreover, Chen *et al.* (2011) revealed that a greater focus on labour input and correspondingly less on yield-increasing inputs like agricultural machinery resulted in slow growth in grain yields. This means that fluctuations in the rural labour supply have had no direct impact on grain yields. It may yet, however, have positive or negative indirect effects on grain yields. For instance, a huge surplus rural labour supply puts great pressure on farmland and facilitates farmland degradation and fragmentation. Our findings remind the government, policymakers, and other specialists in food security to place more emphasis on the quality rather than the quantity of rural labour. Investing in the cultivation of trained rural labour in particular will play a significant role in answering the food demands of the growing population.

Conclusions and policy recommendations

Although a lot of research has been done into the factors affecting grain yield, no studies have hitherto investigated the short- and long-term impact of farmland supply, the level of agricultural mechanisation, and supply of rural-labour on grain yields. Thus, the purpose of this article was to examine the existence and extent of the short- and long-term impacts of these three factors over the period 1978-2017. Based on the available data gathered from the National Bureau of Statistics of China, we designed and applied the ARDL co-integration bond test approach and error correction model (ECM). Our findings reveal that both the supply of farmland and the level of agriculture mechanisation exhibit strong and positive short- and long-term impacts on total grain yield. This indicates that

China's dynamic land policy plays a significant role in continuing grain yield growth. The mechanisation policies also contribute significantly to the effective growth of agricultural productivity. Thus, the government should continue to reinforce the nation's farmland protection policy and to advance innovative agricultural mechanisation.

Our findings also reveal that, during the study period, rural labour flow has had no perceptible influence on total grain yield in China. This finding provides a rationale for further investigation into the relationship between China's rural-labour and grain policies, as the supply of rural labour has an indirect impact on grain yields. We conclude that promotion of sustainable growth in grain yields must be regulated in such a way as to facilitate efficient allocation of farmland, innovative labour, and agricultural mechanisation. The scope of this article was limited to determining the existence of the long- and short-term impacts of farmland supply, the level of agricultural mechanisation, and rural-labour supply on grain-yield in China, but the cause-effect relationships between these variables were not discussed. Consequently, the impacts of the interaction between these all variables should be further explored by incorporating other grain-yield improving inputs such as fertilisers, irrigation, agricultural infrastructures, and seed quality into the analysis.

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Drivers of agricultural foreign divestment

This paper has used multilateral foreign divestment (FD) data covering 1991 to 2017 for 50 countries, fitted to an optimised model based on microeconomic theory, to estimate the drivers of FD out of agriculture. Identifying the factors that determine FD would offer an opportunity for policymakers to know what kind of policies can discourage FD. Furthermore, knowledge of the directional effect would offer a way to use the policy variables to appropriately influence FD. Market size, exchange rate, political regime characteristics and transitions as well as the level of development drive FD out of agriculture globally. Trade openness and access to land resources have not been found to determine FD. Consequently, agricultural economy managers should work towards increasing the size of the agricultural economy; they should also liaise with their respective country's Central Banks with a view to ensure exchange rate stability, and with their governments in order to promote better political regime characteristics and smoother political transitions.

Keywords: Foreign direct investment, foreign divestment, foreign exchange, agriculture, market size

JEL classification: Q14

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Introduction

Agriculture is a source of food and nutrition, and raw materials for industry. The sector accounts for 4 per cent of global gross domestic product (GDP) and in some developing countries, contributes more than 25% of GDP (World Bank, 2020). Growth in the sector is between two and four times more effective in increasing wealth among the poorest compared to other sectors. It is understood that in 2016, 65% of poor working adults made a living through agriculture (World Bank, 2020). Therefore, developing agriculture is one of the most potent tools to terminate extreme poverty, enhance shared prosperity and feed a projected 9.7 billion people by 2050 (World Bank, 2020). Global investment needs (domestic and foreign direct investment) are in the range of $5 trillion to $7 trillion per year. Estimates for investment needs in developing countries alone range from $3.3 trillion to $4.5 trillion per year, mainly for basic infrastructure, and food security, among others (United Nations, 2014). Thus, investments including foreign direct investment are required to support the agricultural sector.

Therefore, governments globally have pursued macroeconomic policies to attract foreign direct investment (FDI). This is an investment made by an enterprise dwelling in one economy in order to attract lasting attention to an enterprise that is dwelling in another economy (Punthakey, 2020; UNCTAD, 2020; United Nations, 2015). "Lasting attention" in this regard suggests the presence of a long-term association between the direct investor and the direct investment enterprise that exerts a substantial influence on the leadership of the enterprise. This substantial influence is evidenced by domestic investors typically possessing 10% or more of the voting power of a direct investment enterprise (UNCTAD, 2020). Inward FDI is important for a range of reasons. Firstly, inward FDI enhances local investment by increasing domestic investment via connections in the production value-chain; this occurs when foreign firms buy locally made inputs or when foreign firms supply transitional inputs to local firms. Secondly, the FDI supplements the supply of funds for investment, a situation that fosters capital formation. Thirdly, inward FDI increases the host countries' ability to export, initiating a rise in foreign exchange earnings. Finally, new job openings, and improved technology transfer are both related to FDI, thereby augmenting overall economic growth (de Mello Jr., 1997; Gallova, 2011; Kim and Seo, 2003; Mileva, 2008; Oualy, 2019; Romer, 1992).

These benefits notwithstanding, there is evidence that foreign divestment (FD) does occur after FDI. Foreign divestment is a strategic decision of foreign firms in a host country that results in changes in their business portfolio, ultimately leading to a reduction in the level of assets. The divestment could be downsizing, relocation of operations or termination (Benito, 2005; Belderbos and Zou, 2006; Boddewyn, 1983a; Chung *et al.*, 2010; Nyuur and Debrah, 2014). Nyuur and Debrah (2014) explained downsizing as partial sale or disposal of physical and organisational assets and the reduction of workforces of the organisation. Relocation entails the complete shutdown of facilities and moving these facilities and the foreign firms' operations to another country (Belderbos and Zou, 2006; McDermott, 2010; Nyuur and Debrah, 2014). Finally, termination involves the complete sale or disposal of physical and organisational assets, shutdown of facilities, and foreign firms' operations in a country without relocating to another country (Nyuur and Debrah, 2014). The assets of the subsidiary are usually repatriated back to the headquarters (Nyuur and Debrah, 2014). Irrespective of the form, FD does reduce the stock of FDI and total domestic investment in the host country, leading to loss of jobs, tax revenue, and foreign exchange and depriving the host economy of other benefits accruing from FDI. Taking all this into consideration, it is important to identify the causal factors of FD in agriculture and the direction of the effects.

Some studies have addressed the drivers of FDI into agriculture (Djokoto, 2012a; Farr, 2017; Husman and Kubik, 2019; Kassem and Awad, 2012; Lv *et al.*, 2010; Rashid and Razak, 2017) but not FD. This paper uses multilateral FD data covering 1991 to 2017 for 50 countries. The paper focuses on agriculture globally. Identifying the factors that determine FD would afford an opportunity for policymakers to understand what kind of policies can discourage FD. Also, knowledge of the directional effect would offer a way for policymakers to use policy to appropriately influence FD. This is relevant as FD reduces not only FDI stock, but it also reduces the total investment stock, which is key to economic growth in the agricultural sector as well as the wider economy.

This paper is organised in five sections. A review of the literature follows next. Section three presents the model and data. The results of the analysis and discussion of same are captured in section four. Concluding remarks constitute the last section.

Literature review

Theoretical review

In the literature, theories of FD have been conceptualised as barriers to exit within the industrial-organisation perspective (Boddewyn, 1983b; Porter, 1976; Wilson, 1980) and as a managerial dimension with a specific focus on what factors cause FD (Boddewyn, 1983a,b ; Spanhel and Johnson, 1982; Spanhel and Boddewyn, 1983). Boddewyn (1983b, p346) succinctly notes "These managerial studies have generally focussed on the deliberate and voluntary reduction or elimination of actively controlled foreign subsidiaries and branches through sale or liquidation, thereby excluding nationalizations, expropriations, spin-offs, 'fade-out' and 'harvest' cases as well as passive subsidiaries". Viewing FD theory as the reverse of Dunning's eclectic theory, Boddewyn (1983b) notes three preconditions for FD. The firm:

1. ceases to possess net competitive advantages over firms of other nationalities.
2. no longer finds it beneficial to use them itself rather than sell or rent them to foreign firms - that is, the firm no longer considers it profitable to 'internalise' these advantages.
3. no longer finds it profitable to utilise its internalised net competitive advantage outside its home country – that is, it is now more advantageous to serve foreign markets by home production, and/or to abandon foreign markets altogether.

The internationalisation theory of Hymer (1976) notes that firms often prefer FDI to licence as a strategy for entering a foreign market. The oligopolistic industries theory of Knickerbocker (1973) posits that firms follow others in entering foreign markets. Firms undertake FDI at stages in the life cycle of the product they pioneered (Vernon, 1966). Foreign markets are accessed when local demand in those countries grows sufficiently to support local production. These theories of FDI can work in the reverse for FD.

Empirical review

As studies on the drivers of FD from agriculture are non-existent, the empirical review addresses the drivers of FDI. The existing literature focused on an individual country (Ghana - Djokoto, 2012a; Egypt - Kassem and Awad, 2012; China - Lv *et al.*, 2010) and country groups (Africa - Husmann and Kubik, 2019; Latin America - Farr, 2017; Organisation of Islamic Countries (OIC) - Rashid and Razak, 2017). The size of the agricultural economy (market size) influences FDI into agriculture (Farr, 2017; Husmann and Kubik, 2019; Kassem and Awad, 2012; Lv *et al.*, 2010; Rashid and Razak, 2017). However, while Kassem and Awad (2012) found that the exchange rate determined FDI, Djokoto (2012a) and Rashid and Razak (2017) found a neutral effect. Openness to trade determines FDI overall (Farr, 2017) although Djokoto (2012a) found a positive but statistically insignificant effect of trade openness on FDI into agriculture. Some have concluded that access to land resources significantly determines FDI into agriculture (Farr, 2017; Husmann and Kubik, 2019; Rashid and Razak, 2017). However, Djokoto (2012a) found the contrary. The effect of inflationary pressures on FDI into agriculture has been mixed. Whilst Djokoto (2012a) found a positive effect, Kassem and Awad (2012) reported a negative effect. Lastly, Djokoto (2012a) found that political openness promoted FDI into agriculture. Combining theory and empirical evidence, market size, exchange rate, inflation, land, and political openness can be said to determine FDI.

Modelling and Data

Owing to the non-existent literature on the drivers of FD in agriculture, the starting point of the model building is the drivers of FDI derived from theoretical and optimisation procedures. This is further justified as the work of Boddewyn (1979a,b, 1983a,b, 1985) have shown that the theories of foreign divestment are the reverse of the theories of FDI.

For example, consider a multinational enterprise (MNE) faced with a cost function for both domestic and foreign production plants. The MNE would decide whether to expand production domestically and export to a foreign market or instead to invest directly in a foreign market (Hymer, 1976; Vernon, 1966). The MNE would thus seek to minimise the cost of production for the two plants. Let C denote the total cost, ω_d and ω_f the unit costs in domestic plants and foreign plants, respectively, and Q_d and Q_f to be the respective quantities produced in each plant. Then,

$$C = \omega_d(Q_d)Q_d + \omega_f(Q_f)Q_f \tag{1}$$

Unit costs in both plants are therefore a function of the quantity produced. The production of the two plants should not exceed $\overline{D}$ given by:

$$\overline{D} = Q_d + Q_f \tag{2}$$

In line with production theory, cost should be minimised, hence the setup of the Lagrangian.

$$\mathcal{L} = \omega_d(Q_d)Q_d + \omega_f(Q_f)Q_f + \\ + \lambda(\overline{D} - Q_d - Q_f) \tag{3}$$

Taking first-order partial derivative of 3 with respect to Q_d, Q_f and λ and equating them to zero, then:

$$\frac{\partial \mathcal{L}}{\partial Q_d} = \frac{d\omega_d}{dQ_d}(Q_d) + \frac{d\omega_d}{dQ_d}(Q_d) - \lambda = 0 \tag{4}$$

$$\frac{\partial \mathcal{L}}{\partial Q_f} = \frac{d\omega_f}{dQ_f}(Q_f) + \frac{d\omega_f}{dQ_f}(Q_f) - \lambda = 0 \tag{5}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = \overline{D} - Q_d - Q_f = 0 \tag{6}$$

To attain the objective decision of locating the foreign plant,

$$Q_f = \left(\frac{\frac{d\omega_d}{dQ_d}}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right) \overline{D} + \left(\frac{1}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right) (\omega_d - \omega_f) \tag{7}$$

where:

$\left(\frac{\frac{d\omega_d}{dQ_d}}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right)$ and $\left(\frac{1}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right)$ are assumed to be positive.

From the above, output in the foreign firm is positively related to the total demand $\overline{D}$ and differences in unit costs. Consequently, the foreign plant increases its production provided $\omega_d > \omega_f$. On the other hand, the firm will expand production in its domestic plant, resulting in a reduction in the output produced in its foreign plant provided $\omega_d < \omega_f$. Thus far, the desired output is established. The next thing to do is decide on the levels of inputs to be used for the production in the foreign firm. For the sake of brevity, two inputs are assumed: labour, *L* and capital, *K*. Let *w* and *k* be wage rate and cost of capital, respectively. Then, the cost of producing the Q_f denoted as C_f is:

$$C_f = wL + kK \tag{8}$$

As the subsequent derivation relates to the foreign firm (production), the subscript, $_f$ is dropped. Assuming a Cobb-Douglas production function:

$$Q = L^{\alpha} K^{\beta} \tag{9}$$

the Lagrangian is set up as in equation 10. Unlike in equation 4, the constraint here is the production function.

$$\mathcal{L} = wL + kK + \lambda(Q - L^{\alpha} K^{\beta}) \tag{10}$$

Taking first-order partial derivatives with respect to *w*, *k* and *λ*, and equating to zero:

$$\frac{\partial \mathcal{L}}{\partial L} = w - \lambda\alpha\left(\frac{Q}{L}\right) = 0 \tag{11}$$

$$\frac{\partial \mathcal{L}}{\partial K} = k - \lambda\beta\left(\frac{Q}{K}\right) = 0 \tag{12}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = Q - L^{\alpha} K^{\beta} = 0 \tag{13}$$

Solving for *K* and substituting *Q* from equation (7):

$$K = \left[\left(\frac{\beta}{\alpha}\right)\left(\frac{w}{k}\right) \right]^{\alpha/(\alpha+\beta)} \left[\left(\frac{\frac{d\omega_d}{dQ_d}}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right) \overline{D} + \left(\frac{1}{\frac{d\omega_d}{dQ_d} + \frac{d\omega_f}{dQ_f}} \right) (\omega_d - \omega_f) \right]^{1/(\alpha+\beta)} \tag{14}$$

Therefore, *K* is positively related to total demand (sum of domestic and foreign demand) and negatively related to the unit costs of foreign costs relative to domestic costs. As the focus is on the foreign firm of the *MNE*, the capital is largely or entirely, *FDI*. Thus, *K* can be replaced with *FDI* in equation (14). Based on the theories of *FDI* (Dunning, 1977, 1988, 1993, 2001; Hymer, 1976; Knickerbocker, 1973; Vernon, 1966) and the empirical evidence for agriculture (Djokoto, 2012a; Farr, 2017; Husman and Kubik, 2019; Kassem and Awad, 2012; Lv, *et al.*, 2010; Rashid and Razak, 2017) and the total economy (Harding and Javorcik, 2007; Morisset, 2003; Barthel *et al.,* 2008; Djokoto, 2012b; Dah and Khadijah, 2010; Nyarko *et al.*, 2011), the function for the drivers of *FDI* is:

$$AGFDI = f(AGGDPC, EXRATE, AGTO, AGLAND, INF, POLITY2) \tag{15}$$

The variables, their definitions and data source are reported in Table 1.

As Boddewyn (1979a,b, 1983a,b, 1985) has amply demonstrated that the theories that explain *FDI* are the reverse of those for *FD*, equation (15) is underpinned by the theories of *FD*. As will soon be shown, the data employed in this study has two important distinguishing characteristics; it is made up of countries at different levels of development, and there are repeated observations for some countries but different years, yet the structure of the data is not such as to qualify as a panel. As such, it is necessary to control for these. Thus, additional variables are introduced into equation (15) and defined in Table 1. According to UNCTAD (2020), negative *FDI* is *FD*. As the focus of the study is *FD*, the *AGFDI* can be replaced with *AGFD*. Consequently, equation 15 can be augmented as:

$$AGFD = f(AGGDPC, EXRATE, AGTO, AGLAND, INF, POLITY2, DVP, TRS, YEAR) \tag{16}$$

Table 1: Variable definitions, measures, and sources of data.

Variable	Definition and measure	Measurement	Source
LNAGFD	Foreign divestment	Negative of foreign direct investment into agriculture	FAOSTAT
LNAGGDPPC	Agricultural Gross domestic per capita	Agricultural Gross domestic product in current prices divided by population	FAOSTAT
LNEXRATE	Nominal Exchange rate	Local currency to 1 US dollar	UNCTADSTAT, WDI
LNAGTO	Agricultural trade openness	Sum of agricultural exports and exports to agricultural GDP	FAOSTAT
LNAGLAND	Proportion of agricultural land in country land area	Ratio of agricultural land to total country land area	FAOSTAT
INF	Inflation	Annual growth rate of consumer price index	UNCTADSTAT, WDI
POLITY2	Political Regime Characteristics and Transitions	-10 to +10	Centre for Systematic Peace
DVP	Developing countries	DVP=1, 0 otherwise	-
TRS	Transition economies	TRS=1, 0 otherwise	-
DVD	Developed countries	DVD=0	-
LNYEAR	Year of data	Four-digit year	-

Notes: 1. The prefix *LN* denotes natural logarithm. 2. FAOSTAT- Food and Agricultural Organisation statistics centre: http://www.fao.org/faostat/en/. 3. UNCTADSTAT – United Nations Conference of Trade and Development Data centre: https://unctadstat.unctad.org/EN/. 4. WDI – World Development Indicators of the World Bank: https://databank.worldbank.org/home.aspx. 5. Centre for Systematic Peace: https://www.systemicpeace.org/inscrdata.html
Source: own composition

Table 2: Descriptive statistics.

Variable	Mean	Standard deviation	Minimum	Maximum
		Explained variable(s)		
FD	0.0071	0.0259	4.50e-06	0.3000
LNFD	-6.631	1.8617	-12.3113	-1.2038
		Explanatory variables		
Theoretical variables				
GDPPC	665.2623	1,261.6060	15.2965	10,252.8200
LNGDPPC	6.0505	0.8186	2.7276	9.2353
EXRATE	339.9892	1,233.2330	0.0568	10,389.9400
LNEXRATE	1.9037	2.6770	-2.8678	9.2486
AGTO	7.6797	26.1065	0.0317	247.5623
LNAGTO	1.0715	1.2773	-3.4510	5.5117
AGLAND	0.4047	0.1729	0.0109	0.8491
LNAGLAND	-1.0450	0.6357	-4.5215	-0.1636
Economic and political controls				
INF	4.6757	8.1377	-0.9222	74.3000
POLITY2	8.4220	3.2638	-6	10
Data controls				
DVP	0.2775	0.4490	0	1
TRS	0.0405	0.1976	0	1
DVD	0.6821	0.4670	0	1
YEAR	2004.751	6.4350	1991	2017
LNYEAR	7.6033	0.0032	7.5964	7.6094

Note: The prefix *LN* denotes natural logarithm.
Source: own composition

The subsequent model specification is:

$$LNAGFD = \alpha_0 + \alpha_1 LNAGGDPC + \alpha_2 LNEXRATE + \\ + \alpha_3 LNAGTO + \alpha_4 LNAGLAND + \alpha_5 INF + \\ + \alpha_6 POLITY2 + \alpha_7 DVP + \alpha_8 TRS + \alpha_9 YEAR + \varepsilon_i \quad (17)$$

Where the prefix *LN* stands for natural logarithm. The data used in this study is made up of 50 countries across all three levels of development according to the United Nations (2020) (Appendix). As the data is not strictly a panel, equation (16) is estimated by Ordinary Least Squares (OLS) having controlled for the repeated observations using the year of observation. Violations of the OLS namely, heteroscedasticity, multicollinearity and misspecifications were tested.

Results and discussion

Background of data

The data ranged from 1991 to 2017 (*YEAR*) and represented observations of countries for which FDI is negative (Table 2). This is the singular driver of the number of countries and years of the data. The FD ranged from 4.50e-06 (Republic of Korea in 2000) to 30% (Belgium in 2005). The maximum is appreciable; indeed, the penultimate highest is 12% (Singapore in 2004), less than half of the maximum. The mean of 0.71% coincides with the value for Lithuania in 2015. The least *AGGPPC* of $15.29/person was for Singapore in 2004 and the maximum of $10,252/person relates to Panama in 2009. Thus, distributing agricultural production by the national population, Singapore gets the least whilst Panama gets the highest. Regarding local currency relative to the US dollar, it was least expensive to acquire $1 using Venezuela's Bolívar in 1991 (Bs 0.0568) and most expensive to acquire $1 in Indonesian Rupiah (Rp 10,390) in 2009. *INF* and *POLITY2* both recorded negative values. The latter shows a low level of democracy and political tolerance (Morocco - 2005, 2008 and Kazakhstan - 2004, 2007). The negative values in the two series prevented their natural logarithm transformation. Regarding the other data controls, most of the countries that experienced FD in agriculture over the study period are developed countries, 68% (28 countries) and the least is economies in transition, 4% (3 countries).

Results from the estimations

The estimations, model 1 to 8, are reported in Table 3. Model 1 is the outcome of estimation with the theoretical variables only. The model appeared to be incorrectly specified with the statistical significance of the Ramsey RESET test (Ramsey, 1969) measured at 1%. Upon correcting for the misspecification by including a square term of the prediction of *LNFD* (*LNFD1SQ*), the adjusted R squared doubled but the highest VIF exceeded the threshold of 10, a result that is indicative of multicollinearity. Furthermore, the variance of model 2 became heteroscedastic (Breusch and Pagan 1979;

Table 3: Estimation results.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LNGDPPC	-0.5914***	-8.3519***	-0.6252***	-9.3453***	-0.6268***	-9.6426***	-0.5375**	-0.5230**
	(0.1953)	(1.9695)	(0.2097)	(2.1453)	(0.2103)	(2.1853)	(0.2106)	(0.2209)
LNEXRATE	-0.1297**	-1.7976***	-0.1273**	-1.8412***	-0.1323**	-1.9753***	-0.1946***	-0.1943***
	(0.0640)	(0.4258)	(0.0644)	(0.4243)	(0.0659)	(0.4493)	(0.0713)	(0.0716)
LNAGTO	0.0331	0.5494***	0.0273	0.4936***	0.0324	0.5931***	0.2091	0.2209
	(0.1425)	(0.1889)	(0.1434)	(0.1785)	(0.1444)	(0.1932)	(0.1607)	(0.1694)
LNAGLAND	0.1066	2.0277***	0.0989	1.9609***	0.0875	1.8223***	0.0579	0.0568
	(0.2221)	(0.5300)	(0.2233)	(0.5036)	(0.2259)	(0.4710)	(0.2276)	(0.2283)
LNFD1SQ		0.9719***						
		(0.2455)						
POLITY2			0.0209	0.3434***	0.0295	0.4904***	0.1353**	0.1347**
			(0.0465)	(0.0906)	(0.0520)	(0.1218)	(0.0658)	(0.0660)
LNFD2SQ				1.0224***				
				(0.2504)				
INF					0.0077	0.1233***	0.0113	0.0109
					(0.0204)	(0.0340)	(0.0223)	(0.0224)
LNFD3SQ						1.0535***		
						(0.2543)		
DVP							1.1188**	1.1317**
							(0.5034)	(0.5081)
TRS							2.1595**	2.1987**
							(0.9708)	(0.9891)
LNYEAR								-10.3939
								(46.1164)
Constant	-2.7298**	5.8056**	-2.7074**	6.7523**	-2.8140**	5.3604**	-4.7618***	74.1650
	(1.3433)	(2.5119)	(1.3474)	(2.6512)	(1.3802)	(2.3724)	(1.5643)	(350.1924)
Model diagnostics								
Observations	173	173	173	173	173	173	173	173
R-squared	0.0959	0.1735	0.0970	0.1794	0.0978	0.1828	0.1334	0.1336
R-squared Adjusted	0.0744	0.1487	0.07	0.1498	0.0652	0.1482	0.0911	0.0858
F- statistic	4.46***	7.01***	3.59***	6.05***	3.00***	5.27***	3.15***	2.79***
Highest VIF	1.78	216.55	1.79	229.98	1.81	239.13	2.79	2.83
Breusch-Pagan test	2.46	5.16**	2.29	3.55*	2.03	3.76*	0.03	0.01
Ramsey RESET test	5.4***	-	6.15***	-	6.34***	-	2.25*	2.20*

Notes: 1. Dependent variable is LNFD. 2. Standard errors in parentheses. 3. *** is p<0.01, ** is p<0.05, and * is p<0.10.
Source: own composition

Cook and Weisberg, 1983). In model 3, with the inclusion of *POLITY2*, there was misspecification and the subsequent correction created a new multicollinearity problem (VIF = 229.98) (Model 4) (Cuthbert and Wood, 1980). On adding *INF,* model 5 is also incorrectly specified and correcting for this also led to above 10 threshold VIF of 239.13. It is instructive to note that the corrections for the misspecification always created a multicollinearity problem. The misspecification correction variable then gives rise to another problem whose most appropriate resolution would require dropping the correction variable.

To get out of the dilemma, the data controls were added. First, the levels of development (Model 7). Second, is the year control variable (LNYEAR) as in model 8. Whilst producing statistically significant F statistics, the VIFs are below 3.00 and no evidence of heteroscedasticity. Based on a cut-off of 5%, models 7 and 8 are not incorrectly specified. Thus, they do not violate the assumptions of the OLS hence appropriate for discussion. The difference between model 7 and 8 is the introduction of *LNYEAR* that drove the statistical significance of the constant (model 7) to statistical insignificance (model 8).

Using model 8, the statistical significance and sign of the coefficients of *LNGDPPC* and *LNEXTRATE* are consistent across all eight models. The magnitude and sign of the coefficients of *LNAGTO* and *LAGLAND* are consistent across the models not corrected for misspecification. The sign and statistical significance of the magnitude of *POLITY 2* are consistent for four out of six models. That for inflation is consistent for three out of the four models containing *INF*. The sign and statistical significance of the magnitude of the development controls are also consistent in model 7 and 8.

It is worth noting that the F statistics are statistically significant. These imply that the explanatory variables jointly explain the variability in the explained variable. However, the adjusted R squared values of model 7 and 8 are small, about 10%. As the R-squared represents the scatter around the regression line, the low R squared shows a wide variation around the trend line. This does not, however, vitiate the relationship between the explanatory variables and the explained variable which is the focus of the paper.

Discussion of drivers of foreign divestment

The statistically significant coefficient of -0.5230 for *LNGDPPC* suggests a 1% decrease in *LNGDPPC* would increase FD by 0.5230%. It would be observed that the magnitude of 0.5230 is the largest among the coefficients of the theoretical, macroeconomic and political controls. Thus, not only is market size a driver of FD, but it is also the single most important theoretical driver of FD. This finding is synonymous with those for FDI. Just as market size increased with FDI (Djokoto, 2012a; Farr, 2017; Husmann and Kubik, 2019; Kassem and Awad, 2012; Lv *et al.*, 2010; Rashid and Razak, 2017), market size increased with the decline in FD. Increase in market size affords the sector's economic agents to purchase the products of the sector. This is further enhanced by households from other sectors as agriculture remains the most important provider of food. Increase in the size of the sector is also associated with the increased availability of resources. Thus, the decrease in market size would discourage FDI and invariably encourage FD.

The negative and statistically significant coefficient of *LNEXRATE* means that depreciation of the country local currency by 1% would induce 0.19% decrease in FD. Owing to concessions for imports for MNEs, they tend to import materials including raw materials. Depreciation of the country's currency would make the imports more expensive. Also, this could lead to an increase in other imported goods, leading to an increased cost of living. This could drive up wages. Generally, the increased cost of production could diminish profits and encourage FD out of agriculture. This finding is consistent with Kassem and Awad (2012) with regard to the significance of the coefficient. Whilst the exchange rate promoted FDI, the price of the currency discouraged FD. Djokoto (2012a) and Rashid and Razak (2017) however, found no effect of exchange rate on FDI.

Openness to trade is positive but statistically insignificant. This is consistent with the findings of Djokoto (2012b) but at variance with the conclusions of Farr (2017) and Kassem and Awad (2012). As the exchange rate depreciates, although exports become cheaper, imports become more expensive. MNEs in agriculture that depend on imported raw materials would face high costs. They would thus, fail to reap the benefits of cheaper exports. The interaction of the exports and imports would, therefore, have no discernible effect on FD.

In theory, location resources should determine FDI and for that matter FD. The findings of this study, however, show that access to land resources does not have a discernible effect of FD. Although consistent with Djokoto (2012a), the finding disagrees with Farr (2017), Husmann and Kubik, (2019) and Rashid and Razak (2017). The measure of land used in this study is agricultural land use as a proportion of total country land. Not only does this reflect agricultural land use in the country, but it also captures land grab influences on agriculture (Byerlee *et al.*, 2015; Deming, 2012; Escresa, 2014; Fraser, 2019). Divestments that involve transfers of capital leaving control of land resources or transfer of land to domestic or other MNEs could account for the statistically insignificant effect.

Increase in *POLITY2* variable by 1% would induce 0.1347% rise in FD. Although this is not an encouraging outcome, it is to be expected. Improvements in political regime characteristics and transitions promote FDI into agriculture (Djokoto, 2012a). This is often associated with investment laws that guarantee the security of investment. Just as these attract FDI into the sector, the same window offers an opportunity to MNE's affiliates in host countries to divest if or when it becomes necessary. The consolation, however, is that the agricultural sector of the host economy would have attracted FDI and reaped the benefits therefrom before the FD. Moreover, between the period of 1991 to 2017, the FAOSTAT reported 984 instances of FDI (positive) whilst the occurrences of FD number 173 (less than 20% of the FDI). Further, the instances of FD did not mean there was no FDI, rather the FD was more than the FDI.

The positive sign of the coefficient of *INF* suggests as inflation worsens FD increases. This is not surprising as Kassem and Awad (2012) reported worsening inflation drove down FDI. Djokoto (2012a) however, reported a positive effect of inflation on FDI in Ghana and explained that the generally high inflationary environment was accommodated by FDI. Moreover, other drivers are known to have stronger effects on FDI than inflation. In the case of the current study, the magnitude of the coefficient of the *INF* is statistically insignificant.

The development controls show statistically significant coefficients. The magnitude of *TRS* is more elastic than that of *DVP*. Whilst these suggest *TRS* experienced more FD than *DVP*, the sum of the outcome is that developing countries and transition economies experienced FD more than developed countries. This seemed to depart from the univariate position that most developing countries experienced FD because other variables have now been accounted for. Indeed, developed countries tended to be more stable politically than developing and transition economies. Moreover, although agriculture becomes less and less important as its shares to total GDP decline, the size of the sector continues to be large. A combination of the transition process and some instability within the three transition countries could have accounted for the higher elasticity.

Although not statistically significant, the coefficient of *LNYEAR* is negative. This presents a situation of decline in FD over time, which is encouraging. This is to be expected as the size of the agricultural economies of countries tends to increase over time.

Concluding remarks

This paper used multilateral FD data covering 1991 to 2017 for 50 countries to estimate the drivers of agricultural FD. Identifying the factors that determine FD would offer an opportunity for policymakers to know the policies that can discourage FD. Also, knowledge of its directional effect would suggest ways to use policy to appropriately influence FD. It has been found that market size, exchange rate, political regime characteristics and transitions as well as a country's level of development drive FD out of agriculture globally. However, a country's openness to trade and access to land resources have not been found to determine FD.

As market size was measured as GDP per person, agricultural economic managers acting together with Central Government should formulate policies to control their country's population as increased technology adoption is leading to increased unemployment in the agricultural sector. A declining population would increase the size of GDP per capita *ceteris paribus*. Agricultural GDP should be increased through increasing domestic and foreign investment. The use of such policy tools should increase the size of the economy and decrease FD from the sector.

There is also a need to manage foreign currency exchange rates in order to reduce the cost of acquiring the US dollar within bounds that would not unduly discourage essential imports whilst simultaneously facilitating exports from the sector. Policymakers need to balance consideration of the effects of exchange rate movements on the agricultural sector with those of the wider economy as the exchange rate affects all other sectors.

Notwithstanding the positive effects political regime characteristics and political transitions have been shown to have in relation to FD, political regime characteristics should be enhanced as the benefits to the sector in terms of FDI outweigh the effects of FD. As developed countries have tended to experience less FD than developing and transition economies, these less advanced countries must redouble their efforts as they push on towards becoming developed countries themselves. This would require, among other things, increasing efficiency in the agricultural sector through appropriate and improved technology, as well as measures such as expanding the non-agricultural sector to absorb the resultant excess labour. Generally, increasing the share of the non-agricultural sector feeds into the structural transformation narrative of economic development. Although the model discussed fits the data despite the low adjusted R squared, future studies could usefully employ machine learning; this could improve the model fit.

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Appendix 1: List of countries in the sample.

Developing			Developed		
Bolivia	Madagascar	Uruguay	Australia	France	Netherlands
Cambodia	Malaysia	Venezuela	Austria	Germany	Poland
Chile	Morocco	Transition	Belgium	Greece	Romania
Colombia	Mozambique	Albania	Bulgaria	Iceland	Slovakia
Costa Rica	Panama	Kazakhstan	Croatia	Italy	Slovenia
El Salvador	Paraguay	North Macedonia	Cyprus	Japan	Spain
Honduras	Rep. of Korea		Czechia	Latvia	Sweden
Indonesia	Singapore		Denmark	Lithuania	UK
Israel	Thailand		Estonia	Malta	USA

Source: own composition

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