

# The Role of Clusters in Managing Technological Challenges and Achieving Resilient Agri-Food Systems at the Global Level

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**Abstract.** *There is a strong need to transform agriculture from its heavy dependence on staple crops to an increased production that can, on the one hand, address the needs and quality requirements of domestic and export markets, but also grow into a resilient agri-food system. The paper acknowledges the emergence of agro-clusters as an essential element in promoting sustainable agriculture practices and in supporting export performance. The main objective of our research is to investigate the role of clusters in promoting knowledge transfer, improve competitiveness and boost technological investments through the example of selected relevant agri-clusters. To extend the existing literature, our research aims to evaluate the link between export performance - measured considering the volume of trade – and the existence of agri-clusters. We have assumed that there is a strong direct relationship between the existence and stage of development of agricultural clusters, the performance of agricultural exports – expressed in terms of total value of agricultural exports - and resilient agri-food systems. To test our hypothesis, we use data from the United Nations Comtrade Database on changes in export share and value of agricultural products over the last decade, complementary with qualitative analysis based on more than 100 sources (government documents, webpages, presentations, projects) of the top five global agricultural exporters to evaluate the existence of agricultural clusters, the government support and implication, and the integration of other actors such as universities, research centers, financial institutions. The results indicate a positive correlation between the development stage of analysed agricultural clusters, the resilience of agri-food systems and the performance of agricultural exports of the country of origin.*

**Keywords:** agri-clusters, export performance, agri-food systems, resilience

## Introduction

In the modern economy, continuous investments in innovative systems and artificial intelligence (AI) along the agricultural value chain, from crop cultivation to sustainable packaging and transportation, are inextricably linked to building a resilient agri-food system. Nowadays, companies have better access to goods, capital, information, and technology and they need to access other levers to stand out in a competitive world - *the power of clusters*. Overall, competition became more dynamic and location has become less significant. Therefore, competitive advantages are now created today by utilizing inputs in a more creative, efficient, and sustainable manner that necessitates ongoing investments in research and development and innovation.

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The cluster-based development model has gained prominence in both developed and developing countries as a means to reform sectorial performance in agriculture given its capacity to improve efficiency through synergies and collaboration within the local value chains and to facilitate the aggregation of resources from various small investors to support cluster development.

The EU Commission also prioritises the establishment of "world-class clusters" to enhance national and sectorial competitiveness. Clusters are regarded as catalysts for competitiveness and innovation, as evidenced by higher employment rates in specific sectors, which indicates economic specialisation and comparative advantage (European Commission, 2008).

Clusters have been demonstrated to positively influence agricultural performance by creating a conducive setting for knowledge exchange, fostering innovation and a closer collaboration between stakeholders (farmers, research institutes and investors). At a sector level, this promotes the share of good practices and the adoption of new technologies, resulting in higher productivity and efficiency. Moreover, economic agglomerations frequently draw in investments and resources to enhance infrastructure, facilitate market access and value chain integration. These factors collectively contribute to enhanced agricultural performance. In addition, clusters can promote the dissemination of information and practices, enabling participants to acquire better knowledge and address common challenges. This collective learning approach can lead to the development of more sustainable and resilient agricultural systems, as farmers are able to adapt and respond to changing environmental conditions and market demands (Huseynov et al., 2024).

Our research aims to evaluate the link between export performance - measured considering the volume of trade – and the existence of agri-clusters. For the world-top five agricultural exporters, we evaluate the existence and level of development of agricultural clusters, the government support and assistance and the collaboration with other actors such as universities, research centers, financial institutions.

## Literature review

Agri-clusters are geographical concentrations of interconnected agrifood processing firms and associated institutions that face common challenges and pursue common opportunities. Agri-clusters can be developed by fostering collaboration between key stakeholders, including farmers, upstream and downstream companies (suppliers, processors, distributors), research institutions and government. In the agricultural sector clusters can be grouped into special economic zones, agro-industrial parks and agri-clusters (Ulimwengu and Jenane, 2019). They can be formed through a managed process often initiated by deliberate government intervention as a means of promoting economic growth, formed organically without or with limited government intervention, or formed through a combination of these factors.

Ulimwengu and Jenane (2019) have noted that clustering among agrifood processing firms has the potential to facilitate coordination among various actors along the agrifood value chain and can help reduce costs, increase profits, and facilitate market access. Therefore, creating an enabling the environment for the development of clusters is crucial for enhancing value chain investment and ensuring inclusive transformation for firms in the agrifood processing sector (Reardon et al., 2019). In the context of developing countries, clusters can help to compensate for the small size of firms by facilitating access to markets and upgrading of technology, as well as improving efficiency and productivity (McCormick, 1999). Clusters play a crucial role in advancing sustainable agricultural practices and rural development by facilitating collaboration and cooperation among different stakeholders in the agricultural value chain. Clusters foster the dissemination of knowledge, technology transfer and innovation by bringing in proximity farmers, agribusinesses,

research organizations and government agencies. This collaborative environment enables farmers to adopt best practices, access new markets, improve productivity, and enhance their resilience to challenges such as climate change (FAO, 2014).

Performant agricultural clusters are influenced by factors such as their geographic location, proximity and collaboration between cluster companies, and the emergence of innovation. Clusters that possess a significant capacity of innovation benefit from the ability to swiftly respond to shifts in consumer demand, access to emerging technologies and better face competitive pressure in the market (Borisova et al., 2015). Furthermore, agricultural clusters frequently gain advantages from the utilization of common infrastructure, access to specialized suppliers, knowledge spillovers and reduced shared costs. Through collaboration cluster firms can save costs, enhance productivity, penetrate new markets and utilize their combined expertise and knowledge to effectively tackle shared obstacles and seek prospects for expansion and economic growth. By pooling their resources and expertise, agricultural clusters are able to collectively address challenges such as market fluctuations, changing consumer preferences, and technological advances and capitalize on opportunities in the agricultural sector (Nogales, 2010). Consequently, economic agglomerations create the opportunity to exchange best practices, innovative and sustainable farming methods, which in the end lead to a more resilient and performant agricultural sector. This not only enhances the efficiency and competitiveness of businesses within the cluster but also drives overall economic development in rural areas (Kwasi & Daniel, 2022; Jenane, 2022; Butorin, 2019).

Empirical studies on industrial clusters have emphasized that these clusters can contribute to firm growth and performance by promoting innovation and improving access to international markets (Oyelaran-Oyeyinka and McCormick, 2007; World Bank 2011; Zeng, 2008). Also, apart from facilitating knowledge spillovers, it is relatively easier and more cost effective for governments to provide fundamental infrastructure to clustered firms than to firms that are dispersed (Oyelaran-Oyeyinka and McCormick, 2007). The existence of such infrastructure can enable firms to adopt the advanced technologies needed to sustain themselves and become more competitive. Other empirical studies highlight the advantages of agro-clusters in enhancing networks and partnerships, marketing access, and economies of scale: Joffre et al. (2020) emphasize the role of agro-clusters in enhancing interaction and cooperation among cluster farmers through trust-building and network development with supply chain actors. According to Galvez-Nogales (2010), agro-clusters promote different types of interactions among farmers and other actors in the value chain to generate synergies, improve competitiveness, increase access to services, and reduce risks. In a study conducted by Montiflor et al. (2015), it was demonstrated that vegetable agro-clusters have a positive impact on institutional markets, market information, and linkages in the Philippines. Goetz et al. (2004) emphasize the economic advantages and efficiency effects of clusters for small-scale farmers. Clusters help counterbalance market dominance and support regional competitive edge.

Whether or not powerful clusters in a country's agro-food sector can improve its position in international agricultural commerce also depends on the type of cluster and its potential to develop a competitive advantage (Keijiro, 2020). The competitiveness of the country's agro-food sectors was strongly correlated with the features of the clusters, which were mostly service and export-oriented (Figiel et al., 2012). Export-oriented agri-clusters have also shown considerable success in promoting sustainable farming practices and reducing the environmental impact of agriculture. By producing high-quality and export performant goods, these clusters have been able to attract financial resources and create new jobs. Furthermore, the presence of export-oriented

agricultural clusters has helped diversify local economies and improve overall resilience to external market fluctuations (Vanka, 2015; Victor et al., 2021; Matkovski et al., 2022).

## Methodology

The role of cluster organizations in stimulating and increasing the competitiveness of a sector is intensively discussed in international scientific publications. To extend the existing literature, our research was driven by the following questions: Are agricultural clusters part of the agricultural ecosystem of the five agrarian exporters? What are their specific characteristics, and how do they differentiate from other agri-clusters? We have assumed that there is a strong direct relationship between the existence and stage of development of agricultural clusters, the performance of agricultural exports – expressed in terms of total value of agricultural exports - and resilient agri-food systems.

To test our hypothesis, we first extracted the latest data from the United Nations Comtrade Database (<https://comtradeplus.un.org/>) covering 2012-2022 and selected agricultural products as the product group. We have analyzed the change in export value in absolute terms during the last decade, and the value and share in value in global exports expressed as a percentage (%) in 2022.

Qualitative research was used to inquire the existence of agricultural clusters for the top five global agricultural exporters, the United States of America, Brazil, the Netherlands, Germany and France. This analysis stage consisted of consulting more than 100 sources (government documents and webpages, presentations, project webpages), where the data was available and language barriers were not a constraint. *Figure 1* comprises the primary data that we found on the agricultural clusters of the selected countries.

We aim to extend the existing literature on the role of clusters in agricultural development and performance (eg, Zhang (2023) for China and Africa, Shabanov et al. (2021) and Mindlin et al. (2022) for Russia (Shabanov, Vasilchenko, Derunova, & Potapov, 2021), Mubarik (2020) for Pakistan’s agricultural transformation through cluster development).

## Results and Discussion

As the data on trade flows and market share illustrate, the main exporters of agricultural products in terms of trade value are the United States (10.2%), Brazil (7.1%), Europe (the Netherlands, Germany, France, Spain, Italy and Belgium - 24.9%), China (4.4%) and Canada (3.4%). As *Table 1* indicates, the most significant increase in agricultural exports during the last decade was registered by Brazil (68.85%) and China (67.91%), followed by Italy (57.53%), Spain (52.61%) and Canada (49.52%).

**Table 1. List of exporters of agricultural products (2012-2022) (value, million USD)**

Exporter	2012	2015	2018	2020	2021	2022	Value Change (2022/2012) (%)	Share in value in world's exports (% , 2022)
United States of America	149	142	150	154	181	201	34.33	10.2
Brazil	83	74	85	87	104	140	68.85	7.1
the Netherlands	92	84	99	102	117	118	27.84	6
Germany	83	76	85	84	93	97	16.59	4.9
France	73	66	73	70	83	88	20.32	4.5
China	51	57	66	65	73	86	67.91	4.4
Canada	45	45	47	52	61	67	49.52	3.4

Exporter	2012	2015	2018	2020	2021	2022	Value Change (2022/2012) (%)	Share in value in world's exports (% , 2022)
Spain	43	44	53	58	67	66	52.61	3.3
Italy	41	41	50	53	63	64	57.53	3.3
Belgium	43	40	47	47	54	58	34.43	2.9
World	1390	1331	1512	1554	1820	1974	41.95	100

Source: Authors' Authors calculations based on data retrieved from <https://comtradeplus.un.org/> (2024).

We have assumed that those countries with the highest value of agricultural exports may also be the hub for the most performing agricultural clusters worldwide. From the selected countries, the US Corn and wine clusters, the French Wine Clusters, the Dutch Flower Cluster, the Italian Tile and Textile Cluster and the Bali Tourism Cluster are representative examples that emphasize the role of clusters in strengthening a sector's performance, building resilient production and delivery systems.

### *The United States*

California, Texas, Illinois, Wisconsin, Pennsylvania, Ohio, New York, Minnesota, Michigan, and Indiana are the top 10 states that registered the highest number of employees in the Food Processing and Manufacturing Cluster in 2020. In terms of percentage increase, the states that registered a growth in employment of at least 10% for food processing and manufacturing from 2014 to 2018 are New Hampshire (32%), Arizona (31%), Connecticut (29%), South Carolina (28%), and Colorado (23%), Washington (17%) and Texas (16%).

More in depth, the sub-clusters that have had the highest employment levels in 2020 were: Specialty Foods and Ingredients, Baked Goods, Dairy Products, Packaged Fruit and Vegetables, Malt Beverages, Soft Drinks and Ice, Candy and Chocolate, Wineries, Animal Foods, Farm Wholesalers. Among the most traditional and well-known clusters are California's wineries, Colorado's breweries, and Wisconsin's dairy and cheese plants. (Cluster Mapping, 2023)

Over the last century, agriculture has become more heterogeneous in farm size, scale of production, and product mix. Additionally, farm and non-farm sector interactions are more complex than ever. Climate, soil type, topography, and demographic characteristics play a role in determining variations within the agricultural industry.

The US government has made an investment in [clustermapping.us](http://clustermapping.us), an online national platform that offers comprehensive data on several aspects of current clusters, including employment, earnings, job creation, specialisation and innovation. The US maize and wine clusters exemplify excellent sustainable farming techniques by implementing a comprehensive strategy that encompasses both environmental and economic sustainability. Through the allocation of resources towards research and development, these clusters have successfully optimised agricultural productivity while simultaneously reducing negative effects on the environment. Moreover, the adoption of effective irrigation systems and crop rotation techniques has contributed to the preservation of water and soil integrity. All in all, the achievements of the maize and wine clusters in the United States emphasise the significance of comprehensive approaches in promoting sustainable agricultural progress. For example, the corn cluster in Iowa has implemented precision agriculture techniques, such as GPS-guided tractors and drones, to optimize fertilizer and pesticide use, reducing the environmental impact. Additionally, the wine cluster in California has adopted

organic farming practices and integrated pest management strategies to minimize chemical inputs and promote biodiversity in vineyards.

### ***Brazil***

In the case of Brazil investments in education, in technology and R&D have proven to play a key role in the agricultural performance. First, during the late nineteenth century, Brazil initiated its agricultural-based educational system. Second, trade openness and external demand played a crucial role – the Brazilian-American Commission for the Production of Food Supplies partnership. Third, in the 1970s, Brazil started to invest in revolutionizing the industry and created the ‘Empresa Brasileira de Pesquisa Agropecuária’ (Brazilian Agricultural Research Corporation) to help modernize and diversify the operations of Brazilian farmers with over 46 research centers in different locations across the country. More than 1.125 startups were established in the agro-tech sector. (UNCTAD, 2023)

Currently, Brazil is transferring technological knowledge in all the agricultural fields to improve its yield efficiency and to perfect its sustainability approach through the *Internet of things* (e.g., sensor technologies, the monitoring of solutions, food tracking), *artificial intelligence* (e.g., precision farming, robotics, and drones), *precision farming* or ‘*Site Specific Crop Management (SSCM)*’ (e.g., imagery of drones and satellites to optimize the crop efficiency and farm management), *drones & satellites* (e.g., measure, monitor, create terrain maps, supervise the quality of tillage and sowing works, and provide extensive phytogeographical data for farming management optimization), *robotics & automation* (e.g., advanced robotics, automated machinery, and drones), *3D-printing* (e.g., to ‘print out’ food in itself), *augmented reality* (e.g., the usage and integration of digital information with the user’s environment, all in real-time), *virtual reality* (e.g., digital environment), and *biotechnology* (e.g., to expand productivity and eliminate the high risks of diseases and threats and to ensure environmental safety) (Daglia Calil & Ribera, 2019), (Flanders Investment & Trade, 2020).

Some key examples of agricultural clusters are the Brazil Biotech Cluster (Minas Gerais region), Cotton Clusters (Barreiras – Matopiba – production cluster), and Fruit Clusters (Vale do São Francisco – Matopiba – production cluster). UNCTAD and 14 partners have jointly launched an industrial innovation cluster of agribusinesses based in Petrolina, Brazil, to raise productivity and transform farming operations into more sustainable ones (Flanders Investment & Trade, 2020).

### ***The Netherlands***

The Netherlands is the land of greenhouses and more than half of the nation's land area is used for agriculture and horticulture. Wageningen University & Research (WUR) is perceived as the world's top agricultural research institution; WUR is also the link part of Food Valley, an expansive cluster of agricultural technology startups and experimental farms. (Weerdt, et al., 2018)

The Netherlands is just a small country that feeds the world; it has only half of the US's value of agricultural exports, while the US has 270 more land. The success of Dutch agriculture can be attributed to continuous investments in technology, particularly in the field of precision farming; this strategic approach has propelled the Netherlands to become a global frontrunner agricultural innovation. The country’s commitment to efficiency and sustainability is further bolstered by government support.

The country's agriculture is centered on clustering, and it enlarged its regional and national borders and chose to collaborate closely with countries worldwide. Dutch producers are so committed to increasing their efficiency per yield – through, for instance, climate control. They

have become the global leaders in the export of tomatoes and potatoes, and it has a competitive advantage in dairy, flower bulbs, poultry, and pigs. More than a third of the global trade in vegetable seeds comes from the Netherlands (Schouten, 2011), (Viviano, 2016).

Some relevant examples of agro-clusters are *Rotterdam Food Clusters* (associated with 'Food for the Future consortium of educational and knowledge institutions), Foodvalley NL (a non-profit agrifood innovation cluster based in Wageningen, founded in 2004 as one of the first agrifood innovation clusters); *Aalsmeer* (known for its floriculture, especially the auctioning of flowers; the flower auction building, the Aalsmeer Flower Auction, is one of the most significant commercial buildings in the entire world); *Agriport A7* (a modern agribusiness park; mainly large modern greenhouses); *Boskoop* (it is an international center for arboriculture; a cluster of production, trade, logistics, supply, services, knowledge, and education); *Seed Valley* (an international center for plant breeding and seed technology situated in North-Holland) (Schouten, 2011), (Weerd, et al., 2018).

### Germany

Germany's agriculture sector includes different farm structures, from highly specialized farms to family farms in the mountains; there are more than 276.000 farms with an average size of 61 hectares. With respect to production value, milk, cereals, vegetables, and horticultural products are the most critical sectors. (European Commission, 2023a)

Three of Germany's agricultural clusters have been awarded by ECEI with the Silver Label – namely Food-Processing Initiative e.V.; food active e.V.; foodRegion, and it has seven other clusters awarded with the Bronze Label. Another relevant cluster is the Bavarian Food Cluster (European Commission, 2020a). Being stirred by several ambitions, Berlin is becoming the center of Germany's food tech center. For example, a Food Tech Campus was established as a facility where startups can test their ideas, and Kitchen Town which serves as an incubator and accelerator specifically designed for food and food-tech startups (Business Location Center, 2023).

Germany is committed to creating an adequate agricultural ecosystem, adding value to the value chain, support sustainable competitiveness and resilience while protecting natural resources and climate through investments, knowledge transfer, and innovation.

More than 933 million are allocated to modernize more than 8,700 farms, and more than 177 million euros will support agricultural insurance schemes (European Commission, 2023a). However, current challenges still under the "planning phase" are projects aiming to reduce livestock antibiotics and implement a more humane husbandry and nutrition strategy.

### France

France has the highest value of agricultural production in the EU and is adding up to EUR 72.9 billion; the products with the highest production value are wine (13.2%), milk (13.1%), cereals (13%), and cattle (9.9%). Furthermore, the agricultural sector has the highest number of recognized producer organizations in the EU (724), and there are approximately 456.000 farms with an average size of 69 hectares and 708.170 farmers (European Commission, 2023b).

Four of France's agricultural clusters have been awarded by ECEI with the Gold Label, namely Agri Sud-Ouest Innovation, Pole Valorial, Vegepolys, and Vitagora and it has six other clusters awarded with the Bronze Label. Other examples of clusters are the AgreenTech Valley located in the Centre-Val de Loire region of France, Industrie et Agroressources (IAR), Nutrition Santé Longévité (NSL), Agrimip Innovation, Céréales Vallée, Aquimer, Industries Agro Ressources cluster (A biorefinery for processing and recycling non-food agricultural materials).

France is designing policies to enhance territorial economic development by establishing competitiveness clusters [*pôles de compétitivité*]; local authorities are also investing in developing such clusters. The French Government's Competitiveness Clusters Policy was approved in 2005 with a selection of 66 Competitiveness Clusters, increasing to 71 in 2009. (Ben Arfa, Daniel, & Fontaine, 2013)

France has continuously supported the agri-food sector with investment and loans granted through multiple programs or issued by institutions such as the country's banking system, the EAFRD, the EFSI, and other national/regional resources. (European Commission, 2020) France's policy is to achieve both food security and sustainable competitiveness, fostering value-added, support farmers' resilience and improve the use of inputs. In accordance with the objectives of the Green Deal, France is committed to carbon neutrality by promoting farm diversification, the conservation of permanent grasslands, the production of plant proteins, agroecology and organic farming. In 2023, France has invested significantly in the development of plant proteins – the budget for these measures increased by 70% compared to 2020. Also, to avoid abandoning agricultural activities in remote rural areas, France supports areas with natural constraints. By 2027, France aims to double the agricultural area under organic farming and allocate a budget of EUR 340 million per year (European Commission, 2023b).

Figure 1 shows a structured perspective on the agricultural clusters located among the top 5 global exporters of agricultural products.

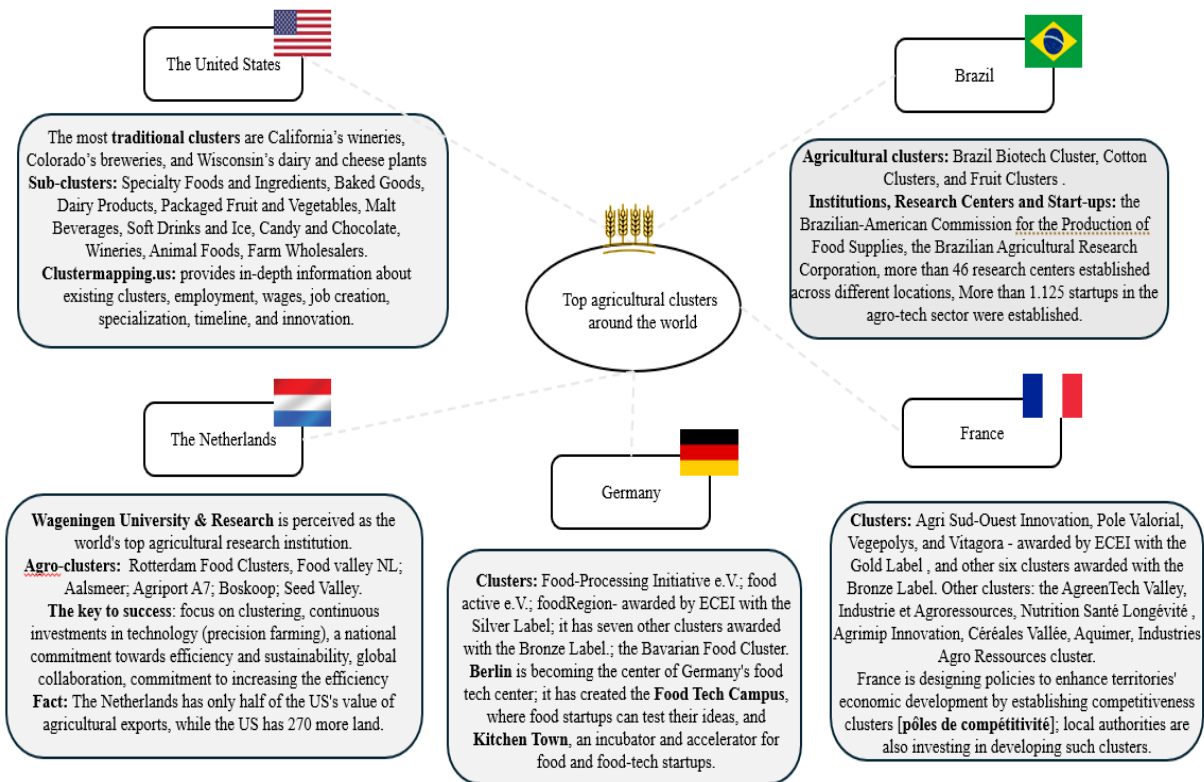


Figure 1. The existence of agricultural clusters among the top five agricultural exporters

Source: Authors' creation based on research.



## Conclusion

The paper looks at the role of clusters in stimulating and increasing the competitiveness of the agricultural sector by analyzing the differentiating particularities of agricultural clusters of top agricultural exporting countries. From selected countries, the US Corn and wine clusters, the French Wine Clusters, the Dutch Flower Cluster, the Italian Tile and Textile Cluster and the Bali Tourism Cluster are representative examples that emphasize the role of clusters in strengthening a sector's performance, building resilient production and delivery systems. The analysis shows that there is a strong direct relationship between the existence and stage of development of agricultural clusters, the performance of agricultural exports and resilient agri-food systems. Export-oriented agri-clusters have shown considerable success in promoting sustainable farming practices and reducing the environmental impact of agriculture.

The maize and wine clusters in the United States employ an integrated approach towards achieving sustainable farming practices, which yield positive outcomes for both the environment and the economy. The agricultural performance of Brazil has been positively influenced by factors such as education, technology, and investment in research and development (R&D). The Netherlands has emerged as a prominent player in the field of agriculture, showcasing its prowess in agricultural innovation on a global scale given the country's unwavering commitment to investing in cutting-edge technologies, with a particular emphasis on precision farming. Germany is engaged in solid investment, information transfer, and innovation in order to establish a suitable agricultural ecosystem. These efforts aim to enhance the value chain, promote sustainable competitiveness and resilience, and preserve natural resources and climate. France has implemented a strategy to enhance territorial economic development by establishing competitiveness clusters, also known as "pôles de compétitivité", supported by local governments through investments but also through investment and loans from the country's banking system, such as the European Agricultural Fund for Rural Development (EAFRD), the European Fund for Strategic Investments (EFSI), and other national and regional resources.

Overall, the analyzed clusters provide valuable insights into the potential benefits of implementing environmentally conscious practices. These clusters serve as exemplary cases that demonstrate how such practices can contribute to both economic growth and environmental stewardship. One conclusion is that through the allocation of resources towards research and development, these clusters have successfully optimized agricultural productivity while simultaneously reducing negative effects on the environment. The promotion of research and development in the field of agricultural innovation has the potential to yield novel techniques and solutions, thereby improve productivity and efficiency.

Secondly, it becomes evident that the promotion of collaboration and the provision of government incentives play a crucial role in ensuring the long-term sustainability and export performance of agricultural clusters in the agricultural sector. This finding highlights the importance of fostering cooperation among various stakeholders and creating a supportive environment through policy measures and financial support from the government. Moreover, in order to enhance the value chain, it is helpful to implement training programs and establish knowledge-sharing platforms to facilitate the dissemination of cutting-edge agricultural technologies and techniques among farmers in clusters. A lack of collaboration between farmers, researchers, and industry experts in sharing best practices and innovative techniques may hinder the development of innovative techniques and best practices despite any government support and investment.

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