FOSTERING INNOVATION IN AGRICULTURE THROUGH RESEARCH AND DEVELOPMENT IN GERMANY: IMPLICATIONS FOR VIETNAM

Hoa Huu Cuong[1]
Institute for European Studies

Abstract:

Agriculture plays a vital role in the global economy, especially when facing pressing challenges such as climate change and the depletion of natural resources. Fostering innovation in this sector through research and development (R&D) is one of the most effective solutions to enhance productivity and sustainability in agriculture. The Federal Republic of Germany has implemented robust R&D strategies that have fostered the development of advanced technologies and sustainable agricultural practices. This paper analyzes Germany's agricultural R&D policies and strategies in agriculture and draws key implications for Vietnam in its efforts to promote innovation in the agricultural sector.

Keywords: *Innovation; Agriculture; R&D; Germany; Vietnam.*

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1. Introduction

Modern agriculture is no longer solely about food production; it plays a pivotal role in ensuring food security and fostering sustainable development in every nation. In the context of climate change, the depletion of natural resources, and a rapidly growing global population, the agricultural sector is facing severe challenges. Climate change, with its extreme phenomena such as droughts, floods, and temperature fluctuations, has reduced crop yields and made it increasingly difficult for farmers to secure reliable food supplies. Simultaneously, the degradation of arable land and water resources is placing immense pressure on agricultural production, while the demand for food continues to rise.

To address these issues, innovation through research and development (R&D) has become a crucial factor in improving productivity, minimizing environmental impact, and promoting sustainable agricultural development. Germany, with its strong R&D policies, has successfully developed advanced agricultural technologies that enhance yields while protecting the environment. Initiatives such as precision agriculture, smart farming, and the integration of technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data have enabled German farmers to optimize cultivation processes, reduce costs, and conserve natural resources. Moreover, Germany has implemented supportive policies to facilitate the transition to organic farming and the development of disease-resistant crop varieties, contributing to environmental protection and the production of clean, eco-friendly agricultural products. These achievements in fostering innovation through R&D have not only boosted productivity but also established a model of sustainable agriculture that safeguards natural resources.

[1] Author's contact: cuongeu25@gmail.com

Therefore, Germany's experience in implementing these policies offers valuable lessons for Vietnam in developing smart and sustainable agriculture. In the face of climate change and food security challenges, Vietnam can learn from and adapt Germany's R&D strategies to improve production efficiency, protect the environment, and advance its agricultural sector in a sustainable manner.

2. Main content

2.1. Policies and measures

2.1.1. National strategies and programs

To promote innovation in agriculture through investment in research and development (R&D), Germany has implemented a range of key strategies and programs aimed at improving production efficiency, protecting the environment, and fostering sustainable agricultural development. These strategies and programs not only emphasize the adoption of modern technologies but also encourage collaboration among research institutes, universities, businesses, and farmers. Specifically:

- The National BioEconomy Strategy 2030, issued by the German Federal Ministry of Education and Research (BMBF) in 2020, places particular emphasis on investing in research and the development of biotechnology, opening opportunities to foster innovation across multiple sectors. Specifically, the strategy focuses on utilizing biological resources as alternatives to mineral-based ones while developing sustainable products and production processes to minimize environmental impact. The application of biotechnology not only enables the creation of eco-friendly products such as bio-based materials and alternative foods, but also offers innovative solutions for renewable energy use and the reduction of greenhouse gas emissions. Germany has actively promoted innovation through collaboration among research institutes, government bodies, and private enterprises, resulting in the development of new products and enhancing the competitiveness of the bio industry. Financial mechanisms and incentives for research, invention, and the application of advanced technologies are key drivers of innovation in the bioeconomy sector. The overarching goal is to position Germany as a global leader in the bio industry by 2030 *(BMBF, 2020);*
- The Digital Strategy for Agriculture (2019) is a key initiative of the German government, implemented by the Federal Ministry of Food and Agriculture (BMEL). This strategy aims to accelerate the digital transformation of the agricultural sector by funding research projects and the development of advanced technological applications, particularly in the areas of the Internet of Things (IoT), Artificial Intelligence (AI), and agricultural robotics. These initiatives not only enhance the efficiency of agricultural production but also contribute to building a modern and sustainable agricultural system in Germany *(BMEL, 2019);*
- The Federal Organic Program, launched by the German Federal Ministry of Food and Agriculture (BMEL) in 2019, also plays a significant role in promoting innovation in agriculture. This program not only supports farmers in transitioning to organic farming practices but also encourages the development

and adoption of innovative cultivation methods that reduce the use of chemical fertilizers and pesticides. Research in biology and microbiological technologies has contributed to the advancement of sustainable farming techniques, forming a core component of the program's innovation strategy. Government funding and research support have further stimulated the creation of new technologies in organic agriculture, such as the development of climate-resilient crop varieties and bio-based materials derived from agricultural by-products. By integrating scientific research, emerging technologies, and financial support from the government, Germany has established a robust innovation ecosystem in the field of organic agriculture. Additionally, the program fosters creativity in developing organic agricultural products that meet global market demands, creating substantial export opportunities and enhancing both the productivity and quality of organic produce *(BMEL, 2019);*

- Another key initiative is the Agriculture 4.0 Program, launched by the German Federal Ministry of Food and Agriculture (BMEL) in 2021 to drive the transformation of the agricultural sector through technology. This program focuses on integrating modern technologies - including the Internet of Things (IoT), Big Data, and Artificial Intelligence (AI) - into agricultural production processes. Its primary goal is to enhance precision in farming activities, optimize productivity, and minimize negative environmental impacts. German farmers now utilize sensors, drones, and intelligent monitoring systems to track soil conditions, moisture levels, crop health, and other environmental factors. These sensors provide real-time data, enabling farmers to make more informed decisions regarding irrigation, fertilization, and pest control. The application of these technologies not only boosts productivity but also reduces the use of water and fertilizers, thereby lowering pollution and cutting production costs. The Agriculture 4.0 Program has achieved notable success. For instance, the use of IoT and drone technologies in wheat production areas has led to a 30% reduction in fertilizer and pesticide usage, while increasing yields by up to 15% over the past few years *(BMEL, 2021);*
- The Sustainable Agriculture Program is another key initiative of the German government, issued by the Federal Ministry of Food and Agriculture (BMEL) in 2020. The program aims to promote efficient agriculture and environmental protection by transitioning from traditional farming methods to organic cultivation models and the application of biotechnology. The German government has provided financial support and training programs for farmers, encouraging them to adopt organic farming and environmentally friendly cultivation practices. The area of organic farmland in Germany has grown significantly over the years - from 6% of total agricultural land in 2000 to nearly 10% by 2020 *(BMEL, 2020)*. A notable initiative within the program is the promotion of renewable energy use in agriculture, which helps reduce CO_2 emissions and lower energy costs for farmers;
- Finally, the Smart and Automated Agriculture Program, launched by the Federal Ministry of Food and Agriculture (BMEL) in 2022, focuses on the development of automation technologies such as agricultural robots, intelligent irrigation

systems, and automated machinery. These initiatives aim to optimize production processes, reduce dependence on manual labour, and increase productivity. The German government also provides financial support to agricultural technology startups and research institutes to foster the development of new technologies. Today's agricultural robots are capable of autonomously harvesting, planting, and tending crops, thereby reducing labour intensity and improving precision in farming operations. Smart irrigation systems use sensors to adjust water levels according to the actual needs of crops, helping to conserve water and minimize resource waste *(BMEL, 2022)*.

Germany's strategies and programs not only support the development of new technologies but also create a favourable environment for innovation in the fields of bioeconomy and sustainable agriculture. The integration of scientific research, advanced technologies, and strong policy support has established a solid foundation for Germany to maintain its leadership in technological advancement while enhancing the competitiveness of its agricultural sector amid globalization and climate change. These initiatives demonstrate that innovation is a decisive factor in building a smart, sustainable, and environmentally friendly agricultural system.

2.1.2. Measures to Promote Innovation

To promote the development of sustainable agriculture and enhance productivity, the German government has designed and implemented various initiatives to support research and development (R&D). These initiatives not only focus on developing new technologies and cultivation methods but also assist farmers in applying technological solutions to real-world agricultural production. Below are some notable measures:

- *First, the establishment of research investment funds:* The German government has created multiple research investment funds dedicated to the agricultural sector, aiming to finance innovative research projects and the development of advanced technological solutions in agricultural production. These funds support research institutions, agricultural startups, and pilot projects that seek to improve farming efficiency, protect the environment, and enhance the quality of agricultural products.

One prominent example is the *Agri-Tech Fund*, established in 2018. This fund provides financial support for projects related to smart farming, precision agriculture, sensor technologies, AI-based agricultural data analysis, the development of disease-resistant crop varieties, and environmental protection. According to statistics from the Federal Ministry of Food and Agriculture (*BMEL, 2020*), approximately €50 million was allocated to projects under this fund in 2020. A distinctive feature of the fund management model is the close alignment between enterprise selection mechanisms and practical application orientation. Priority is given to startups and small- to medium-sized enterprises (SMEs), especially those that demonstrate innovation capacity, the ability to bring products to market quickly, and a positive impact on sustainable agricultural production (*Fraunhofer ISI, 2019*). Support is not limited to financial assistance but also includes technical training, implementation consulting, and connections to experimental agricultural regions, thereby creating a closed-loop technology transfer ecosystem *(GIZ, 2021)*.

In parallel with the investment and project selection process, intellectual property rights and research outcome management mechanisms are clearly defined to ensure transparency and public benefit orientation. According to regulations, research outcomes funded by public budgets are owned by the implementing institutions, while the state retains control over their exploitation to prevent monopolistic commercialization and ensure that technologies serve the public interest (*BMEL, 2019)*. Open licensing or conditional licensing mechanisms are applied, allowing eligible enterprises to access the technologies while ensuring that the state recovers its public investment.

Finally, all funding activities are closely monitored through a system of periodic reporting and impact assessment conducted by the Federal Ministry of Education and Research (*BMBF, 2020*). This ensures not only the efficient use of public budgets but also fosters strong linkages between research, enterprises, and the market - thereby promoting innovation and enhancing the competitiveness of Germany's agricultural sector both domestically and internationally.

- *Second, the establishment of the Julius Kühn Institute (JKI*), one of Germany's leading agricultural research institutions, plays a vital role in advancing precision and sustainable farming initiatives. Founded in 1912, the institute specializes in plant protection, crop variety improvement, biotechnology development, and cultivation methods that minimize environmental impact. With over 1,000 staff members working across research facilities nationwide, JKI collaborates extensively with international research organizations.

One of JKI's most notable research projects is the Smart Farming 2020 Project, which aims to develop technologies that help farmers reduce the use of plant protection products and improve crop yields. The institute has researched and developed smart cultivation methods, such as using sensors to accurately measure the nutritional needs of crops, thereby optimizing the application of fertilizers and pesticides and minimizing environmental pollution.

Beyond technological research, JKI also focuses on developing disease-resistant crop varieties, helping farmers reduce their reliance on chemical plant protection. The institute conducts studies on soil and water conservation solutions, particularly in the context of climate change, which affects crop productivity and development. The outcomes of JKI's research are not only applied within Germany but also shared with other countries, contributing to the improvement of global agricultural product quality.

Third, promoting international cooperation and interdisciplinary research initiatives. In addition to domestic research programs, Germany places strong emphasis on collaboration with other countries and international organizations to advance agricultural research and technology application. Institutions such as the German Agency for International Cooperation (GIZ) and the Food and Agriculture Organization of the United Nations (FAO) have partnered with Germany to implement research and development projects in areas such as crop protection, natural resource management, and ecological conservation. These initiatives not only focus on developing new technologies but also involve knowledge and experience sharing, enabling other countries to access advanced agricultural solutions.

Notably, Germany also promotes interdisciplinary research initiatives that integrate agriculture, information technology, and environmental science. A prime example is the Interdisciplinary Agriculture and Biotechnology Program, funded by the German Ministry of Agriculture. This program encourages research projects that combine biotechnology and information technology to develop disease-resistant crop varieties and optimize cultivation processes.

- *Fourth, implementing pilot projects and precision agriculture models.* To support the development of smart agriculture, the German government has also funded pilot projects and precision farming models. These projects are typically conducted on experimental farms, where farmers can apply new technologies in real-world settings. The pilot models help farmers become familiar with technologies such as intelligent monitoring systems, water and nutrient management, and automation in agricultural production.

In 2021, Germany launched a series of pilot projects utilizing drone and sensor technologies to monitor crop health and soil moisture in agricultural areas. Initial results from these projects demonstrated a significant reduction in the use of fertilizers and pesticides, while crop yields increased by approximately 15–20% compared to traditional farming methods *(BMEL, 2021).*

Fifth, promoting public-private partnerships (PPPs) is a key pillar of Germany's agricultural R&D strategy, fostering strong collaboration among stakeholders, including the government, enterprises, research institutions, and farmers. PPP models not only create a supportive environment for research and technology application but also ensure that scientific outcomes are rapidly translated into practical, marketable, and sustainable solutions.

The government plays a central role in establishing comprehensive policy frameworks and support mechanisms for PPPs. Specifically, it develops transparent legal structures, launches research funding programs (such as the Agricultural Innovation Fund), and designs financial incentive policies to minimize investment risks for businesses and farmers. Additionally, the government acts as a coordinator, ensuring that R&D objectives are aligned with sustainable agricultural development, environmental protection, and climate change adaptation goals *(BMEL, 2020).*

Private enterprises - particularly technology corporations and startups - play the role of investors and technology adopters. They actively participate in the development of new technologies, ranging from sensor devices and automated farming systems to artificial intelligence platforms for agricultural data analysis. In addition to providing financial and technical resources, these companies bring products to market and tailor solutions to meet real-world needs. For example, firms such as BASF and Bayer CropScience have collaborated with research institutes to develop disease-resistant crop varieties and biological plant protection products, helping to reduce negative impacts on ecosystems.

Research institutes serve as knowledge hubs, responsible for providing scientific foundations, designing technological solutions, and acting as bridges between research and practical application. Institutions such as the Julius Kühn Institute and the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) not only

conduct academic research but also work directly with farmers to test advanced cultivation models, thereby adapting technologies to local production conditions. The role of research institutes is increasingly interdisciplinary, as they integrate fields such as biology, information technology, and environmental science within collaborative R&D projects.

Farmers, rather than being mere beneficiaries of technology, have now become active partners in the research and testing process through programs such as the Farmers' Innovation Network. They contribute practical production insights, provide feedback on technological effectiveness, and co-develop optimized solutions with research institutes. The government supports farmers through preferential loans, experimental equipment, and training programs, enabling them to master new cultivation techniques and improve production capacity.

The collaboration among stakeholders is further strengthened through the establishment of sustainable cooperation platforms such as German Agri-Tech and AgriTech East, where enterprises, research institutes, investors, and farmers can meet, exchange ideas, and jointly develop technological products. These platforms not only operate at the national level but also expand international cooperation, aiming to export German agricultural technologies to global markets.

Notably, to encourage innovation from the private sector, the German government has made substantial investments in support programs for AgriTech startups, such as the AgriTech Start-up Hub and specialized Innovation Hubs. These programs provide financial assistance and startup consulting and facilitate connections between emerging companies, research institutes, and farming communities. This ecosystem enables innovative initiatives to be tested, refined, and rapidly commercialized.

- *Finally, market orientation and export expansion* are key strategies for promoting the commercialization of agricultural R&D products in Germany. This approach involves a tightly integrated chain of solutions, beginning with the commercialization of research outcomes. The government supports this process by establishing and nurturing high-tech agricultural startups - entities capable of bringing innovations from the laboratory to the marketplace. Subsequently, products are widely introduced and promoted through international trade fairs such as AGRITECHNICA, which serve as vital platforms connecting inventors, businesses, and markets. Additionally, organizations like GIZ act as intermediaries, facilitating access to foreign markets, promoting international cooperation, and transferring technologies to developing countries with high demand for sustainable agricultural solutions. All these elements are interconnected and reinforced by a strategic focus on developing R&D products that meet global standards and are integrated into green, smart, and circular value chains. This alignment not only secures a strong domestic presence for Germany's high-tech agricultural products but also enables significant expansion into international markets.

2.2. Achieved outcomes

The Federal Republic of Germany has emerged as a leading model in promoting innovation in agriculture through comprehensive R&D policies, with the goal not

only of increasing productivity and production efficiency but also of protecting the environment and fostering sustainable development. Innovation in Germany's agricultural sector has become a key factor in maintaining the country's position in the global agricultural landscape. Germany's agricultural success is driven not only by advanced technologies and modern production processes but also by strategic marketing approaches and effective public-private partnership (PPP) models:

First, advancing a more sustainable agricultural sector. In the face of growing challenges from climate change and environmental pollution, Germany has placed a strong emphasis on developing sustainable agriculture, with one of its core priorities being investment in research and development (R&D) to foster innovation. A notable outcome of this policy is the significant increase in organic farmland - from 6.5% in 2016 to approximately 11.4% in 2023. Germany's long-term goal is to reach 20% to 30% organic farmland by 2030. This transition not only reflects Germany's commitment to sustainable agriculture but also demonstrates the effectiveness of R&D in developing organic farming methods and reducing dependency on chemical pesticides and fertilizers.

In addition, investment in agricultural renewable energy research has yielded impressive results. By 2023, Germany had established over 9,500 biogas plants, contributing around 5% to the country's total electricity supply. This achievement not only mitigates environmental impact but also provides a vital source of renewable energy for the national economy. These outcomes highlight the success of applying scientific research and microbiological technologies to agricultural production - not only enhancing sustainability but also delivering economic and environmental value.

Table 1. Key outcomes in sustainable agricultural development through innovation promotion

Year	Organic Agricultural Land Area (%)	Number of Biogas Plants	Share of National Electricity Supply (%)
2016	6.5%	6,500	4%
2020	8%	8,000	4.5%
2023	11.4%	9,500	5%

Source: Federal Ministry of Food and Agriculture (BMEL), 2023.

These outcomes clearly demonstrate that substantial investment in research and development (R&D) has led to major progress in transforming German agriculture toward greater sustainability and environmental friendliness. The expansion of organic farmland and the development of renewable energy from agriculture serve as strong evidence of the effectiveness of innovation initiatives - not only contributing to environmental protection but also driving economic growth through the provision of clean energy and sustainable agricultural products.

Second, one of the most important and successful strategies in Germany's agricultural development policy is the strong investment in technology and digitalization to promote innovation in the sector. A prime example is the Digital Strategy for Agriculture (2019), implemented by the Federal Ministry of Food and

Agriculture (BMEL), which aims to accelerate the digital transformation of agriculture. To achieve this goal, the German government has funded research and development projects focused on advanced technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), and agricultural robotics. These technologies have not only brought significant improvements to cultivation processes but have also fundamentally changed how farmers manage land and produce agricultural goods.

One of the most notable outcomes of this investment is the rapid advancement of precision farming. Precision agriculture utilizes GPS systems and soil sensors to monitor and analyze environmental and soil conditions in real time, enabling farmers to make more accurate decisions regarding water usage, fertilizer application, and plant protection products. This has led to a 15–20% increase in cultivation efficiency across large areas, reducing costs and boosting productivity for producers.

Furthermore, the momentum generated by high-tech initiatives has encouraged the growth of AgriTech startups. Companies such as FarmBlick and AgriCon attracted over €500 million in investment from venture capitalists between 2020 and 2023, reflecting the strong interest and growth potential of the agricultural technology sector in Germany. This development not only delivers economic benefits but also enhances the sustainability and global competitiveness of Germany's agricultural industry in an increasingly dynamic market.

Table 2. Technologies implemented in the agricultural development of the Federal Republic of Germany

Applied Technology	Increase in Cultivation Efficiency (%)	Investment in AgriTech (Million EUR)
Precision Agriculture (IoT, AI)	15-20%	500+
GPS system and soil sensor	15-20%	500+

Source: Federal Ministry of Food and Agriculture (BMEL), 2022.

These results clearly indicate that investment in research and development (R&D) in technology and digitalization has had a profound impact on promoting innovation and improving agricultural productivity in Germany. These achievements not only enhance cultivation efficiency but also help reduce negative environmental impacts, while opening growth opportunities for the AgriTech sector - laying the foundation for the future sustainability of the national agricultural system.

- *Third, promoting commercialization.* The German government has established a robust public–private partnership model involving renowned research institutions such as Fraunhofer and Max Planck, universities, and enterprises through the German Agricultural Research Alliance (DAFA). This model provides an effective platform for connecting research organizations with the business community, thereby accelerating technology transfer and the practical application of research in agricultural production.

This collaboration has led to the commercialization of scientific inventions, including climate-resilient crop varieties and bio-based materials derived from

agricultural by-products. Moreover, agricultural innovations developed through this model not only improve the productivity and quality of agricultural products but also contribute to sustainability goals in farming. Thanks to these efforts, Germany currently leads the European Union in the number of patents in agricultural technology, accounting for 15% of all AgriTech patents in the EU as of 2022 *(Fraunhofer ISI, 2022; DAFA, 2022).*

- *Fourth,* fostering the growth of high-tech agriculture. Germany places particular emphasis on providing financial support and legal incentives for enterprises engaged in agricultural research and development (R&D). A prime example is the Innovation Program of the Federal Ministry of Food and Agriculture (BMEL), which allocates €500 million annually to promote R&D projects in the agricultural sector. In addition, tax incentives for R&D startups have significantly contributed to the robust development of the AgriTech industry, which experienced a steady 8% annual growth rate from 2020 to 2023. Investment in R&D has not only fueled the expansion of AgriTech but has also created opportunities to penetrate global markets. Notably, Germany's agricultural technology exports reached €7.4 billion in 2022, accounting for 25% of the global market share in this sector - demonstrating the successful application of research outcomes in production and commercialization.

Table 3. Growth of high-tech Agriculture in the Federal Republic of Germany

Year	AgriTech Industry Growth Rate (%)	Agricultural Technology Exports (Billion EUR)
2020	8%	6.5
2021	8%	7.0
2022	8%	7.4

Source: Federal Ministry of Food and Agriculture (2022).

Fifth, increasing human resource participation in agricultural innovation. A key component of Germany's agricultural development policy is investment in education and the training of high-quality human resources, particularly in the field of research and development (R&D). Prestigious universities such as the University of Hohenheim have proactively integrated R&D programs into their curricula, enabling students to engage in research projects from early stages of their academic journey. As of 2023, approximately 20% of agricultural students had participated in R&D projects, reflecting a strong emphasis on cultivating a skilled and innovative workforce for the future of agriculture. This approach not only enhances the quality of human capital but also contributes to driving innovation in agriculture by generating new technological solutions and improving production processes.

Table 4. Percentage of agricultural students participating in R&D projects

Year	Percentage of Agricultural Students Participating in R&D (%)
2018	15%
2020	18%
2023	20%

Source: Hohenheim University, 2023.

2.3. Key challenges in promoting R&D investment in Germany

- *First*, one of the significant obstacles in commercializing research outcomes is the cautious mindset and slow adoption of new technologies among farmers. Many farming households - particularly small-scale or traditional farms in rural Eastern Germany - remain skeptical about the effectiveness of technology and are concerned about investment costs and operational complexity. According to a survey conducted by the Julius Kühn Institute (2021), only around 35% of farmers in Germany stated that they were "willing to adopt digital technologies in cultivation within the next two years," despite having access to information and training support.
- *Second*, the implementation of high-tech solutions in agriculture - particularly precision farming, smart sensors, AI, and robotics - requires substantial initial investment. This includes not only the cost of equipment but also the necessary digital infrastructure, such as high-speed internet, data storage systems, management software, and skilled operational teams. These requirements pose significant challenges for small farms in accessing and deploying such technologies, even when government support programs are available. Ongoing costs for maintenance, software updates, and technical training also represent a long-term financial burden.
- *Third*, in the context of digitalized agriculture, data has become a critical asset across the agricultural value chain - from soil and weather data to crop genetics, production, and consumption information. However, Germany currently lacks a unified legal framework governing ownership, sharing, and protection of agricultural data. Many farmers are concerned that their data could be misused by large tech companies or compromised through cloud-based platforms. This issue slows down the digital transformation process and hinders the practical application of AI and Big Data solutions in agricultural production *(Fraunhofer ISI, 2020).*
- *Fourth*, although Germany possesses numerous high-quality research institutions, coordination among interdisciplinary research units is sometimes fragmented. This can lead to overlapping topics or underutilization of available resources. Some projects lack strong connections with businesses or farming communities, making it difficult to effectively transfer research outcomes into practice. Additionally, funding policies are not yet sufficiently flexible and tend to concentrate on major research centers, which limits access to research capital for rural areas and smaller universities.

2.4. Key Implications for Vietnam

** Some Limitations in Promoting Agricultural Innovation in Vietnam*

In recent years, innovation activities in Vietnam's agricultural sector have made notable progress. Various initiatives and innovation policies have gradually been implemented, contributing to improved productivity and production efficiency while generating added value for the rural economy. However, investment in

research and development (R&D) to promote innovation in agriculture still faces several challenges, such as:

- *Limited access to technology*: Although smart agriculture is developing in Vietnam, most farmers have yet to adopt high-tech solutions, particularly in areas such as precision farming, sensor technologies, and automation. Many farmers continue to rely on traditional cultivation methods and lack awareness of modern technological solutions, which restricts the application of advanced technologies in agricultural production;
- *Lack of policy coherence*: Although the Vietnamese government has introduced several policies to support smart agriculture, these programs remain relatively weak and lack effective coordination among ministries, research institutes, businesses, and farmers. Some support schemes do not sufficiently incentivize private sector participation in high-tech agriculture, thereby failing to generate momentum for the sector's development;
- *Insufficient investment in agricultural R&D*: Funding for agricultural technology research and development (R&D) in Vietnam remains relatively low, despite its critical role in driving innovation. Existing R&D support programs are not strong enough to motivate startups and research institutions, resulting in limited sustainable growth within the agricultural sector;
- *Challenges in human resource development*: Training and developing specialized human resources in agricultural technology and R&D in Vietnam still face considerable limitations. Agricultural universities and research institutes have yet to establish strong connections with businesses to deliver training programs aligned with the practical needs of the industry, which reduces the capacity to apply technology effectively in agricultural production;
- *Limited international cooperation*: Vietnam has participated in several international agricultural cooperation initiatives. However, the implementation of new technologies and the application of global knowledge in domestic agricultural practices remain insufficient. Barriers to technology transfer and experience sharing continue to hinder access to advanced agricultural solutions from developed countries.

** Key Policy Implications for Vietnam*

Drawing from Germany's experience and the current state of agricultural innovation in Vietnam, several key implications can be identified:

- *First*, increase investment in agricultural R&D. One of the critical factors behind Germany's success in promoting agricultural innovation is its strong commitment to research and development (R&D). Vietnam should learn from Germany by enhancing resource allocation for agricultural R&D projects, especially in areas such as precision farming, automation, and smart technologies. It is essential to establish robust R&D investment funds to encourage research institutions and agricultural enterprises to engage in the development of advanced technological solutions;

- *Second*, ensure coherent and effective agricultural support policies. Germany's innovation support policies in agriculture have been implemented in a coordinated manner, with strong connections among government agencies, research institutes, businesses, and farmers. Vietnam should develop and implement more integrated support policies that foster effective collaboration among stakeholders. This includes launching training programs, providing financial assistance, and creating favourable conditions for high-tech agricultural enterprises to participate in the market;
- *Third*, strengthen capacity building and specialized human resource training. Germany has established high-quality training programs for agricultural professionals. Vietnam should focus on developing a specialized workforce in agricultural technology, particularly by fostering close collaboration among universities, research institutes, and businesses to deliver training programs aligned with agro-sectoral needs. This will help cultivate a creative and capable workforce that can apply new technological solutions to agricultural production;
- *Fourth*, promote public–private partnerships and international cooperation. The public–private partnership (PPP) model is a key driver of agricultural innovation in Germany. Vietnam should learn from Germany by establishing collaborative frameworks among government agencies, research institutes, businesses, and farmers to develop advanced agricultural technologies. At the same time, participating in international agricultural cooperation initiatives and sharing knowledge and experience will enable Vietnam to access new technologies and solutions, creating opportunities to improve the quality and productivity of agricultural products;
- *Fifth*, encourage the adoption of high-tech and precision agriculture. Germany has focused on applying advanced technologies such as sensors, artificial intelligence (AI), and automation in agriculture to boost productivity and protect the environment. Vietnam should promote the adoption of modern technologies such as precision farming, intelligent monitoring systems, and automation in agricultural production. The government can support this effort through training programs, financial assistance, and the provision of technological solutions that help farmers reduce production costs, enhance efficiency, and ensure sustainability;
- *Finally*, creating favourable conditions for agricultural startups is essential. Germany places strong emphasis on supporting startups in the high-tech agricultural sector. Vietnam can learn from this experience by developing support programs for agricultural technology startups, including accelerator initiatives, innovation hubs, and platforms that connect startups with research institutes and farmers to implement innovative solutions in real-world production.

3. Conclusion

Innovation is a crucial factor in enabling the agricultural sector to develop sustainably and respond effectively to modern challenges such as climate change, limited natural resources, and the growing demand for food production. Investment in research and development (R&D) is the key to driving innovation in this field.

Germany's experience demonstrates that a well-structured and strategic approach to R&D investment can yield significant results in promoting agricultural innovation. In Germany, collaboration among research institutions, businesses, and the government has fostered a robust innovation ecosystem within the agricultural sector. Advanced technologies - such as smart farming systems, drought-resistant crop varieties, and the application of biotechnology - have contributed to improving both productivity and product quality. The German government not only invests in research but also establishes supportive policies and financial mechanisms that enable enterprises and research organizations to access resources more easily.

Although Vietnam has taken initial steps toward applying high technology in agriculture, a clearer and stronger strategy for R&D investment is still needed. The government should develop long-term support policies, provide financial resources for agricultural research projects, and create an enabling environment that fosters collaboration among research institutions, businesses, and farmers. This approach will not only promote sustainable agricultural development in Vietnam but also enhance the productivity, quality, and value of Vietnamese agricultural products in international markets. To transform Vietnam's agricultural sector into a smart and sustainable industry, substantial investment in R&D is a critical factor. Germany's experience offers valuable lessons that Vietnam can learn from and adapt to its own context - laying the foundation for a modern, innovative, and efficient agricultural system./.

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