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Evaluation *Insight* Note

New insights from existing evidence to inform decisions, address knowledge gaps, and enhance operational learning

Agricultural Innovation and Technology in World Bank Projects

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Drawing from the Independent Evaluation Group's rich knowledge repository, Evaluation Insight Notes respond to the need for more rapid and focused evaluative evidence. These notes systematically analyze data from a range of evaluations, validations, and other studies to generate insights in a timely manner around important strategic and operational issues.

Critical Role of Agricultural Technologies in Increasing Productivity, Enhancing Market Linkages, and Building Climate Resilience

Developing countries need to dramatically increase their use of agricultural innovation and technology to eliminate poverty,[1] meet the rising demand for food, and cope with climate change. In doing so, they must also adapt such technologies to local environmental and social conditions (Fuglie et al. 2020). Adoption of agricultural technologies can increase productivity by improving crop yields through advanced planting materials and agronomic practices that are more resistant to pests and diseases. Enhancing market linkages can be achieved through technologies such as mobile platforms that connect farmers directly with buyers, which improves supply chain efficiency and reduces transaction costs. Building climate resilience involves the development of drought-resistant crop varieties, irrigation systems that conserve water, and weather forecasting tools that help farmers plan better and mitigate the risks associated with climate variability and change.

The World Bank defines *innovation* as a process by which individuals or organizations master and implement the design and production of goods and services that are new to them, irrespective of whether they are new to their competitors, their country, or the world (World Bank 2007a). Adoption of more advanced technologies has increased, and in more recent times, disruptive agricultural technologies, such as increased digitization, have received increasing attention for their potential to catalyze productivity and coordinate gains throughout the entire value chain—for example, by providing accurate time- and location-specific price, weather, and agronomic data; improving access and linkages; and providing digital platforms (Fuglie et al. 2020; Schroeder, Lampietti, and Elabed 2021).

[1] Based on the World Bank's classification, developing countries have low- or middle-income levels.

> **Disruptive agricultural technologies, such as increased digitization, have received increasing attention for their potential to catalyze productivity and coordinate gains throughout the entire value chain.**

Data-driven digital agriculture is a core component of the current World Bank Group strategy on agriculture and food, which aims to encourage the use of data, digital technology, and innovation to transform the agrifood system. The strategy promotes use of data and digital technology by smallholders to increase productivity, enhance market linkages, and build climate resilience (World Bank 2023d).

Use of Technologies in Agriculture and Irrigation Projects

This Evaluation Insight Note answers the question, How are World Bank agriculture and irrigation projects using technologies, and what insights can be drawn from them? To do this, the Independent Evaluation Group (IEG) conducted a portfolio identification and review of World Bank agriculture and irrigation projects to describe the extent and use of agricultural technologies in projects (see the Methodology section).[2] The review covered 158 active and 113 closed projects between fiscal years 2016 and 2023.[3] The findings were supplemented by insights drawn from four project evaluations (Project Performance Assessment Reports [PPARs]) undertaken by IEG in Bangladesh, Brazil, Côte d'Ivoire, and Viet Nam.

[2] The Evaluation Insight Note does not prioritize advanced over low-tech technologies and simply presents the coverage of technologies in project documents.

[3] The use of advanced (that is, digital) technologies has been promoted in World Bank projects for the past five years or so. Therefore, to be able to comprehensively capture their usage, both closed and active projects were included in the review.

What Are the Main Insights from This Synthesis?

1 The World Bank's agriculture and irrigation portfolio shows limited coverage of advanced technologies.[4]

The portfolio identification and review using text mining showed that the incorporation of advanced technologies into World Bank projects remains limited; however, over time, projects have shifted toward including a more diverse range of technologies. In addition, within the four projects evaluated by IEG in the field, findings regarding technology uptake varied (World Bank 2023a, 2023b, 2023c, 2023e). The project in Bangladesh promoted diverse range of technologies and practices, including the use of high-yielding seed varieties for crops (such as saline-, drought-, and flood-tolerant rice seeds), improved generations of fish seed and fish culture practices, and improved fish varieties for farmers' use. The project also promoted advanced irrigation technologies, including buried pipe networks, water management practices such as alternate wetting drying, and the use of vermicompost fertilizer. The project in Viet Nam promoted innovative technologies such as biodigesters, which were novel for small farmers when the project was designed. In contrast, the project in Côte d'Ivoire concentrated only on promoting standard seed technologies for cocoa and cotton, although the potential to promote other technologies was feasible. The project in Brazil supported only the uptake of low-tech pasture renewal techniques.

2 The technologies prevalent in projects focus mainly on increasing agricultural productivity, with limited attention to technologies for facilitating market linkages.[5]

Results from a text mining exercise showed that the use of agricultural technology–related terms in the project documents of both active and closed projects focused

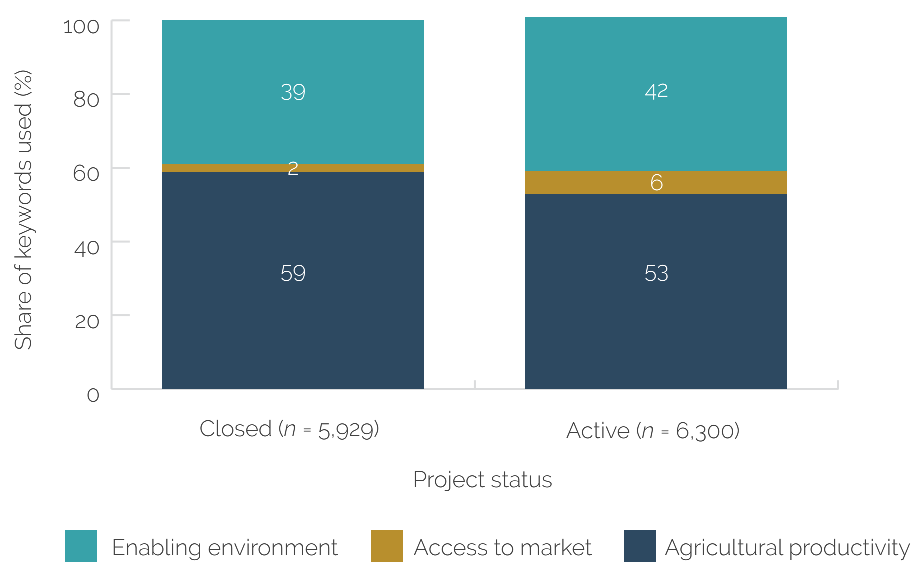
[4] This Evaluation Insight Note considers advanced technologies to be digital and other key technologies, such as biotechnology, biofortified crops, precision agriculture, alternate wetting and drying, and so on.

[5] These results could also be partially explained by the choices made when determining the project development objectives, which may drive the categories of technologies promoted and adopted.

mostly on technologies that boost agricultural productivity (over half of the agricultural technology–related terms used). However, only a small fraction of search terms (2 percent for closed projects and 6 percent for active projects) related to technologies focused on improving market access (figure 1). Interestingly, a significant share of search terms (over one-third) included technologies that serve as important enablers. These technologies are categorized in this review as "enabling environment" and encompass digital platforms, early-warning systems, information communication technologies, management information systems, and so on. Such technologies support projects in enhancing productivity and market access and assist them with their monitoring and evaluation functions. Detailed examples of these technologies are provided in table 1.

> **The use of agricultural technology–related terms in the project documents focused mostly on technologies that boost agricultural productivity (over half); only a small fraction (2–6 percent) related to technologies focused on improving market access.**

Figure 1. Technology Categories Used in Closed and Active Projects by Share



Source: Independent Evaluation Group, based on Project Appraisal Documents.

Note: n = number of search terms found in the documents.

This finding is consistent with the insights derived from the PPARs. In the four evaluated projects, we found that technologies used to increase agricultural productivity were more prominent. Even projects that supported interventions aimed at promoting market access (for example, the Agriculture Sector Support Project in Côte d'Ivoire and the Livestock Competitiveness and Food Safety Project in Viet Nam) did not leverage advanced technologies to facilitate improvements in market linkages.

Table 1. Agricultural Technology Keywords Found in Closed and Active Projects

TECHNOLOGY TYPE	CLOSED (%)	ACTIVE (%)	TECHNOLOGY TYPE	CLOSED (%)	ACTIVE (%)
Productivity					
Agricultural research	33	35	Microirrigation	15	22
Research and development	12	22	Alternate wetting and drying	0	4
Technology adoption	11	18	Water-saving technologies	0	1
Agricultural mechanization	1	4	Conservation agriculture	10	13
Biofortification	0	2	Sustainable land management	19	18
Biotech	9	9	Sustainable water management	2	1
Climate-smart technologies	2	11	Precision agriculture	0	3
Crop intensification	3	3	Precision livestock farming	0	1
Crop rotation	4	12	Artificial insemination	8	8
E-extension	4	13	Biogas	12	16
E-voucher	2	7	Manure management	5	13
Fertilizer management	2	3	Artificial intelligence	0	3
Hydroponic	1	4	Innovation lab	0	2
Vertical farming	0	1	Drones	0	8
Seed breeding	0	1	Digital application	1	5
Improved seed varieties	3	6	Index-based insurance	0	0
Genetically modified organisms	4	1	Internet of Things	0	1
Integrated pest management	43	32	Robotics	0	1
Irrigation technologies	8	14	Sensor	3	3
Automated irrigation	0	0	Soil moisture sensor	0	0

(continued)

TECHNOLOGY TYPE	CLOSED (%)	ACTIVE (%)	TECHNOLOGY TYPE	CLOSED (%)	ACTIVE (%)
Market access					
Food safety system	1	3	Fintech	0	2
Blockchain	0	2	Warehouse receipt system	1	4
Traceability system	0	3	Marketing platform	1	7
Credit platform	0	0	Mobile application	1	4
Digital credit scoring	0	1	Mobile banking	1	6
Digital finance	0	3	Processing technologies	7	9
Digital payment	3	0	Storage technologies	1	1
Enabling environment					
Registry systems	0	2	Digital platform	1	8
Agricultural observatory	0	1	Early-warning system	12	20
Agricultural innovation	10	11	Geographic information system	24	27
Big data	1	8	Smart subsidy program	0	1
Agriculture data	3	11	Surveillance (pest and disease tracking)	7	10
E-agriculture	0	2	Hackathon	0	1
Decision support system	11	11	Start-ups	7	20
Data platform	3	5	ICT	19	40
Digital agriculture	0	9	Management information system	67	91

Source: Independent Evaluation Group, based on Project Appraisal Documents.

Note: The total number of projects is 113 closed and 158 active. The average number of technologies was 3.9 per closed project and 6.1 per active project. Technologies highlighted in dark green (white text on dark) are more concentrated, those in dark orange (white text on medium) are moderately covered or have seen greater increase and use from a lower base, and those in beige (black text on light) have limited coverage. ICT = information and communication technology.

Among the technologies promoted in World Bank agriculture and irrigation projects, geographic information systems, early-warning systems, and management information systems are most common.

Text mining of project documents reveals a notable concentration of certain technologies and applications in active projects, including geographic information systems (27 percent), early-warning systems (20 percent), information communication technologies (40 percent), and monitoring information systems (91 percent). In addition, the project documents frequently mention integrated pest management (32 percent), irrigation technologies such as microirrigation (drip or sprinkler irrigation; 22 percent), and agricultural research (35 percent). However, advanced technologies, such as digital technologies, are generally less represented, albeit with a slight uptick in active versus closed projects. This upward trend is evident with the use of technologies for climate-smart agriculture (increasing from 2 percent in closed projects to 11 percent in active projects), crop rotation (from 4 percent to 12 percent), e-extension (from 4 percent to 13 percent), and e-vouchers (from 2 percent to 7 percent), all aimed at boosting agricultural productivity.[6] Technologies related to financial access, such as mobile applications (4 percent of active projects) and mobile banking (6 percent of active projects), have also seen growth, but their overall presence remains modest.[7] The use of drones in 8 percent of active projects underscores a growing interest in their potential, although, considering this, their use remains relatively limited (see table 1).

In addition to the portfolio review analysis, the findings highlight some key lessons on technology diffusion in projects based on the PPAR fieldwork.

Combining demand-based technological solutions with training and technical assistance supports uptake of solutions.

The participatory or demand-driven extension model focuses on bottom-up approaches by working closely with farmer field schools or organized farmer groups on dissemination and uptake of technologies. Several studies confirm the effectiveness of demand-driven agricultural services on adoption of technologies (World Bank 2006, 2012b). In two of the PPARs, this approach was implemented and successfully promoted technology adoption. The project evaluation in Brazil underscored the effectiveness of a demand-

[6] These increases are all statistically significant at $p < .05$.

[7] Although the increase in mobile banking is statistically significant at $p < .05$, the increase in mobile applications is not statistically significant at $p < .05$.

driven extension model complemented by farmer training and technical assistance. This approach was reinforced by the project's work with a private extension agency (the National Rural Learning Service) with a strong decentralized presence, which enabled effective outreach to farmers. During project implementation, 82 percent of farmers chose to adopt pasture renewal techniques. After the project closed, farmers interviewed during the field evaluation were found to continue using the technology, supported by ongoing services provided by the extension agency.

In Bangladesh, the adoption of crop technologies leveraged a similar demand-driven model based on farmer group approaches. This model was underpinned by a decentralized extension structure comprising a network of extension staff from the Department of Agricultural Extension and other local agencies. These staff members were supported through district- and community-level staffing to promote deep engagement with farmers. This participatory and demand-driven technology adoption approach facilitated the generation, adaptation, and dissemination of technologies tailored to the diverse agroecological and environmental challenges faced by the country. Emphasizing community mobilization through capacity-building training, the model not only facilitated a higher uptake of technologies but also instilled a sense of ownership among farmers, contributing to sustained adoption rates.

5 Technology diffusion works well when key research and extension agencies collaborate effectively, each with clearly defined roles and responsibilities in projects.

Expanding on finding 4, effective technology diffusion hinges on robust collaboration among the key agencies responsible for research and extension. Existing literature highlights that a lack of collaboration or interaction among institutions can lead to limited access to new knowledge and a weak articulation of demand for research and training (World Bank 2007a).

> **A lack of collaboration or interaction among institutions can lead to limited access to new knowledge and a weak articulation of demand for research and training.**

The Bangladesh case illustrates a positive example in which strong collaboration and links among research and extension agencies significantly contributed to the project's success. During project implementation, the Project Management Unit demonstrated strong capacity in facilitating collaboration among implementing agencies focusing on research and those disseminating technologies at the farm level, supported by regional units that closely monitored ground activities. This collaboration resulted in the expedited and more efficient dissemination of technologies from research to farmer adoption.

Conversely, the experiences in Côte d'Ivoire and Brazil show how weak collaboration hindered project implementation and possibly affected the uptake of technology. In Côte d'Ivoire, the project encountered unintended competition and conflicts among agencies because of unclear demarcation of roles and responsibilities between the public and private implementing agencies. In Brazil, two key agencies were engaged in technology diffusion. The National Rural Learning Service provided training and technical assistance, and the Brazilian Agricultural Research Corporation (Embrapa) was responsible for technology generation. The institutions operated without clearly defined roles and responsibilities, which hampered collaboration during both project implementation and postproject closure, mirroring the challenges observed in Côte d'Ivoire.

6 Combining technology dissemination efforts with investments in enabling environment factors, such as good-quality infrastructure, facilitates technology adoption.

In Côte d'Ivoire, the project's approach went beyond merely promoting technology adoption to rehabilitating and maintaining rural roads. These investments were crucial for ensuring the continued and timely delivery of technologies, such as the improved seeds, promoted by the project. In Bangladesh, the project focused on promoting irrigation technologies through investments in infrastructure, such as buried pipe networks, pumps, and tube wells. Irrigation technologies play a significant role in enabling agricultural innovation because they can substantially improve crop yields. The literature shows that farmers with access to irrigation systems tend to adopt new technologies more quickly (Ahmed, Hernandez, and Naher 2016; World Bank 2012a). The literature also underscores the importance of integrating agricultural extension with market linkages and rural road infrastructure to enhance agricultural productivity and improve farmers' incomes (World Bank 2007b). It highlights the need for market-driven extension and well-functioning agricultural markets to promote sustainable agricultural development (Swanson and Rajalahti 2010). IEG's evaluation on agrifood economies also highlighted that efforts to support production technologies should be complemented by efforts to improve market access and develop effective agrifood systems (World Bank 2022).

In Viet Nam, the project invested in marketing infrastructure and promoted the adoption of food safety standards alongside technology adoption initiatives. Specifically, investments were directed toward upgrading meat slaughterhouses and wet markets and promoting the adoption of good animal husbandry practices to ensure the production of safe and high-quality food products. By combining investments in technologies with supportive measures such as physical marketplaces and regulatory compliance, the project aimed to strengthen the value chain for livestock. Conversely, the challenges of technology diffusion without sufficient investment or assessment of enabling factors became apparent in the case of biodigester technology, which was promoted in the same project in Viet Nam. Although it was introduced with the intention of supporting cooking and electricity generation, the PPAR found that only a small proportion of interviewed farmers used it for cooking and none used it for electricity generation (World Bank 2023e). This lack of sustained use was due to adequate availability and affordability of state-supplied electricity. It seems that the project may not have conducted a thorough assessment of these enabling factors before introducing the technology.

IEG's evaluation on agrifood economies also highlighted that efforts to support production technologies should be complemented by efforts to improve market access and develop effective agrifood systems.

Building sustainable institutional models—key for technology uptake and use—continues to be challenging in World Bank–supported projects.

As highlighted by the World Bank report *Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems,* investing in rural organizations can significantly enhance agricultural innovations' effectiveness (World Bank 2007a). The project evaluations also found that most of the projects either worked with or supported the development of farmer organizations to facilitate technology diffusion. In Viet Nam, for example, the focus was on forming and supporting livestock producer groups and cooperatives to enhance and share good animal husbandry and livestock management practices. In Bangladesh, technology diffusion was promoted via initiatives such as farmer field schools and community-based organizations such as water user groups. In Côte d'Ivoire, the project engaged cooperatives and farmer organizations, in partnership with the private sector (interprofessional organizations), to advance technology adoption for various crops.

In all the cases, the project evaluations revealed that, despite their active involvement during project implementation, most of these local institutions had ceased operations. The absent or limited operations of these local institutions demonstrate that unless a sustained effort is made to either build the capacity of such organizations or ensure continued engagement with them on technology use after project closure, the results achieved by the projects may not be sustained.

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Methodology

Portfolio review analysis. As part of the portfolio review for this Evaluation Insight Note, we used text mining techniques to identify a relevant set of projects and then scan the contents of project documents to identify and quantify references to various agricultural technologies. First, we developed a search taxonomy and shared it with the Agriculture and Food Global Practice (GP),[8] and additional keywords were included based on the GP's feedback. The terms in this taxonomy were classified into three broad categories: agricultural productivity enhancement technologies, market access technologies, and enabling environment technologies. Within these categories, key search terms were grouped within the subset of technologies. Second, we conducted a portfolio identification process that identified 101 closed and 146 active projects mapped under the Agriculture and Food GP and additional irrigation projects (24 closed and 25 active) under the Water GP between fiscal years 2016 and 2023. For the 296 projects, we found project documents (Project Appraisal Documents, Implementation Completion and Results Reports, and Implementation Completion and Results Report Reviews)[9] in the World Bank's system for 271 projects (113 closed and 158 active)[10] that formed the basis for text mining.

After scanning the documents, we reviewed the results, and the following threshold was applied as an inclusion criterion: only search terms found more than once per project were retained and presented in the analysis. Finally, the results of the text mining exercise were manually checked in randomly selected project documents. The text mining work was carried out using Microsoft Excel, R, and Python.

Limitations. The portfolio did not include projects mapped to GPs other than the Agriculture and Food GP and the Water GP; thus, it did not capture agricultural

[8] The taxonomy included, for example, improved seed variety, climate-smart technology e-extension, biotechnology, precision agriculture, microirrigation, marketing platform, mobile application, geographic information system, and data platform.

[9] Initially, we included Implementation Completion and Results Reports and Implementation Completion and Results Report Reviews to be reviewed and assessed. However, during data analysis, we realized that for active projects, the only documents used for the assessment were Project Appraisal Documents (PADs). Therefore, for consistent comparison between active and closed projects, the assessment used only PADs. With the use of PADs, the issue of duplication of searches among PADs, Implementation Completion and Results Reports, and Implementation Completion and Results Report Reviews was also avoided.

[10] For the project search, we were able to bulk download from the World Bank's external document repository interface (see https://documents.worldbank.org/en/publication/documents-reports/api).

technologies specific to other GPs, such as the Finance, Competitiveness, and Innovation GP or the Environment, Natural Resources, and Blue Economy GP. Furthermore, because a simple search was conducted that did not consider the different meanings of some search terms in different contexts, the results may have contained false positives.

PPARs. IEG reviewed the portfolio of World Bank projects closed between 2010 and 2020 to select candidate projects to be included in the PPAR cluster (380 projects). We ran a simple text search related to agricultural technologies stated in project objectives and component descriptions. The four selected PPARs include the following: (i) technology innovations to enhance productivity; (ii) value chain aspects, although not with respect to technology innovation; and (iii) project designs that could potentially be adapted for various subsectors.

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