# Ex-ante Cost-Benefit Analysis of High-end and Low-cost Wireless Sensor Network (WSN) Technology Packages for Efficient Irrigation Water Management in the Philippines

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## ABSTRACT

Four wireless sensor network (WSN) technology packages developed for efficient irrigation water management in the Philippines were subjected to ex-ante cost-benefit analysis (CBA) to assess their financial viability. The WSN technologies include high-end and low-cost wireless sensors for upland crop production with drip irrigation system and lowland crop production with alternate wetting and drying (AWD). Results showed that the high-end WSN technology packages are only viable for high-value crops such as red onion, bell pepper, and hot pepper. The low-cost WSN technology packages are viable for all selected crops except sweet corn. Minimum areas were also generated for each crop for the technology packages to be viable. Sensitivity analysis showed that the viability of the technologies generally declines at higher discount rates but can be improved by reducing the investment cost and increasing the cropping intensity and crop production area.

**Keywords:** *cost-benefit analysis, irrigation water management, low-cost sensor, sensitivity analysis, wireless sensor network*

## Introduction

The ever-increasing population puts extreme pressure on food systems to match the world's rapid growth. By 2050, the world population is forecasted to grow by 9.7 billion, which may require a 40% to 54% increase in food, feed, and biofuel feedstock production compared to 2012, according to the Food and Agriculture Organization of the United Nations (FAO 2021). However, this pressure is intensified further by major drivers that impact food security and nutrition: bio-physical and environmental drivers (e.g., climate variability and extremes), economic and market drivers (e.g., economic slowdowns and downturns), political and institutional drivers (e.g., conflict), economic and sociocultural drivers (e.g., poverty and inequality), and technology and innovation drivers (e.g., intensive production systems focusing on profitability without regard to the environment) (FAO *et al.* 2021). Adversities brought about by these drivers on food systems include inefficient use of resources (such as irrigation water), natural resource degradation, loss of biodiversity, low productivity, loss of agricultural outputs, trade barriers, and lack

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of access to safe and nutritious food. All of which undermine food security, hence the persistence of hunger and malnutrition.

Building and strengthening resilience to major drivers can be done at different levels to ensure the continued functioning of healthy, sustainable food systems. One way to build and strengthen resilience is through technological interventions aimed toward sustainable crop production. With the advent of Industry 4.0, so is Agriculture 4.0, which is characterized by the application of the Internet of Things (IoT), sensing technologies, big data, robotics, automated equipment, and satellite image and positioning in farming (Santos Valle and Kienzle 2020). It is in this light that WSN technologies were developed for efficient irrigation water management in the Philippines through a collaborative research project between the University of the Philippines Los Baños (UPLB) and the University of California, Berkeley (UC Berkeley) through the support of the Commission on Higher Education – Philippine-California Advanced Research Institutes (CHED–PCARI) program (Ella and Glaser 2021). This project, named PCARI-WiSEIr Project, essentially aimed to address contemporary issues such as climate change and climate variability, inefficient irrigation under upland and lowland crop production systems, water scarcity, food security, lack of modern and efficient water management technologies, aging Filipino farmers, among others.

The PCARI-WiSEIr Project generated at least four WSN technology packages using high-end and low-cost wireless sensors for upland crop production systems with drip irrigation system and lowland crop production employing AWD (Ella and Glaser 2021). The WSN technologies using high-end wireless sensors for upland and lowland crop production systems were described fully by Ramirez *et al.* (2022). These high-end WSN technologies use state-of-the-art hardware and sensors for real-time monitoring of soil moisture, water level, and weather conditions with the sensors wirelessly connected in a low-power mesh network that sends data to a central server. On the other hand, the WSN technologies using low-cost wireless sensors for upland and lowland crop production systems made use of relatively cheaper and mostly locally available components to perform real-time monitoring of soil moisture in upland crop production and water level in lowland crop production systems. The development of the low-cost wireless sensors for upland crop production was described fully by Aringo *et al.* (2022) while its counterpart for the lowland crop production with AWD was described by Dela Cruz *et al.* (2022). The locally available drip irrigation systems hooked up to the WSN technologies were evaluated in terms of water distribution uniformity as reported by Martinez *et al.* (2022). In addition, a mobile application was also developed to facilitate the monitoring of the irrigation water management parameters for both upland and lowland crop production systems. This mobile application was described fully by Agulto and Ella (2022). Moreover, the potential for adoption of the WSN technologies developed in the PCARI-WiSEIr Project was also assessed through a market survey as reported by Panaligan *et al.* (2022).

While the WSN technologies particularly the low-cost types already indicated some potential for local adoption (Panaligan *et al.* 2022), the biggest issue is still on the financial viability of the WSN technologies developed. To date, no study has been published in peer-reviewed literature on the financial viability of WSN-based irrigation water management technologies in the Philippines hooked up with drip irrigation system for upland crop production systems and employing AWD for lowland crop production systems. While other studies on irrigation with economic aspects have been published (e.g., Quilloy *et al.* 2018, Carambas *et al.* 2015, Gomez *et al.* 2014), no other studies exist in published literature particularly on the application of IoT in irrigation water management in the Philippines.

This study aimed to assess the financial viability and profitability of the four WSN technology packages intended for efficient irrigation water management of crop production systems using an ex-ante CBA for selected upland high-value crops and traditional lowland crops like rice.

## Theoretical and Conceptual Framework

Figure 1 shows the conceptual framework used in this study. The inputs essentially consist of investment costs of the WSN technologies with a drip irrigation system or AWD and crop production costs. On the other hand, the outcomes or benefits of the technology packages are represented by the increase in crop yield and profit, increased water savings, and a decrease in labor costs. These costs and benefits reflect the costs and benefits from the viewpoint of a private individual, the farmer, or the farm owner. Results of the viability analysis would consequently serve as supplementary information in assessing how well the WSN technology packages will be received by Filipino farmers and farm owners, particularly those involved in high-value crop production systems, given that financial limitations are deemed as major constraints to the adoption of the WSN technology packages.

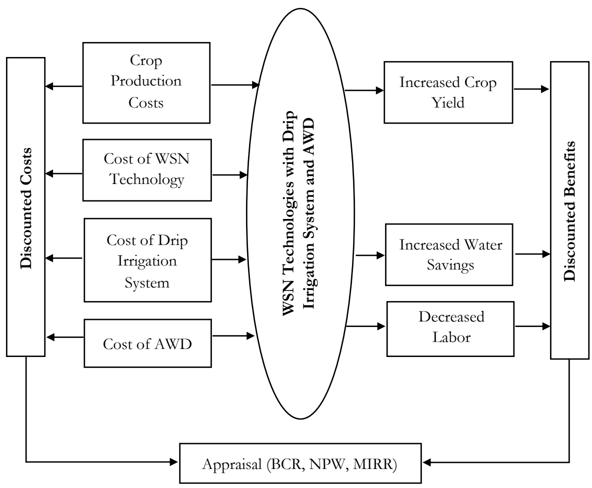


**Figure 1. The conceptual framework for cost-benefit analysis of the WSN technology packages**

## Methodology

### *Brief Description of the Four WSN Technology Packages*

WSN technologies are composed of interconnected nodes, herein called stations, that communicate among themselves wirelessly to monitor environmental conditions and collectively send this information to the base station for storage, analysis, and processing. The WSN technologies developed in this project were combined with drip irrigation system for upland crop production systems and AWD for lowland crop production systems. Each WSN technology package typically consists of four stations: sensor stations, weather station, base station, and repeaters. For upland crop production systems, a tank station was included, which was integrated with the drip irrigation system.

The sensor and weather stations are scattered throughout the field to monitor real-time changes in soil moisture content (in upland crop production systems) or water level (in lowland crop production systems), and weather parameters such as air temperature, relative humidity, air pressure, and rainfall. Data gathered by the sensor and weather stations are then sent to the base station. In the case of adopting the WSN technology with a drip irrigation system, the base station sends an instruction to the tank station to start irrigation when the base station detects that soil moisture content has dropped below the allowable threshold. Once the base station receives information from the sensor stations that field capacity has been reached, the base station signals the tank station to stop irrigation, and the cycle continues. Repeaters, on the other hand, are used to extend the transmission of other stations by receiving the data themselves and resending the data to the respective stations.

Because of the nature of WSN technologies, they are highly flexible in solving problems in a wide range of applications. However, they are also usually expensive, making them unaffordable to most Filipino farmers and farm owners. Hence, a cheaper alternative was developed for upland and lowland crop production systems. Therefore, a total of four WSN technology packages were developed in this project, namely, (1) upland high-end WSN technology package (i.e., the high-end WSN technology with drip irrigation system), (2) upland low-cost WSN technology package (i.e., the low-cost WSN technology with drip irrigation system), (3) lowland high-end WSN technology package (i.e., the high-end WSN technology with AWD), and (4) lowland low-cost WSN technology package (i.e., the low-cost WSN technology with AWD).

Figures 2 to 5 show the design setup of each WSN technology package which includes additional information on the components of each WSN technology package.

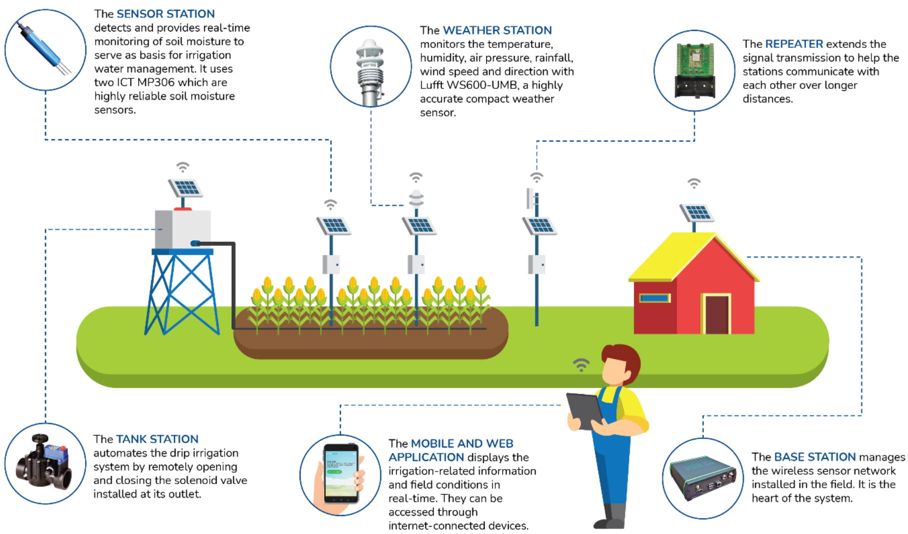


**Figure 2. Design setup of the high-end WSN technology with drip irrigation system**

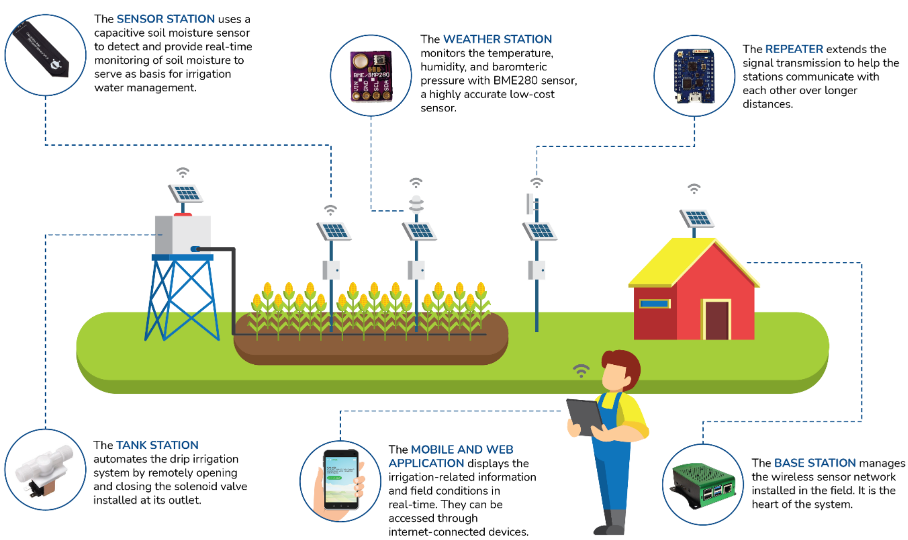


**Figure 3. Design setup of the low-cost WSN technology with drip irrigation system**

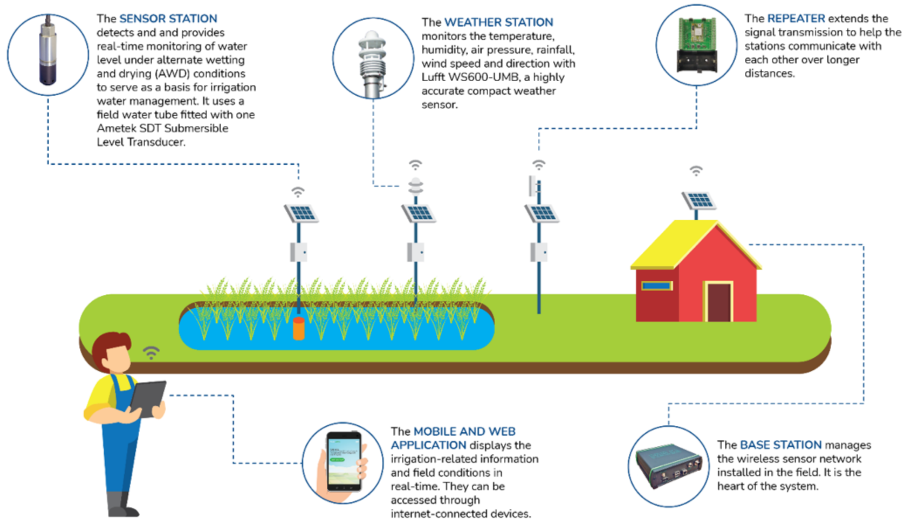


**Figure 4. Design setup of the high-end WSN technology with AWD**

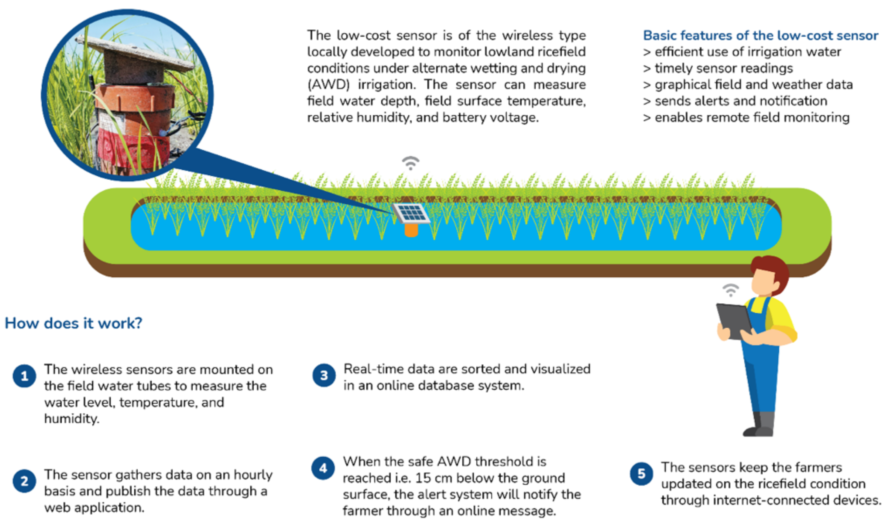


**Figure 5. Design setup of the low-cost WSN technology with AWD**

Each WSN technology package was developed in a way wherein farmers and farmworkers need not manually operate the system; that is, each station of a WSN technology package was programmed to automatically perform their respective tasks from data collection to starting or stopping irrigation. Although irrigation is automated by default, the farmer or farmworker can manually start or stop irrigation by pressing a mobile application button. Moreover, real-time data can be viewed in the mobile application, which also sends notifications to the farmer or farmworker when irrigation has started or has stopped. Because of this, the farmer or farmworker does not have to be highly skilled or highly trained to use the WSN technology packages but instead be knowledgeable enough to use a computer or smartphone.

***Data Collection***

Data used in this study were gathered through communications with experts on WSN technology, drip irrigation system, AWD, and suppliers from where said technologies and other necessary equipment were purchased. Hence, these data provided information on the initial investment and operations and maintenance (O&M) costs of adopting the high-end and low-cost WSN technologies with drip irrigation system for upland crop production systems and AWD for lowland production systems.

On the other hand, publicly available secondary data from government agencies' and technology manufacturers' websites and published papers were used to obtain crop production data and other pertinent data not acquired through direct communications. The 2021 edition of the production costs and returns of selected agricultural commodities published by the Philippine Statistics Authority (PSA) and crop production guides made by the Bureau of Plant Industry of the Department of Agriculture (DA-BPI) were used to gather relevant data such as crop production cost per hectare, farmgate price, crop yield per hectare, and the number of cropping seasons for each selected crop. Moreover, electricity rates for households serviced by Manila Electric Company (Meralco) were used to compute the electricity consumption of adopting the technologies. Lastly, percent changes in crop yield, water usage, and labor were obtained from the official website of Netafim (a manufacturer of drip irrigation systems) for adopting a drip irrigation system and from published papers for adopting AWD.

***Data Analysis***

Ex-ante CBA, rather than ex-post CBA, was performed because the technology packages are yet to be deployed in actual settings. The commonly used decision criteria in determining the financial viability of a project include a benefit-cost ratio (BCR), net present worth (NPW), payback period (PP), and internal rate of return (IRR). In this study, the methods employed are BCR, NPW, PP, and modified IRR (MIRR) instead of IRR.

IRR, though commonly used as a method in determining the feasibility of a project, has its drawbacks (Hayes, 2022). For projects with alternating positive and negative cash flows, there can be at least two IRRs. Therefore, MIRR is used instead to solve the problem of multiple IRRs (Hayes 2022, Kierulff 2008). Moreover, MIRR more accurately reflects the cost and profitability of a project than IRR because MIRR assumes that cash flows are reinvested at the cost of capital and not the IRR itself, which is unrealistic (Kierulff 2008).

Computing for BCR, NPW, MIRR, and PP entails the projection of cash flows throughout the project duration with and without the technology package. Cash flows to be projected include the cost, benefit, discounted cost, discounted benefit, and net benefit gained per year. Discounted costs, discounted benefits, and net benefits were computed using Equations (1), (2), and (3), respectively. Afterward, the BCR and NPW were manually computed using Equations (4) and (5), respectively.

$$DC_t = C_t \left[\frac{1}{(1+r)^t}\right] \tag{1}$$

$$DB_t = B_t \left[\frac{1}{(1+r)^t}\right] \tag{2}$$

$$NB_t = (DBWP_t - DBWOP_t) - (DCWP_t - DCWOP_t) \tag{3}$$

$$BCR = \frac{\sum_{t=1}^{T}(DBWP_t - DBWOP_t)}{\sum_{t=1}^{T}(DCWP_t - DCWOP_t)} \tag{4}$$

$$NPW = \sum_{t=1}^{T} NB_t \tag{5}$$

where

| | | |
|---|---|---|
| $DC_t$ | = | discounted cost at time *t* (PhP) |
| $DB_t$ | = | discounted benefit at time *t* (PhP) |
| $NB_t$ | = | net benefit at time *t* (PhP) |
| $BCR$ | = | benefit-cost ratio |
| $NPW$ | = | net present worth (PhP) |
| $C_t$ | = | cost at time *t* (PhP) |
| $B_t$ | = | benefit at time *t* (PhP) |
| $DBWP_t$ | = | discounted benefit with technology package at time *t* (PhP) |
| $DBWOP_t$ | = | discounted benefit without technology package at time *t* (PhP) |
| $DCWP_t$ | = | discounted cost with technology package at time *t* (PhP) |
| $DCWOP_t$ | = | discounted cost without technology package at time *t* (PhP) |
| $r$ | = | discount rate (decimal form) |
| $t$ | = | time at which the cash flow is observed (years) |
| $T$ | = | duration of project (years) |

The MIRR was computed using the MIRR function of Microsoft Excel. On the other hand, the PP was determined by computing for the fractional year at time *t* at which the cumulative cash flow equals the initial investment or becomes positive and adding the number of years preceding time *t*.

In interpreting BCR, NPW, and MIRR values, the technology package can be reckoned financially viable if the following decision criteria are considered true: (1) NPW is positive, (2) BCR is greater than one, and (3) MIRR is greater than the applicable discount rate. All three financial indicators usually agree; however, there are instances wherein the computed MIRR value deviates from this agreement, i.e., NPW is positive, and BCR is greater than one, but MIRR is less than the discount rate. When the investment and reinvestment rates are different from the discount rate, MIRR is the better financial indicator because "it directly accounts for the reinvestment of the cash flows at the different rate" (Kierulff 2008, p. 327). Contrariwise, when the investment and reinvestment rates are equal to the discount rate, MIRR is just the equivalent percentage form of the NPW.

After determining the financial viability of the four technology packages for selected crop productions in a one-hectare land, the minimum area beyond which the technologies become financially viable was also computed.

## Results and Discussion

***General Assumptions***

The cost-benefit analysis was based on the following simplifying but realistic assumptions:

- The economic life of the project is ten years, which is the expected service life of the sensors, particularly the high-end type. While the service life of low-cost sensors is shorter, the same period was used for this type for proper comparative analysis by allowing the necessary sensor replacements within this period.
- Each WSN technology package will be operating on a one-hectare land. For upland crop production systems, it was assumed that a one-hectare land is composed of 16 plots, each equaling 20-by-20 meters. On the other hand, for lowland crop production systems, it was assumed that a one-hectare land is composed of six plots, each equaling 47-by-31 meters.
- The selected crops for determining the financial viability of the technology packages include sweet corn, tomato, eggplant, ampalaya, cabbage, cauliflower, red onion, bell pepper, hot pepper, and irrigated rice. Among the selected crops, irrigated rice is the only lowland crop because it is grown in flooded conditions, opposite of the upland crops. The choice of the crop was based on whether it is high yielding, has a high farmgate price, or if it is a major crop in the Philippines.
- Production costs and returns for each crop were based on data published by PSA (2021a, 2021b) and DA-BPI (Mariano and Jimenez n.d.).
- An electricity rate equal to PhP 9.773/kWh (Rey 2021) was used to compute the electrical power consumption in operating the technologies.
- The farmer or farm owner already has the necessary farm tools and equipment, and irrigation structures have already been established.
- Parts, tools, and equipment shall be replaced at the end of their useful life.
- Additional costs due to damage or loss of any component of a WSN technology package were not accounted for. However, system troubleshooting shall be done by the project staff once a year for ten years for each WSN technology package installed.
- The use of a drip irrigation system increases crop yield by 40% and decreases water usage by 50% and labor by 30% (Netafim n.d.).
- On the other hand, the use of AWD increases rice yield by 25% and decreases water usage by 30% and labor by 30% (Lampayan *et al.* 2009, Rejesus *et al.* 2011, Viandar *et al.* 2020, Yang *et al.* 2007, Yao *et al.* 2012).
- The adoption of WSN was assumed to decrease labor by 20%.
- A discount rate of 12% was used to reflect the opportunity cost of the capital. This rate is midway between the previous discount rate of 15% and the current discount rate of 10% set by the National Economic and Development Authority (NEDA 2016).
- The financing rate was assumed to be 12%, whereas the reinvestment rate was assumed to be equal to 20% (Kriya Finance Limited 2022), which were used to compute for the MIRR.

***Cost-benefit Analysis***

After projecting the cash flows for each combination of technology package and crop production, the BCR, NPW, MIRR, and PP were computed. The computed values for BCR, NPW, MIRR, and PP for each combination of technology package and crop production are shown in Table 1.

**Table 1. Summary of benefit-cost ratio (BCR), net present worth (NPW), modified internal rate of return (MIRR), and payback period (PP) for adopting high-end and low-cost WSN technologies with drip irrigation system/AWD in a one-hectare land using 12% discount rate**

| Crop | High-end WSN Technologies | | | | Low-cost WSN Technologies | | | |
|---|---|---|---|---|---|---|---|---|
| | BCR | NPW (PhP) | MIRR (%) | PP (yr) | BCR | NPW (PhP) | MIRR (%) | PP (yr) |
| Sweet corn | 0.06 | (5,399,897) | -23.93 | indef. | 0.19 | (1,505,699) | -15.51 | indef. |
| Tomato | 0.52 | (2,457,996) | 4.52 | indef. | 2.14 | 1,436,202 | 23.91 | 2.20 |
| Eggplant | 0.42 | (3,166,991) | 1.20 | indef. | 1.47 | 727,207 | 19.57 | 3.60 |
| Ampalaya | 0.72 | (1,531,984) | 7.84 | indef. | 2.55 | 2,362,214 | 27.58 | 1.55 |
| Cabbage | 0.31 | (3,887,549) | -3.39 | indef. | 1.00 | 6,649 | 12.94 | 9.94 |
| Cauliflower | 0.50 | (2,864,460) | 2.84 | indef. | 1.57 | 1,029,738 | 21.30 | 2.92 |
| Red onion | 1.22 | 1,187,691 | 14.16 | 7.11 | 4.65 | 5,081,889 | 35.41 | 0.82 |
| Bell pepper | 5.20 | 19,514,965 | 30.99 | 1.31 | 32.26 | 23,409,163 | 56.46 | 0.21 |
| Hot pepper | 3.59 | 13,281,423 | 27.17 | 1.81 | 14.96 | 17,175,621 | 51.51 | 0.29 |
| Irrigated rice | 0.20 | (869,046) | -5.02 | indef. | 3.44 | 156,868 | 37.87 | 0.76 |

Note: indef. means indefinite

Based on the results of the CBA, adopting the high-end WSN technology with a drip irrigation system or AWD in the production of the selected crops for a one-hectare land is infeasible except for red onion, bell pepper, and hot pepper. In general, adopting the technology package in the production of most of the crops will result in a net loss for the farmer or farm owner as indicated by the BCR values that are less than one, negative NPW values, and MIRR values much less than the discount rate of 12%, thus indefinite payback periods which are due to negative cumulative net benefits throughout the ten-year duration.

Conversely, adopting low-cost WSN technology with a drip irrigation system or AWD in the production of the selected crops for a one-hectare land is feasible except for sweet corn. The BCR values for all crop productions are greater than one, meaning the technologies' benefits outweigh the costs except for sweet corn production. The NPW values are also positive, indicating that the earnings are greater than the initial investment. Furthermore, MIRR values greater than the discount rate of 12% suggest that adopting the technologies is acceptable.

Among the combinations of technology packages and crop productions, the most profitable scenario based on the analysis is adopting the low-cost WSN technology with a drip irrigation system in the production of bell pepper for a one-hectare land. It garnered the highest BCR, NPW, and MIRR values. In addition, its initial investment can be recovered in less than three months from the start of the project.

To address economies of scale, the minimum area for a chosen crop beyond which the WSN technology package becomes financially viable was also determined. Results are shown in Table 2.

**Table 2. Summary of the minimum area beyond which the WSN technology packages become financially viable for various crops and the corresponding benefit-cost ratio (BCR), net present worth (NPW), modified internal rate of return (MIRR), and payback period (PP)**

| Crop | Min. Area (ha) | Equiv. No. of Plots | BCR | NPW (PhP) | MIRR (%) | PP (yr) |
|---|---|---|---|---|---|---|
| | **High-end WSN Technologies** | | | | | |
| Sweet corn | - | - | n/a | n/a | n/a | n/a |
| Tomato | - | - | n/a | n/a | n/a | n/a |
| Eggplant | - | - | n/a | n/a | n/a | n/a |
| Ampalaya | 5.00 | 80 | 1.03 | 535,427 | 12.00 | 9.56 |
| Cabbage | - | - | n/a | n/a | n/a | n/a |
| Cauliflower | - | - | n/a | n/a | n/a | n/a |
| Red onion | 0.69 | 11 | 1.04 | 161,702 | 12.27 | 9.41 |
| Bell pepper | 0.13 | 2 | 1.33 | 740,982 | 15.99 | 5.43 |
| Hot pepper | 0.19 | 3 | 1.33 | 852,380 | 15.97 | 5.47 |
| Irrigated rice | - | - | n/a | n/a | n/a | n/a |
| | **Low-cost WSN Technologies** | | | | | |
| Sweet corn | - | - | n/a | n/a | n/a | n/a |
| Tomato | 0.44 | 7 | 1.02 | 25,172 | 12.96 | 9.69 |
| Eggplant | 0.63 | 10 | 1.07 | 92,693 | 13.93 | 8.95 |
| Ampalaya | 0.38 | 6 | 1.07 | 97,108 | 13.90 | 8.94 |
| Cabbage | 1.00 | 16 | 1.00 | 6,649 | 12.94 | 9.94 |
| Cauliflower | 0.56 | 9 | 1.06 | 85,226 | 13.75 | 9.10 |
| Red onion | 0.25 | 4 | 1.20 | 271,598 | 16.10 | 4.99 |
| Bell pepper | 0.06 | 1 | 1.21 | 263,123 | 16.30 | 4.89 |
| Hot pepper | 0.13 | 2 | 1.76 | 991,191 | 22.89 | 2.53 |
| Irrigated rice | 0.50 | 3 | 1.38 | 30,238 | 26.08 | 1.84 |

Note: n/a means not applicable

For upland crop production systems, the smallest unit that was used in determining the minimum area at which the WSN technology packages became financially viable is one plot of land which corresponds to 1/16th of one-hectare for upland crop production systems, and 1/6th of one-hectare for lowland crop production systems.

Results of the analysis showed that the high-end WSN technology packages are infeasible for all selected crop productions regardless of the farm size; thus, no minimum area was computed except for ampalaya, red onion, bell pepper, and hot pepper. On the contrary, the low-cost WSN technology packages enabled the determination of the minimum viable area except for sweet corn.

The least minimum area at which the high-end WSN technology packages become financially viable is 0.13 ha (2 plots of 20-by-20 meters) for bell pepper production. However, hot pepper production garnered the highest NPW value with a minimum area of 0.19 ha (3 plots of 20-by-20 meters), second only to bell pepper production. For low-cost WSN technology packages, the least minimum area is 0.06 ha (1 plot of 20-by-20 meters) for bell pepper production. Likewise, hot pepper production also garnered the highest NPW value with a minimum area of 0.13 ha (2 plots of 20-by-20 meters).

The high returns acquired from bell pepper and hot pepper productions may be attributed not only to their high farmgate price but also to their higher cropping intensity or frequency of cropping and harvests in a year. Based on this data, it is recommended to use WSN technologies for high-value crops that can be grown and harvested multiple times a year, i.e., with a short maturity period, to generate more profit when adopting the WSN technology packages.

It should be noted, however, that costs incurred from damage or loss of any component of the WSN technology packages due to unforeseen circumstances were not considered in the analysis. Nevertheless, it is worthwhile to anticipate the potential risks caused by these unforeseen circumstances and determine the possible effects of these risks on the financial viability of the WSN technology packages.

A primary example of an unforeseen risk is equipment damage or loss due to debris hitting the WSN technology during a severe storm with strong winds. Another more probable cause of equipment damage or loss is contact with fire. At the same time, other hazards may be human-induced (e.g., accidentally damaging the equipment during land preparation or getting any of the WSN technology components stolen). The risk of damage or loss of any components of the WSN technology packages will only result in more costs for the farmer or farm owner and thus affect the financial viability of the WSN technology packages. When these costs become enormous, the WSN technology packages may become infeasible for some selected crop productions. Therefore, it is important to take into account the risks and be able to identify means to efficiently and effectively address them. Risk assessment is beyond the scope of this study, but it is recommended to be done in a separate study.

***Sensitivity Analysis***

<u>Using Higher Discount Rates</u>

The analysis performed in the previous section constitutes the base case scenario of adopting the four WSN technology packages. However, when the discount rate increases, the present worth of future cash flows decreases. Hence, analysis of the feasibility of adopting the technologies using higher discount rates was performed. This could also help farmers and farm owners make proper WSN technology adoption decisions.

The effect of using higher discount rates on the financial viability of the technology packages was determined through sensitivity analysis. Discount rates greater than 12% (i.e., 13%, 14%, and 15%) were used while keeping all other factors constant. The results in terms of feasibility or infeasibility of both the high-end and low-cost WSN technology packages at different discount rates are summarized in Table 3.

**Table 3. Feasibility of the WSN technology packages using different discount rates**

| Crop | High-end WSN Technologies | | | | Low-cost WSN Technologies | | | |
|---|---|---|---|---|---|---|---|---|
| | **12%** | **13%** | **14%** | **15%** | **12%** | **13%** | **14%** | **15%** |
| Sweet corn | N | N | N | N | N | N | N | N |
| Tomato | N | N | N | N | Y | Y | Y | Y |
| Eggplant | N | N | N | N | Y | Y | Y | Y |
| Ampalaya | N | N | N | N | Y | Y | Y | Y |
| Cabbage | N | N | N | N | Y | N | N | N |
| Cauliflower | N | N | N | N | Y | Y | Y | Y |
| Red onion | Y | Y | N | N | Y | Y | Y | Y |
| Bell pepper | Y | Y | Y | Y | Y | Y | Y | Y |
| Hot pepper | Y | Y | Y | Y | Y | Y | Y | Y |
| Irrigated rice | N | N | N | N | Y | Y | Y | Y |

Note: Y means feasible, while N means infeasible

Based on the results, the high-end WSN technology packages proved to be infeasible for most crops except hot pepper and bell pepper, up to a discount rate of 15%, and red onion, up to a discount rate of 13%. On the other hand, the low-cost WSN technology packages in the production of the selected crops for a one-hectare land are still feasible at 13%, 14%, and 15% discount rates except for sweet corn and cabbage.

At higher discount rates, the BCR, NPW, and MIRR values are expected to decrease. The NPW values computed using the original discount rate of 12% decreased largely at the 15% discount rate, thus becoming infeasible for most crops.

Using Less Sensor Stations per Hectare

Results of the preceding analysis imply that even at higher discount rates, the low-cost WSN technology packages are still feasible for most high-value crops compared to the high-end WSN technology packages. Therefore, in the interest of making the high-end WSN technology packages feasible for more crop productions, further analysis was performed to determine the effect of reducing investment costs by using fewer sensor stations on the viability of the technologies.

Among all the components of a high-end WSN technology package, the sensor stations make up the greatest portion of investment cost due to the expensive soil moisture sensors and a large number of sensor stations to be deployed in a one-hectare land. Based on the proposed package of high-end WSN technology, a one-hectare land for upland crop production systems will be installed with 16 sensor stations corresponding to its 16 plots. In contrast, a one-hectare land for lowland crop production systems will be installed with 6 sensor stations corresponding to its 6 plots.

However, because of the flexible nature of WSN technologies, it is possible to add or remove components from the initially proposed packages of WSN technology to cater to the needs of the client. In this case, the number of sensor stations per hectare can be reduced to lower the investment cost.

For upland crop production systems, the number of sensor stations per hectare was reduced from 16 to 8 stations and 4 stations. On the other hand, the number of sensor stations per hectare for lowland crop production systems was not reduced because each plot needs at least one sensor station; hence, this was not included in the sensitivity analysis. The feasibility of the modified technology packages for upland crop production systems was determined using the same methods (BCR, NPW, MIRR, and PP) for the same factors used in the base case scenario. Moreover, the minimum area at which the modified technology packages become financially viable was also determined.

A summary of the computed values for BCR, NPW, MIRR, and PP for each scenario is shown in Table 4. The minimum areas beyond which the modified technology packages become financially viable for various crops and the corresponding BCR, NPW, MIRR, and PP values are summarized in Table 5.

**Table 4. Summary of benefit-cost ratio (BCR), net present worth (NPW), modified internal rate of return (MIRR), and payback period (PP) of adopting high-end WSN with drip irrigation system using 8 sensor stations and 4 sensor stations for each crop production in a one-hectare land using 12% discount rate**

| Crop | 8 Sensor Stations | | | | 4 Sensor Stations | | | |
|---|---|---|---|---|---|---|---|---|
| | BCR | NPW (PhP) | MIRR (%) | PP (yr) | BCR | NPW (PhP) | MIRR (%) | PP (yr) |
| Sweet corn | 0.08 | (4,202,817) | -21.97 | indef. | 0.09 | (3,604,277) | -20.73 | indef. |
| Tomato | 0.68 | (1,260,916) | 7.43 | indef. | 0.80 | (662,376) | 9.30 | indef. |
| Eggplant | 0.54 | (1,969,911) | 4.02 | indef. | 0.63 | (1,371,371) | 5.82 | indef. |
| Ampalaya | 0.92 | (334,904) | 10.81 | indef. | 1.07 | 263,636 | 12.71 | 8.92 |
| Cabbage | 0.40 | (2,690,469) | -0.72 | indef. | 0.46 | (2,091,929) | 0.98 | indef. |
| Cauliflower | 0.63 | (1,667,380) | 5.68 | indef. | 0.73 | (1,068,840) | 7.50 | indef. |
| Red onion | 1.58 | 2,384,771 | 17.31 | 4.70 | 1.85 | 2,983,311 | 19.32 | 3.81 |
| Bell pepper | 7.01 | 20,712,045 | 34.64 | 0.96 | 8.48 | 21,310,585 | 36.98 | 0.81 |
| Hot pepper | 4.69 | 14,478,503 | 30.69 | 1.33 | 5.53 | 15,077,043 | 32.95 | 1.09 |

**Table 5. Summary of the minimum area beyond which the modified technology packages became financially viable for various crop productions and the corresponding benefit-cost ratio (BCR), net present worth (NPW), modified internal rate of return (MIRR), and payback period (PP)**

| Crop | Min. Area (ha) | Equiv. No. of Plots | BCR | NPW (PhP) | MIRR (%) | PP (yr) |
|---|---|---|---|---|---|---|
| | **8 Sensor Stations** | | | | | |
| Sweet corn | - | - | n/a | n/a | n/a | n/a |
| Tomato | 3.50 | 56 | 1.03 | 299,656 | 12.05 | 9.53 |
| Eggplant | - | - | n/a | n/a | n/a | n/a |
| Ampalaya | 1.31 | 21 | 1.02 | 93,924 | 12.01 | 9.71 |
| Cabbage | - | - | n/a | n/a | n/a | n/a |
| Cauliflower | 7.38 | 118 | 1.03 | 568,302 | 12.02 | 9.54 |
| Red onion | 0.50 | 8 | 1.05 | 144,649 | 12.49 | 9.27 |
| Bell pepper | 0.13 | 2 | 1.42 | 890,617 | 17.06 | 4.75 |
| Hot pepper | 0.13 | 2 | 1.02 | 45,935 | 12.30 | 9.65 |
| | **4 Sensor Stations** | | | | | |
| Sweet corn | - | - | n/a | n/a | n/a | n/a |
| Tomato | 1.69 | 27 | 1.03 | 132,734 | 12.10 | 9.57 |
| Eggplant | 4.25 | 68 | 1.03 | 293,572 | 12.07 | 9.52 |
| Ampalaya | 0.94 | 15 | 1.02 | 78,792 | 12.12 | 9.65 |
| Cabbage | 0.00 | 0 | n/a | n/a | n/a | n/a |
| Cauliflower | 2.38 | 38 | 1.02 | 138,755 | 12.02 | 9.65 |
| Red onion | 0.44 | 7 | 1.03 | 89,087 | 12.35 | 9.48 |
| Bell pepper | 0.13 | 2 | 1.42 | 890,617 | 17.06 | 4.75 |
| Hot pepper | 0.13 | 2 | 1.02 | 45,935 | 12.30 | 9.65 |

Note: n/a means not applicable

When the number of sensor stations per hectare of the upland high-end WSN technology package was reduced, the technology package is still infeasible for the majority of selected crop productions. However, aside from red onion, bell pepper, and hot pepper, the modified technology package using 4 sensor stations per hectare also became feasible for ampalaya.

Among the combinations of the modified technology packages and crop productions, using 4 sensor stations per hectare in the adoption of the upland high-end WSN technology package for bell pepper production is the most profitable scenario based on the sensitivity analysis, garnering the highest BCR and NPW values.

On the other hand, the determination of the minimum area at which each modified technology package becomes feasible was possible for all selected crop productions except for sweet corn, eggplant, and cabbage using 8 sensor stations, and sweet corn and cabbage using 4 sensor stations. Furthermore, the least minimum area at which both the modified technology packages become financially viable is 0.13 ha (2 plots of 20-by-20 meters) for bell pepper and hot pepper productions, with bell pepper production garnering the highest BCR and NPW values in both scenarios.

Based on the results of the sensitivity analysis, reducing the number of sensor stations per hectare of the upland high-end WSN technology package as well as increasing the minimum cropping area could potentially make the technology package more financially viable for the majority of selected crops. However, reducing the number of sensor stations per hectare may lead to inaccurate monitoring of soil moisture content in a one-hectare land.

It should be noted that two soil moisture sensors (corresponding to two soil depths) are connected to one sensor station. Although there is no established standard for the number of soil moisture sensors that should be installed for a specific crop, it is reasonable to install more than one soil moisture sensor for crops that are deep-rooted to account for depth variabilities of soil moisture. This was also suggested by Shortt *et al.* (2011). Moreover, the number of sites at which soil moisture sensors are installed will depend on the degree of heterogeneity of soil across fields (Zotarelli *et al.* 2013). For a field as large as one hectare, the soil tends to be heterogeneous across the one-hectare land, which requires more soil moisture sensors and more sensor stations to be installed.

Using 16 sensor stations per hectare may seem excessive. Still, the one-to-one ratio of sensor station to plot was set as the minimum requirement to ensure the reliability of soil moisture measurement for the one-hectare land. Using less than 16 sensor stations per hectare decreases the reliability of soil moisture measurement, which may lead to over-irrigation or under-irrigation and, consequently, a decrease in crop quality, crop yield, and profit.

Ultimately, further field testing and data analysis are needed to more accurately quantify the impact of reducing the number of sensor stations per hectare on crop productivity and irrigation efficiency, the outcomes of which would help in identifying other possible methods to make the high-end WSN technology packages feasible to more crops without compromising crop productivity and irrigation efficiency aside from increasing the volume of production.

## Summary and Conclusion

To assess the financial viability of the four WSN technology packages developed under the PCARI-WiSEIr Project, namely (1) upland high-end WSN technology package, (2) upland low-cost WSN technology package, (3) lowland high-end WSN technology package, and (4) lowland low-cost WSN technology package, an ex-ante cost-benefit analysis was performed in this study. Sensitivity analysis under higher discount rates and cost reduction scenarios was also performed.

Results of the CBA suggest that adopting the high-end WSN technology packages is generally infeasible for most of the selected agricultural crops, whereas adopting the low-cost WSN technology packages is feasible for most of the selected crops except for sweet corn at a 12% discount rate in a one-hectare land for a ten-year period. Results of the sensitivity analysis indicate that discount rates higher than 15% generally reduce the viability of the high-end WSN technology packages for most of the selected crops except for hot pepper and bell pepper. At a discount rate of higher than 13%, red onion becomes infeasible. However, the low-cost WSN technology packages still proved viable with increasing discount rates of up to 15%, except for cabbage and sweet corn. Moreover, decreasing the investment cost of the upland high-end WSN technology package by reducing its number of sensor stations per hectare hardly made the technology package feasible for the selected crops. However, increasing the volume of production by increasing the minimum area of land (more than one hectare) made the technology package feasible for almost all selected crops. In addition, growing high-value crops that can be harvested multiple times a year could help generate more profit. Hence, concurrently decreasing inputs in terms of costs and increasing outputs in terms of crop yield and profit could potentially make the upland high-end WSN technology package feasible for high-value crop production systems under the assumption that market prices of yield remain the same. The results of this study may also serve as useful information to supplement the study on assessing the potential for adoption of the WSN technology packages for high-value crop production in the Philippines.

## Recommendations

Based on this study, more profit can be generated in producing high-value crops grown and harvested multiple times a year. However, it should be noted that the CBA was performed on the assumption that only one type of crop was grown in the field (monoculture) year after year (monocropping). Both monoculture and monocropping are not sustainable as they can aggravate pest and disease problems, soil nutrient loss, natural resource degradation, and vulnerability to climate change. Therefore, it is recommended to use other sustainable farming methods such as growing more than one type of crop in the same field (intercropping) and growing a different type of crop in the succeeding year (crop rotation). Further analysis should be conducted to determine the profitability of adopting the WSN technologies for each combination of crops under various sustainable farming systems.

Moreover, despite the appealing features of the WSN technology, its high capital requirement may immediately discourage potential adopters. To partly address this potential problem, access to credit by Filipino farmers and farm owners should be further improved to enable them to finance the needed costs associated with the use of the WSN technology. More importantly, the government may provide subsidies and incentives to farmers who will adopt the WSN technology. After all, this technology has the potential to increase crop yield and efficiency of irrigation water management and is therefore aligned with and supportive of the government's goal of food security and sustainable water resources management, particularly under water-scarce conditions like during the occurrence of El Niño.

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