DLSU Business & Economics Review 28(2018), pp. 121–146

RESEARCH ARTICLE

Philippine Irrigation Investment Under Climate Change: Scenarios, Economic Returns, and Impacts on Food Security

Nicostrato Perez, Mark W. Rosegrant
International Food Policy Research Institute (IFPRI)
n.perez@cgiar.org

Arlene Inocencio
De La Salle University, Manila, Philippines

Abstract: Three broad strategies in the agricultural water sector can be used to address the challenge posed by climate change: (1) increasing the supply of water for irrigation through investment in infrastructure; (2) conserving water and improving the efficiency of water use in existing systems; and (3) improving crop productivity per unit of water and land through integrated water management and agricultural research and policy efforts (Rosegrant, 2015). This paper analyzes in detail the first strategy for the Philippines, together with a brief comparison with the third strategy. The alternative irrigation investment scenarios also assess different regional allocation rules, expansion targets, and investment costs. Results show that on all the economic and food security outcomes, at the lower irrigation cost estimate of US$3,500/ha, irrigation development has a higher positive impact compared with investment in varietal and seed development and farm level technology. But at higher irrigation cost levels, the varietal and seed and farm level technologies can have higher rates of return, and it would be preferable to shift some of the investment to these other development strategies. If the costs of new irrigation can be kept relatively low, faster irrigation development would make a major contribution to agricultural development and food security in the Philippines.

Keywords: climate change, irrigation investment, adaptation strategy, food security

JEL Classifications: Q54, Q15, Q18, H54

Agriculture—which accounts for one-third of employment—remains a key sector in the Philippines. Historically, low agricultural productivity growth has hindered economic growth and progress on food security. Climate change has the potential to further disrupt crop productivity, and in turn affect agricultural production, consumption, and food security. A primary area where climate change impacts will be felt is through changes in water resources (Water Environment Partnership in Asia, 2012). Water risks such as shortages, flooding, poor quality, and disruptions to freshwater ecosystems are expected to increase. Expansion of irrigation has the potential to contribute significantly to climate change adaptation.

Irrigation systems have the dual functions of increasing effective land area and agricultural land productivity. Agricultural land area is increased two ways, one by opening-up of new lands to agriculture and by increasing the cropping intensity of rainfed areas. Productivity is also increased through intensified cropping and by subsequent switch from low-yield rainfed production to high-yield irrigated production technology. Hence, as irrigated area increases, the average yields of total cultivated area—the sum of irrigated and rainfed—also increases.

Increased water risks and growing uncertainty about future conditions exacerbate existing water security challenges, and will have implications on planning, management, and investment decisions. Adapting to new circumstances will require better informed investment strategies and adaptive water governance that considers climate variability and minimizes potentially costly mismatches between water systems and the future climate. As a response, the Department of Agriculture (DA) is in the process of integrating climate change into its programs to protect and optimize agricultural production. This process could potentially increase investments on specific types of projects, although current changes in allocations for agricultural water appear nominal.

Irrigation development has the potential to be an effective investment strategy for countries with limited land areas, like the Philippines, to expand the agricultural land area and increase productivity, while reducing the impacts of climate change and variability. Alone or in combination with other adaptation technologies, it can also serve as a primary investment tool for countering the negative impacts of climate change and in accomplishing one of the country's vision statements for 2040—a population free of hunger and poverty ("AmBisyon natin 2040", 2016). With the passage of Republic Act 9729 or the Climate Change Act of 2009, climate change was mainstreamed in policy formulation.

This paper presents trends and patterns in water resource investments, programs, and projects, in the agriculture sector, and then assesses the potential impacts and rates of return to future investments in irrigation under climate change through the modeling of alternative scenarios. It concludes with policy discussions.

Public Investment in Irrigation

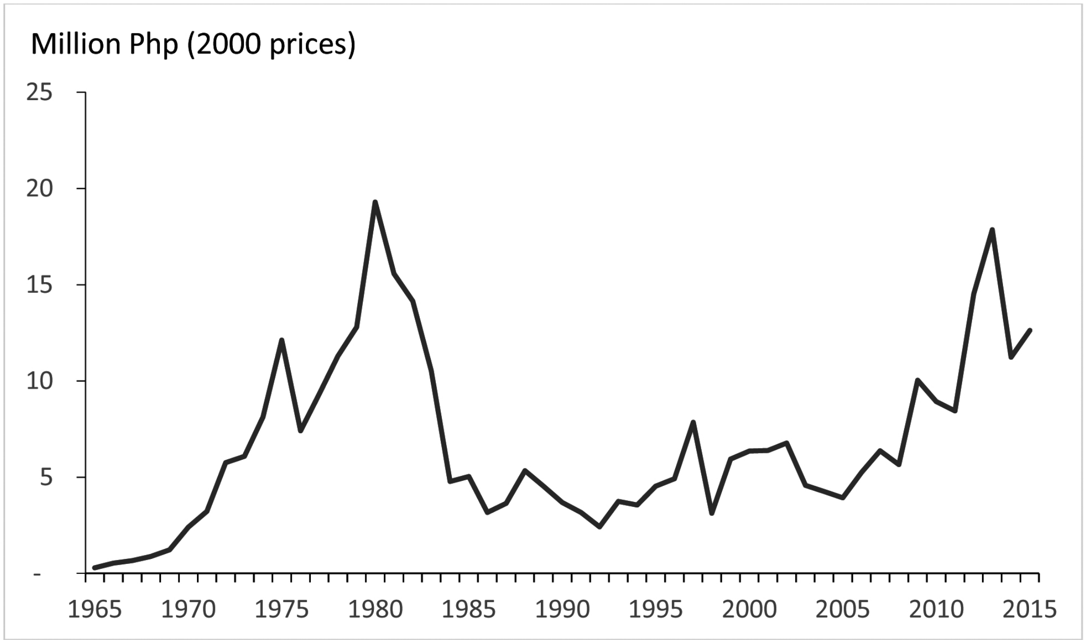
Though irrigation systems have been historically part of the country's agricultural landscape for centuries, it was during the early decades of the Green Revolution in the 1970s that public expenditures for irrigation reached a high peak, accounting for nearly 20% of total public investments in infrastructure and 40% of public support to the agriculture sector. During this period, it was also a major recipient of foreign loans and grants (David & Inocencio, 2012).

During this period, growth in irrigation development was also highest. Irrigated area more than doubled from 1964 to 1980 (396,000 to 934,000 hectares [ha]), adding 538,000 ha and registering an annual growth rate of 5.7%. The following two decades (1980–2000), which added 427,000 ha to irrigated lands, growth declined to 1.6%—and continuing with similar annual growth pathway of 1.7% for the last 15 years (2000–

Table 1. *Growth Rates of Irrigation Development, 1964–2015*

Years	National Irrigation System	Communal Irrigation System	Private or OGA* Irrigation	Total	Annual Growth Rates
	000 ha				%
1964 to 1980	218	126	52	396	5.7
	472	310	152	934	
1980 to 2000	472	310	152	934	1.6
	686	501	174	1,361	
2000 to 2015	686	501	174	1,361	1.7
	755	616	361	1,731	

*Note: * OGA means Other Government Agencies' assisted irrigation system; ha = hectare.*
Source: Appendix Table A1 and Authors' computations



Sources: NIA Yearend Report, various years.

Figure 1. Trends in public investments in irrigation in real terms, 1965–2015.

2015). The current irrigated land area stands at 1.731 million ha equivalent to 57.3% of estimated irrigable lands in the country (Table 1 and Appendix Table A1, from NIA Year-end Reports, various years).

Irrigation has been historically the biggest public expenditure item in agriculture. In the 1970s and 1980s, public expenditures for irrigation accounted for about 45% of total public expenditures for agriculture and 12% of total infrastructure development (David & Inocencio, 2012). Since the late 1980s, the relative importance of irrigation in public agriculture spending declined by more than half, while the ratio to total infrastructure spending fell to about 6%. In recent years, its share to public expenditures for agriculture rose again to nearly 30%, and to about 10% of total infrastructure. The relative importance of irrigation as a policy instrument is even higher within the rice sector—as publicly supported irrigation is primarily for surface gravity systems suited for rice cultivation, and the rice sector accounts for at least two-thirds of public expenditure for agriculture. In 2012, the total public expenditures for irrigation reached ₱28 billion with 87% for capital outlays and the rest for corporate expenditures. From 1976 to 2012, capital outlays averaged 85% of total public expenditures for irrigation.

Figure 1 presents the trends in total public expenditures for irrigation investments in 2000 prices. Over the past four decades, public expenditures for irrigation capital outlays have been characterized by wide fluctuations, rising in the 1970s, dropping drastically in 1983, and recovering to some extent in the early 1990s. The sharp increase in the world rice prices in the 1970s, together with the introduction of modern rice varieties suited to irrigated conditions, raised the marginal rates of returns for irrigation investments.

As world commodity prices declined, yields of modern rice varieties leveled off, the cost of irrigation expansion increased, and public expenditures for irrigation declined. Investments began to rise again in 2008 as a response to the increase in world rice prices in 2007. This trend continues with the present administration's food self-sufficiency program. More systematic analyses indicate that levels of public investments respond to short-run changes in world rice prices as these affect marginal rates of returns to irrigation investments and adoption of rice self-sufficiency instead of consideration of long-term benefits and costs (Hayami & Kikuchi, 1978; Azarcon, Barker, & Associates, 1992; Kikuchi, Maruyama, & Hayami, 2003).

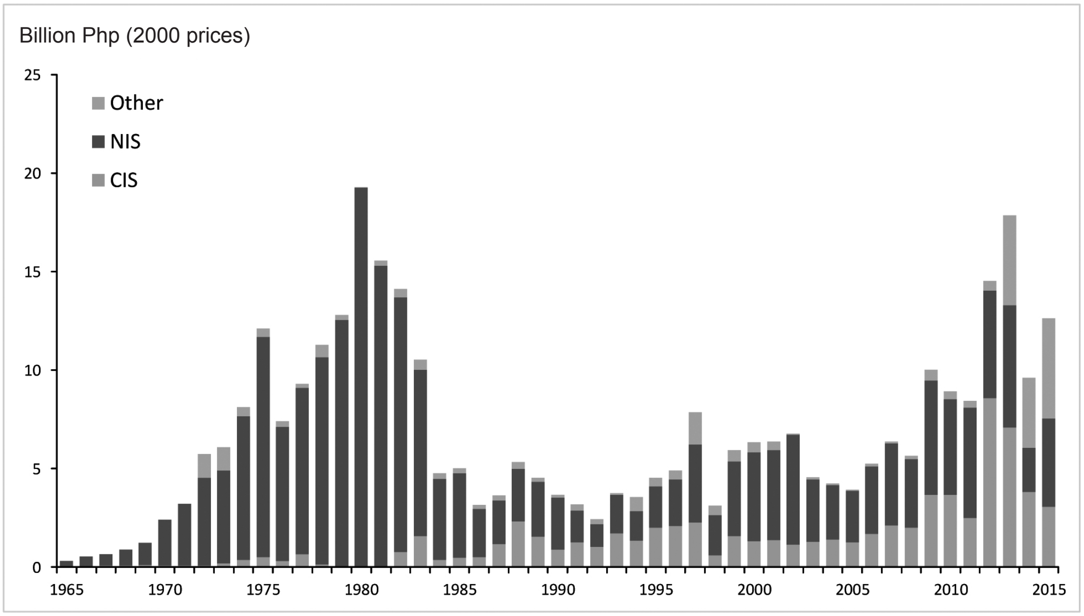


Figure 2. Trends in irrigation investments by type of irrigation projects, 1965–2015.

Types of Agriculture Water Projects and Systems

Public investment by type of project and systems shows where the priorities have been. Over the past four decades, approximately 85% of public expenditures for irrigation investments have been allocated for the construction, rehabilitation, restoration, repairs, and support services of national irrigation systems (NIS); only 12% for communal irrigation systems (CIS); and 3% for small water impounding projects (SWIPs), tubewells, and other individual systems (Figure 2). The share of NIS in total public support for irrigation is higher when the costs of operation and maintenance (O&M) and other support services funded from corporate revenues are included. Even if the budgets for shallow tubewells, SWIPs, and small farm reservoirs allocated by the Bureau of Soils and Water Management and other agencies were included, public expenditures for this type of irrigation will not reach 5%of total.

Budgetary resources for the expansion and rehabilitation of CIS have increased, but there is no data to evaluate the effects of these expenditures on the performance of the systems. The fact that many locally-funded CIS projects have been implemented with Congressional pork barrel and local government units' funds may partly explain the slow growth in irrigated areas. Anecdotal evidence indicates that many CIS have disbanded and are now operated as individual or private systems (Panella, 2004; Euroestudios Ingenieros de Consulta, 2006).

Up to the early 1980s, about 95% of public expenditures for irrigation were allocated for NIS. The share of CIS began to increase by the mid-1980s as donor agencies focused on poverty reduction and the government embarked on the Comprehensive Agrarian Reform Program in 1988. The CIS share to total irrigation investments rose from an average of less than 5% in the 1970s, up to more than 40% in early 1990s. Foreign assisted communal projects were typically part of the integrated area development projects (e.g. Palawan Integrated Development Projects and the Southern Philippines Irrigation Sector Project) and agrarian reform related projects. Local funding for communal projects had been mostly sourced from the Agrarian Reform Funds.

During the late 1990s, the share of the NIS in irrigation investments increased again, despite the passage of the Agriculture and Fisheries Modernization Act in 1997, which directed increased public support for small-scale irrigation systems and groundwater resources development. But the amount and share of investment in CIS has again expanded substantially in recent years.

In recent years, the National Irrigation Administration (NIA) has recomputed service area in terms of "firmed-up service area". It is equal to the Service Area (or command area) less land converted from agricultural to non-agricultural uses and permanently non-restorable areas, likely an area with insufficient water or irrigation facilities which can no longer be completed for technical reasons. Investment in irrigation between 2011 and 2012 almost doubled just as the NIA's five-year rationalization program is nearing completion. This program is intended to generate some surplus incomes to fully cover operating expenses through the implementation of a phased reduction in spending for NIS. What would be the impact of future increases in investment in irrigation? The remainder of this paper explores the potential through a series of scenarios exploring alternative scenarios for irrigation and other agricultural investments.

Impacts of Future Irrigation Investments

Methodology: Simulations and Scenario Analysis

Economic simulations of alternative irrigation investment pathways were conducted using the International Model for Policy Analysis of Aagricultural Commodities and Trade (IMPACT), a global partial equilibrium model of agriculture and food production system, developed by the International Food Policy Research Institute (IFPRI) and widely used in the analyses of food security, agricultural policies, irrigation investment, and climate change adaptation strategies (Rosegrant, Cai, & Cline, 2002; Robinson et al., 2015). The simulations were done under four future climate scenarios from GDFL, HGEM, IPSL, and MIROC general circulation/climate models[1] and used the IPCC's representative concentration pathways (RCPs) of 8.5 that represents the highest amount of greenhouse gas emissions.

In Table 2, the impact of climate change on rice productivity and prices were initially estimated by comparing the "climate change" scenario with the "no climate change" scenario, but in the following analyses, the climate change scenario serves as the baseline from which the impacts of the different irrigation investment scenarios are evaluated. Indicators of productivity (area, production, yields), demand (consumer price and consumption), and food security (food availability and access, and malnutrition) were used to compare and evaluate the different irrigation investment scenarios for the country under the impacts of climate change.

There are four alternative irrigation development scenarios simulated in this paper based on regional allocation and rates of irrigation development. These alternative irrigation development scenarios are compared with the baseline climate change scenario, and later with two sets of crop production adaptation technologies.

Seventy Percent Development and Efficiency-Based Allocation Scenario. This scenario sets the

Table 2. *Projected Rice Supply and Demand in the Philippines, with and without Climate Change to 2040*

Item/Year	2015	2040
Population (million)	101	139
No Climate Change scenario		
Demand for rice (million mt)	13.1	17.8
Production (million mt)	12.3	17.2
Under Climate Change scenario		
Yield (mt/ha)	2.84	3.65
% decline	-0.5	-2.6
Production (million mt)	12.2	17.1
% decline	-0.3	-0.8
World Price (US$/mt)	386	506
% increase	2.7	18.6

Note: Climate change data are averages of 4 GCMs - HGEM, IPSL, GDFL and IPSL. Percentages decline/increase are in comparison with No Climate Change scenario. Mt = metric tons; ha = hectare.
Source: Authors' estimates.

irrigation development target at 70% of the country's total irrigable area in 15 years to 2030, regionally allocated based on efficiency—increase in area and productivity. In this scenario, the additional 390,000 ha targeted for development are all allocated to Luzon.

Seventy percent development and equity-based allocation scenario. Same irrigation development target of 70% in 15 years to 2030, but allocated based on equal 70% development of each region's irrigable area. In this scenario, the 390,000 ha are allocated as 132,000 ha to Luzon and 257,000 ha to Mindanao.

Ninety percent development and efficiency-based allocation scenario. This scenario sets a higher irrigation development target of 90% of the country's total irrigable area in 15 years to 2030, regionally allocated based on efficiency. In this scenario, the development target area of 1 million ha for the country are allocated as 659,000 ha to Luzon and 341,000 ha to Mindanao.

Ninety percent development and equity-based allocation scenario. Same irrigation development target of 90% in 15 years to 2030, but allocated based on equal 90% development of each region's irrigable area. In this scenario, the 1 million ha are allocated to each region as 482,000 ha to Luzon, 59,000 ha to Visayas, and 445,000 ha to Mindanao.

Baseline climate change scenario. Assumes annual growth rates of rainfed and irrigated land areas that can be sustained for the long-term (>50 years), given the limited areas of unutilized arable lands, difficulty of conversion from forestlands, the fixed amount of remaining irrigable areas in the country, and trend investment in irrigation. Growth rates under the baseline are 0.39% per year for rainfed crop area and 0.15% per year for irrigated crop area.

Climate Change and Food Security

Rising population and climate change variability are putting pressure on both the demand and supply sides of food security goals that can influence the pathways of irrigation development of the country's remaining 1.29 million ha of irrigable area.

From 101 million people in 2015, the total population is projected to increase by 37% (139 million people) in 2040. At the same time, total rice demand is projected to increase by similar rate from 2015 value of 13.1 million metric tons (mt) to 17.8 million mt in 2040 (Table 2).

With the effect of climate change, however, rice yields and production are projected to increase at lower rates. Yields are estimated to be 2.6% lower in 2040 due to the negative productivity impact of climate change, which in turn would result in 0.8% decline in production for 2040, since higher prices due to climate change cause increases in area harvested, partially balancing the decline in yields.

The productivity effect of climate change is global and projected to increase world price of rice in 2040 by 18.6%, negatively affecting access to rice for lower-income sectors of the economy, including small farmers who are net consumers of rice. This is projected to reduce per capita consumption of rice and exacerbates the food security and nutritional conditions of the population.

Alternative Pathways for Irrigation Development

Out of estimated total 3.02 million ha of irrigable area in the country, 57% have been developed (Table 3). For the remaining 43% of irrigable land area, there are two alternative investment pathways simulated in this study: 1) historical irrigation investment trends for the past 15 years projected to continue for the next 15 years, approximately equivalent to 70% development of irrigable lands; and 2) accelerated development equivalent to 90% development of irrigable lands to year 2030.

Seventy percent development of irrigable lands. In the last 15 years (2000–2015), irrigation development added around 370,000 ha of irrigated lands at an annual growth rate of 1.7%. Similar development for the next 15 years (2015–2030) would be equivalent to 70% development of irrigable lands—adding around 390,000 ha, though at a lower computed annual rate of 1.4%.

Ninety percent development of irrigable lands. NIA's (2014) 15-year Master Plan for 2014–2028 has a target of roughly 90% development of irrigable area by 2028. From 2013–2015, only around 52,000 ha were developed, thus, this scenario assumes the same target of 90% development to 2030—equivalent to an additional area of around 1 million ha at an annual accelerated rate of 3.1%.

Additionally, these two irrigation investment strategies are briefly compared to two sets of climate

Table 3. *Status of Irrigation Development, December 31, 2015*

Region		Estimated Total Irrigable Area	Firmed-up Service Area					Irrigation Develop-ment (%) (ha)	Remaining Area to be Developed (ha)
			National Irrigation System (ha)	Communal Irrigation System (ha)	Private Irrigation System (ha)	Other Irrigation System (ha)	Total (ha)		
Luzon	CAR	97,310	14,341	49,755	24,878	3,649	92,624	95.2	4,686
	1	262,744	48,222	53,891	20,946	50,592	173,651	66.1	89,093
	2	456,898	151,589	56,508	45,667	21,322	275,086	60.2	181,812
	3	480,783	196,415	69,884	9,279	19,665	295,242	61.4	185,540
	4-A	85,929	20,742	19,457	5,925	2,457	48,581	56.5	37,348
	4-B	138,719	19,008	34,554	14,307	12,262	80,130	57.8	58,588
	5	239,440	23,162	73,681	25,059	16,006	137,908	57.6	101,532
	Sub-total	1,761,822	473,480	357,730	146,061	125,952	1,103,223	62.6	658,599
Visayas	6	189,934	47,145	36,813	15,480	14,983	114,420	60.2	75,514
	7	46,159	11,730	26,170	4,237	1,506	43,643	94.6	2,516
	8	84,081	24,483	37,731	5,916	2,835	70,965	84.4	13,116
	Sub-total	320,174	83,358	100,713	25,633	19,324	229,028	71.5	91,146
	9	74,952	16,959	23,917	2,037	3,631	46,544	62.1	28,408
	10	113,631	25,621	26,198	6,254	3,659	61,732	54.3	51,899
	11	147,313	36,282	25,607	1,471	3,090	66,450	45.1	80,863
	12	286,263	63,509	36,144	3,035	10,256	112,944	39.5	173,318
	CARAGA	159,249	29,784	25,523	3,187	6,691	65,185	40.9	94,063
	ARMM	156,205	25,672	19,965	90	295	46,022	29.5	110,184
	Sub-total	937,613	197,827	157,354	16,074	27,622	398,877	42.5	538,735
		3,019,609	754,666	615,797	187,767	172,899	1,731,128	57.3	1,288,481

Source: (2015) National Irrigation Administration. Annual Report 2015.

change adaptation technologies to give additional insights to the impacts investments in agricultural research and in infrastructure development.

Varietal or seed-based technologies. These are a set of technologies based on varietal characteristics developed through breeding and genetics suitable for countering the effect of climate change, including heat-tolerance, drought resistance, and enhanced nutrient-use efficiency.

Farm management technologies. These are set of technologies based on farm and crop production practices designed to be more efficient in the application of farm inputs and to increase productivity. Examples of these technologies include no-till, integrated soil fertility management (ISFM), water harvesting, and precision agriculture. For irrigated rice, ISFM and precision agriculture are more applicable and thus, are included in the analysis.

Box 1 describes these scenarios in more detail where the two irrigation development strategies are further analyzed in terms of regional prioritization, gains in effective areas, and marginal increases in yields and land productivity.

Regional Prioritization of Irrigation Development

The target areas to be developed under the two irrigation development scenarios (70% and 90%) can be allocated among the three major regions or island groups of Luzon, Visayas, and Mindanao based on equity or based on efficiency, evaluated with the following criteria: (a) equal proportion, where each region would have 70% and 90% developed area; (b) available land, based on the area of remaining area for irrigation development; (c) effective area of land expansion, based on cropping intensity and opening-up of new lands; and (d) volume of production from new irrigation, based on cropping intensity and yields of new irrigated lands.

Equity-based allocation is the equal application of the national irrigation development target rates of 70% and 90% to the regions. The final area allocation is based only on the current level of irrigation development. New areas are to be developed in each region up to the target rates, excluding regions that already reached or exceeded the targets. This allocation is solely evaluated using the criterion of equal proportion of regional development.

The efficiency-based allocation, on the other hand, depends on increases in productivity from irrigation. Priority is given to the region with the highest current volume of production derived from the additional irrigated area. This allocation evaluates the region's average yield levels, cropping intensity, and the proportion of new agricultural lands.

Regional allocations based on any of these prioritization criteria would result in the same 390,000 ha and 1 million ha of new irrigation system at the national level but may differ at the regional level. For example, when regional ranking criteria are used, those with higher ranks are given the priority of fulfilling the equivalent of the 70% and 90% of the national totals, whereas when using equity, the 70% and 90% targets are to be fulfilled at the regional level.

Equal proportion regional allocation of 70% and 90%. Under this criterion, each regional group is to equally develop 70% and 90% of its total irrigable area by 2030. This is equivalent to 132,000 ha for Luzon, 257,000 ha for Mindanao, and none for Visayas since it has already exceeded the 70% development target. Under the 90% target, the allocation is 482,000 ha for Luzon, 445,000 ha for Mindanao, and 59,000 ha for Visayas (Table 4).

Available land for development. Luzon has the largest irrigated land area totaling 1.1 million ha in 2015, but it also has the biggest remaining irrigable area available for development estimated at 659,000 ha. Prioritization by this criterion would allocate all the 390,000 ha to Luzon under the 70% development, and all the 659,000 ha under the 90% development target, and the remaining 341,000 ha to Mindanao (Table 5). This allocation would result in 85% and 100% development of irrigable areas in Luzon, respectively under 70% and 90% development target scenarios. There will be no additional irrigation for both Visayas and Mindanao under the 70% target, and 341,000 ha only for Mindanao under the 90% target.

Total effective area of new irrigation and of new land. This criterion is a combination of the effective irrigated area and the portion of that area taken from existing rainfed agricultural and opening-up of newly irrigated area. These new lands are classified as arable lands but are not currently being utilized for agricultural production. Ranking is based on the equivalent irrigated land resulting from the development of a hectare of irrigable land plus the portion of new lands converted to irrigated land.

The equivalent irrigated land was computed with the use of cropping intensity estimates, as shown in Table 6, based on 2014–2016 average harvested rice area compared with the physical irrigated area in the regions. The portion of new lands developed for irrigation was computed using the estimates of the rainfed-irrigated elasticity of conversion. These elasticities were estimated from regression analysis of regional time series data (1987–2016) of irrigated and rainfed harvested areas (dataset used are in Appendix Table A2).

The elasticities give the proportionate rates of conversion of rainfed and new lands for every hectare of newly irrigated land. For Luzon, the elasticity value is -0.21, which translates into 0.25 ha of rainfed and 0.75 ha of new lands for every hectare of new irrigation, when evaluated with the existing irrigated and rainfed areas in 2015. For Mindanao, the elasticity value is -0.17 for an equivalent conversion of 0.76 ha of rainfed and 0.24 ha of new lands for every hectare of new irrigation. For the Visayas, the elasticity value of -0.41 is equivalent to the conversion of irrigated lands all coming from rainfed areas (Table 7).

Table 4. *Regional Allocation of Irrigation Development Based on Equal Percentage of Developed Areas*

Region	Irrigable Area	Developed Area	% Dev. Area	Remaining Area	70% Dev		90% Dev	
					Add. Area	%DA	Add. Area	%DA
	--------- 000 ha --------			000 ha	000 ha		000 ha	
Luzon	1,762	1,103	62.6	659	132	70	482	90
Visayas	320	229	71.5	91	--	--	59	90
Mindanao	938	399	42.5	539	257	70	445	90
Philippines	3,020	1,731	57.3	1,288	390	70	1,000	90

Note: ha = hectare; DA = developed area.
Source: Authors' estimates.

Table 5. *Regional Allocation of Irrigation Development Based on Remaining Irrigable Area*

Region	Total Irrigable Area	Developed Area	Remaining irrigable Area	70% Development		90% Development	
				Area	%	Area	%
	-------------- 000 ha ---------------			000 ha		000 ha	
Luzon	1,762	1,103	659	390	85	659	100
Visayas	320	229	91	--	--	--	--
Mindanao	938	399	539	--	--	341	79
Philippines	3,020	1,731	1,288	390	70	1,000	90

Note: ha = hectare.
Source: Authors' estimates.

The weighted area of the new irrigation is computed as the sum of the equivalent irrigated area based on cropping intensity, and the portion from new lands. These values are 2.58 ha, 2.06 ha, and 1.94 ha respectively for Luzon, Mindanao, and Visayas and served as the basis of the regional priority ranking.

Based on this effective area criterion, all the 390,000 ha are allocated to Luzon in the 70% development target; and 659,000 ha in the 90% target with the remaining 341,000 ha allocated to Mindanao (Table 8). This allocation also means that for 70% target, the 390,000 ha allocated to Luzon will generate an effective annual planted area of 713,700 ha, a minimal reduction in rainfed lands of only 97,000 ha, and additional new lands of 292,500 ha. Under the 90% target, the 659,000 ha allocated to Luzon and 341,000 ha to Mindanao would mean an annual effective planted area of 1.82 million ha, 424,000 ha less of rainfed areas, and 576,000 ha of additional new lands for the whole country.

Volume of production from new irrigation. This is a productivity-based criterion estimated using 2014-2016 average cropping intensity and yields. In terms of cropping intensity, the Visayas region has the value of 1.94, followed by Luzon with 1.83, and Mindanao with 1.82. However, it also has the lowest historical rice yield level of 2.52 mt/ha as compared with Luzon's 2.98 mt/ha and Mindanao's 2.74 mt/ha (Table 9). The equivalent annual rice production per hectare of irrigated land is estimated to be highest for Luzon at 5.47 mt, Mindanao at 4.97 mt, and 4.87 mt for Visayas and thus, similar ranking and allocation.

Results of the prioritization exercise show that the area and productivity criteria—available land, effective area, and annual production—have similar ranking and allocation outcomes (Tables 5, 8, and 9): Luzon, followed by Mindanao, and Visayas with allocation of 390,000 ha to Luzon in the 70% development target, and 659,000 ha for Luzon and 341,000 ha for Mindanao in the 90% development target. Visayas ranked the

Table 6. *Average Production, Area, Yield by Region, 2015*

Regional Cluster	Average 2014–2016				Physical Area	Cropping Intensity
	Production	Area	Yield			
			Palay	Rice		
	000 mt	000 ha	mt/ha		000 ha	
Irrigated Area						
Luzon	9,144	2,022	4.52	2.98	1,103	1.83
Visayas	1,690	443	3.81	2.52	229	1.94
Mindanao	3,006	725	4.14	2.74	399	1.82
PHILIPPINES	13,840	3,191	4.34	2.86	1,731	1.84
Rainfed Area						
Luzon	1,727	530	3.26	2.15	530	1.00
Visayas	1,409	484	2.91	1.92	484	1.00
Mindanao	1,103	400	2.76	1.82	400	1.00
PHILIPPINES	4,239	1,414	3.00	1.98	1,414	1.00
All						
Luzon	10,871	2,552	4.26	2.81	1,633	1.56
Visayas	3,099	927	3.34	2.21	713	1.30
Mindanao	4,109	1,125	3.65	2.41	799	1.41
PHILIPPINES	18,079	4,605	3.93	2.59	3,145	1.46

Note: mt – metric tons; ha - hectare
Source:Authors' computation. Basic data from Philippine Statistics Authority, http://countrystat.psa.gov.ph

Table 7. *Estimation of Equivalent Irrigated Area and New Land Development*

Region	Unit of Irrigable Land	Average Cropping Intensity	Equivalent New Irrigation	Rainfed-Irrigated Elasticity	Portion from Rainfed Lands[1]	Portion from New Lands	Weighted area
	ha	index	ha				
Luzon	1	1.83	1.83	-0.21	0.25	0.75	2.58
Visayas	1	1.94	1.94	-0.41	1.42*	0.00	1.94
Mindanao	1	1.82	1.82	-0.17	0.76	0.24	2.06

Note: [1] - computed using 2015 area of irrigated and rainfed lands (mainly rice and corn) in each regional group.
** - computed decline of rainfed area can be higher than additional irrigated land due to conversion to other usage like reservoir area, drainage canals, and access roads.*
mt - metric tons; ha = hectare.
Source: Authors' estimates

Table 8. *Prioritization and Allocation Based on Equivalent Irrigated Area and Area of New Lands*

Region	Irrigable Area	Developed Area	% Developed Area	Remaining Area	Weighted area 1 ha	Priority Rank	70% Devt		90% Devt	
							Add. Area	%DA	Add. Area	%DA
	-------- 000 ha -------			000 ha	ha		000 ha		000 ha	
Luzon	1,762	1,103	62.6	659	2.58	1	390	85	659	100
Visayas	320	229	71.5	91	1.94	3	--	--	--	--
Mindanao	938	399	42.5	539	2.06	2	--	--	341	79
Philippines	3,020	1,731	57.3	1,288			390	70	1,000	90

Note: Devt – development; DA – developed area; ha - hectare.
Source: Authors' estimates.

Table 9. *Prioritization and Allocation Based on Production per Unit of Developed Land*

Region	Irrigable Area	Developed Area	% Dev. Area	Remaining Area	CI	Rice Yields	Equiv. Prodn/ year	Priority Rank	70% Dev		90% Dev	
									Add. Area	%DA	Add. Area	%DA
	-------- 000 ha --------			000 ha	index	mt/ha	mt		000 ha		000 ha	
Luzon	1,762	1,103	62.6	659	1.83	2.98	5.47	1	390	85	659	100
Visayas	320	229	71.5	91	1.94	2.52	4.87	3	--	--	--	--
Mindanao	938	399	42.5	539	1.82	2.74	4.97	2	--	--	341	79
Philippines	3,020	1,731	57.3	1,288	1.84	2.86	5.28		390	70	1,000	90

Source: Authors' estimates.

Table 10. *Alternative Regional Allocation Based on Efficiency and Equity*

Region	Irrigable Area	Developed Area	% Developed Area	Remaining Area	70% Development		90% Development	
					Additional Area	%DA	Additional Area	%DA
	-------- 000 ha --------			000 ha	000 ha		000 ha	
Efficiency-based allocation								
Luzon	1,762	1,103	62.6	659	390	85	659	100
Visayas	320	229	71.5	91	--	--	--	--
Mindanao	938	399	42.5	539	--	--	341	79
Philippines	3,020	1,731	57.3	1,288	390	70	1,000	90
Equity-based allocation								
Luzon	1,762	1,103	62.6	659	132	70	482	90
Visayas	320	229	71.5	91	--	--	59	90
Mindanao	938	399	42.5	539	257	70	445	90
Philippines	3,020	1,731	57.3	1,288	390	70	1,000	90

Note: DA = developed area; ha = hectare.
Source: Authors' estimates.

Table 11. *Comparative Projections of Area, Yield, and Production by Irrigation Development Targets and Allocation Criteria Under Climate Change, Combined Irrigated and Rainfed Environment, 2010–2040*

Irrigation Development	Total Area		Average Yield		Total Production	
	2010	2040	2010	2040	2010	2040
	000 ha		mt/ha		000 mt	
70% development						
Efficiency-based allocation	4,230	4,947	2.74	3.66	11,583	18,102
Equity-based allocation	4,230	4,937	2.74	3.66	11,583	18,083
% difference		0.20		-0.10		0.11
90% development						
Efficiency-based allocation	4,230	5,356	2.74	3.62	11,583	19,386
Equity-based allocation	4,230	5,342	2.74	3.62	11,583	19,354
% difference		0.25		-0.08		0.17

Note: Values are averages of the four climate models = HGEM, GDFL, IPSL and MIROC; mt = metric tons; ha = hectare.
Source: Authors' estimates.

lowest in all these criteria and therefore not given any development allocation under the efficiency criteria.

This leaves two development scenarios for irrigation in the Philippines, one is a) efficient investment allocation based on area and productivity, and b) equitable investment allocation based on equal 70% and 90% regional allocation of national development targets (Table 10).

Discussion of Results

Productivity and Food Availability

Irrigation development is projected to result in an increase in rice area by 17% in 2040 under the 70 % development target, and by 27% under the 90% development target, from the 2010 rice harvested area of 4.03 million ha. Irrigation development with

Table 12. *Projected Changes in Rice Production, Consumer Price, and Consumption Due to Irrigation Development, by Development Targets and Allocation Criteria, Compared to 2040 Baseline*

Irrigation Development	Total Production		Consumer Price		Consumption	
	2010	2040	2010	2040	2010	2040
	000 mt		US$/mt		kg/person/year	
70% development						
Efficiency-based allocation	11,583	18,102	711	874	119	118
% from climate change		6.0		-13.0		2.8
Equity-based allocation	11,583	18,083	711	878	119	118
% from climate change		5.8		-12.6		2.7
90% development						
Efficiency-based allocation	11,583	19,386	711	637	119	125
% from climate change		13.5		-36.6		9.6
Equity-based allocation	11,583	19,354	711	642	119	125
% from climate change		13.3		-36.1		9.4
Climate change	11,583	17,084	711	1,005	119	114

Note: Values are averages from four climate models = HGEM, GFDL, IPSL and MIROC; mt = metric tons.

efficiency-based regional allocation is projected to have higher area and production than the equity-based allocation in both development targets—mainly due to new land development in Luzon. However, the difference is very small, and the average rice yields are projected be slightly lower for the efficiency-based allocation due to higher proportion of remaining rainfed rice land, as less rainfed areas would be converted to irrigated land in this scenario (Table 11).

Thus, the difference in projection outcomes between the efficiency and equity scenarios is negligible: 0.20% (10,000 ha) and 0.25% (13,000 ha) on total area respectively for the 70% and 90% development scenarios, and 0.11% (19,000 mt) and 0.17% (32,000 mt) on total production. Both irrigation development scenarios are projected to contribute to substantial increases from 2010 levels. Considering other sources of growth as well, under the 70% target, rice area is estimated to increase by 717,000 ha to 2040, equivalent to the annual growth rate of 1.1% while rice production is projected to increase by 6.52 million mt, equivalent to 3.0% annual growth rate. These rates are even higher under the 90% development target, with rice area increasing by 1.3 million ha at an annual rate of 1.6% and production increase of 7.8 million at an annual rate of 3.5% for 30 years. Rice yields are projected to increase from around 2.74 mt/ha in 2010 to around 3.66 mt/ha in 2040 with an annual growth rate of 1.9%.

The best measure of the direct impact of the irrigation development scenarios is their impact on outcomes in 2040 compared to the baseline climate change scenario. These results are shown in Table 12. Compared with baseline climate change scenarios, rice production levels in 2040 are projected to increase by 6%, consumer prices to decline by 13%, and per capita consumption to increase by 2.8%—under the 70% target and efficiency-based allocation. The values are slightly lower for the equity-based allocation (Table 12). As expected, the changes are even higher for the 90% development target—14% increase in production, 37% decline in consumer prices, and 10% increase in per capita consumption compared to the 2040 baseline for the efficiency-based allocation, and slightly lower for equity-based allocation.

Food availability in terms of daily calories consumption is also projected to increase by 1.2%, and the degrees of malnutrition and under-nourishment to decline by 1.3% (number of malnourished children) and 6.4% (number of people at-risk of hunger)

Table 13. *Projected Changes in Food Security Indicators Due to Irrigation Development, by Development Targets and Allocation Criteria, 2010–2040*

Irrigation Development	Food Availability		Malnourished Children		Person at Risk of Hunger	
	2010	2040	2010	2040	2010	2040
	Kcal/person/day		million		million	
70% development						
Efficiency-based allocation	2,510	2,686	3.07	2.46	16.09	16.61
% from climate change		1.2		-1.3		-6.4
Equity-based allocation	2,510	2,685	3.07	2.47	16.09	16.65
% from climate change		1.1		-1.3		-6.1
90% development						
Efficiency-based allocation	2,510	2,761	3.07	2.39	16.09	14.26
% from climate change		4.0		-4.4		-19.6
Equity-based allocation	2,510	2,760	3.07	2.39	16.09	14.31
% from climate change		4.0		-4.3		-19.3
Climate change	2,510	2,654	3.07	2.50	16.09	17.73

Note: Values are averages from four climate models = HGEM, GFDL, IPSL and MIROC.
Source: Authors' estimates.

respectively, under the 70% development target (Table 13). These values are projected to be higher for the 90% development target—4% increase in available food, 4.4% decline in the number of malnourished children, and 16.1% reduction in the number of people at-risk of hunger. For both development targets, the indicators for efficiency-based regional allocation are somewhat higher than the equity-based allocation.

Results from Tables 12 and 13 clearly indicate that investment in irrigation development can mitigate the negative impacts of climate change, and improve availability and access to food, and improve food security—whether the regional allocation of development is based on efficiency or equity. Below we explore the cost-effectiveness of irrigation and other investments.

Technology or Infrastructure Development

The direct impacts of climate change on agriculture aremostly through changes in the rainfall pattern and temperature, with the net effect of reducing crop yields and agricultural productivity. Climate change adaptation technologies have focused on mitigating both the direct and indirect impacts of climate change—by developing tolerance to changes in rainfall and temperature; by developing higher yielding varieties, and farm, soil, and water management practices that can improve crop yields. These can be broadly classified as: a) seed or varietal technologies; b) farm management technologies; and c) crop protection technologies.

The first two categories are represented in Table 14 to give additional insights into how investment in infrastructure development compares with investment in agricultural research as alternative climate change adaptation strategies.

Results show that the irrigation development strategies at the 70% and 90% development are comparable to technology development in all the supply, demand, and food security indicators. Projections illustrate that through technology, total rice production in 2040 will improve by as much as 3.7% and consequently lower consumer prices by as much as 10% and increase per capita consumption by 2.2%. Thus, enhancing the food security and nutrition situation of the country with 1.2% lower number of malnourished children and 5.7% less number of people at risk of hunger. The 70% irrigation development, on the other hand, is estimated to have 60% higher increase in production over the technologies, 30% lower prices

Table 14. *Comparative Projections of Rice Demand, Supply and Food Security Indicators, Technology, and Irrigation Development Strategies, 2040*

Development Strategy	Total Production	Consumer Price (US$/ mt)	Per Capita Consumption (kg/yr)	Food Availability (Kcal/day)	No. of Malnourished. Children	No. At-risk of Hunger
% change from climate change scenario						
Technology development*						
Varietal/Seed Technology	3.46	-9.04	1.96	0.98	-1.08	-5.24
	0.16	-0.01	0.02	0.08	-0.09	-0.46
Farm Management Technology	3.70	-10.02	2.18	1.07	-1.18	-5.72
	3.40	-8.80	1.90	0.96	-1.05	-5.12
Irrigation Development**						
70% development						
Efficiency-based allocation	5.96	-13.05	2.84	1.19	-1.32	-6.37
Equity-based allocation	5.85	-12.61	2.74	1.15	-1.27	-6.13
90% development						
Efficiency-based allocation	13.48	-36.59	9.58	4.04	-4.39	-19.62
Equity-based allocation	13.29	-36.10	9.41	3.97	-4.31	-19.31

** Values are the best ("high") and worst ("low") in the range of parameter values within the suite of Varietal/Seed and Farm Management technologies; under MIROC climate scenario only. Same analysis as in Perez and Rosegrant (2018 in press) but used 2040 projections instead of 2050.*
*** Values are averages from four climate models - HGEM, GFDL, IPSL and MIROC. Taken from Tables 12 and 13.*
Note: mt = metric ton; kg = kilogram; kcal = kilocalorie.
Source: Authors' estimates and Perez and Rosegrant (2018 in press).

and equivalent of 30% higher consumption, and up to 12% better changes in nutrition condition. Projections for these indicators for the 90% development are 2–3 times higher than for new technology adoption.

The higher impacts of irrigation development on rice production were not only due to higher increases in effective area through higher crop intensities of previously rainfed lands and new lands (see Table 7), but also due to increased yields of the same previously rainfed lands and new lands, which drive the country's average yields to higher values.

Trade Effect and Import Dependency

The country is a traditional net importer of rice, and for the last two decades importing on average 11.5% of its consumption demand, also termed import-dependency ratio (Appendix Table A4). During this period, the highest import dependency ratio of 28.0 was during the El Niño year of 1998, and almost reaching the level of sufficiency in 2013 with dependency ratio of 3.2 before climbing up again to more than 11.1 ratio in 2015.

Rice self-sufficiency through price intervention and trade restrictions is a major policy promoted by the Philippine government. The National Food Authority (NFA) is mandated to provide subsidies to producers and consumers, and to restrict the amount of rice that is imported. This program has high direct fiscal costs, because the government must buy rice at high prices and sell at low ones to create incentives for farmers to plant more rice and provide cheaper food to consumers. This cost adds to the country's fiscal deficit and could

Table 15. *Projected Net Trade and Level of Self-Sufficiency in Rice, by Development Targets and Regional Allocation, 2010–2050*

Irrigation Development	Net Trade				
	2010	2020	2030	2040	2050
			000 mt		
70% development					
Efficiency-based allocation*	-854	-901	--	--	--
Equity-based allocation*	-854	-916	--	--	--
90% development					
Efficiency-based allocation**	-854	-107	--	--	--
Equity-based allocation**	-854	-130	--	--	--
Climate change baseline***	-854	-1,362	-1,241	-483	--

Note: Values are averages from four climate models = HGEM, GFDL, IPSL and MIROC.
** = self-sufficiency in 2029; ** = self-sufficiency in 2021; *** = self-sufficiency in 2045.*
"--" = level of self-sufficiency with minimal net trade.
mt = metric tons.
Source: Authors' estimates.

Table 16. *Benefit-Cost Analysis of Different Irrigation Investment Strategies in the Philippines, Under Climate Change*

Irrigation Development	Economic welfare (Benefits)			Cost of Irrigation Development			Benefit-Cost Ratio (BCR)***
	Producer Surplus	Consumer Surplus	Economic Surplus	Area*	Cost per	Total Cost	
	net present value (US$ million)			000 ha	US$	US$ million	
70% development							
Efficiency-based allocation	6,147	64	6,211	390	3,500	1,365	4.55
Equity-based allocation	5,939	61	6,000	390	3,500	1,365	4.40
90% development							
Efficiency-based allocation	17,582	190	17,772	1,000	3,500	3,500	5.08
Equity-based allocation	17,258	186	17,444	1,000	3,500	3,500	4.98

Note: Values are averages from four climate models - HGEM, GFDL, IPSL and MIROC, measured as changes from climate baseline scenario. Used 5% discount rate, evaluated from 2015-2050, with 2015 as reference year for present value estimates.
** = from Table 10; ** = from NIA Master Plan, converted to US dollars and adjusted to combination of irrigation types, and rounded to nearest hundreds; *** = alternatively written as 4.55:1; 4.40:1; 5.08:1 and 4.98:1.; ha = hectare.*
Source: Authors' estimates.

potentially create negative effect on economic growth in the future. Perhaps even more importantly, this policy causes direct losses to the economy through misallocation of resources. Pradesha and Robinson (2018 in press) estimated an annual economy-wide loss of US$1.2 billion due to the rice self-sufficiency policy.

Therefore, pursuing self-sufficiency through distortionary price and trade policies is very costly. Investing in cost-effective production-enhancing irrigation and agricultural research can reduce rice imports without costly fiscal and economic costs. Investment in irrigation development is projected to enhance the rice trade situation of the country on a cost-effective basis, eliminating rice imports before 2040 through the combinations of increasing productivity and production, declining population growth, and

Table 17. *Benefit-Cost Analysis of Different Irrigation Investment Strategies in the Philippines, with Alternative Costs Structure, Under Climate Change*

Irrigation Development	Economic welfare (Benefits)			Cost of Irrigation Development			Benefit-Cost Ratio (BCR)***
	Producer Surplus	Consumer Surplus	Economic Surplus	Area*	Cost per	Total Cost	
	net present value (US$ million)			000 ha	US$	US$ million	
70% development							
Efficiency-based allocation	6,147	64	6,211	390	4,500	1,755	3.54
Equity-based allocation	5,939	61	6,000	390	4,500	1,755	3.42
90% development							
Efficiency-based allocation	17,582	190	17,772	1,000	5,500	5,500	3.23
Equity-based allocation	17,258	186	17,444	1,000	5,500	5,500	3.17

Note: Values are averages from four climate models = HGEM, GFDL, IPSL and MIROC, measured as changes from climate baseline scenario. Used 5% discount rate, evaluated from 2015-2050, with 2015 as reference year for present value estimates.
** = from Table 10; ** = from NIA Master Plan, converted to US dollars and adjusted to combination of irrigation types, and rounded to nearest hundreds; ***= alternatively written as 4.55:1; 4.40:1; 5.08:1 and 4.98:1.; ha = hectare.*
Source: Authors' estimates.

Table 18. *Benefit-Cost Analysis (BCA) with Higher Development Cost of Different Irrigation Investment Strategies in the Philippines, Under Climate Change*

Irrigation Development	Economic welfare (Benefits)			Cost of Irrigation Development			Benefit-Cost Ratio (BCR)***
	Producer Surplus	Consumer Surplus	Economic Surplus	Area*	Cost per hectare**	Total Cost	
	net present value (US$ million)			000 ha	US$	US$ million	
70% development							
Efficiency-based allocation	6,147	64	6,211	390	7,000	2,730	2.28
Equity-based allocation	5,939	61	6,000	390	7,000	2,730	2.20
90% development							
Efficiency-based allocation	17,582	190	17,772	1,000	8,500	8,500	2.09
Equity-based allocation	17,258	186	17,444	1,000	8,500	8,500	2.05

Note: Values are averages from four climate models = HGEM, GFDL, IPSL and MIROC, measured as changes from climate baseline scenario. Used 5% discount rate, evaluated from 2015-2050, with 2015 as reference year for present value estimates.
** = from Table 10; ** = from NIA Master Plan, converted to US dollars and adjusted to combination of irrigation types, and rounded to nearest hundreds; ***= alternatively written as 4.55:1; 4.40:1; 5.08:1 and 4.98:1.; ha = hectare.*
Source: Authors' estimates.

increasing income. Under 90% irrigation development, rice imports are projected to be eliminated as early as 2021, and to as late as 2029 for the 70% irrigation development target (Table 15). These are much earlier than the 2045 projected for the climate change scenario of depending only through historical trends in rice productivity improvements and decline in population growth.

Table 19. *Benefit-Cost Analysis (BCA) of Cereal Technology Development in the Philippines, Under Climate Change*

Technology Development		Economic welfare (Benefits)			Cost of Technology Development			Benefit-Cost Ratio (BCR)
		Producer Surplus	Consumer Surplus	Economic Surplus	Area*	Cost per hectare**	Total Cost	
		net present value (US $ million)			000 ha	US$	US$ million	
Varietal/Seed Technology		-179	439	260	7,007	6.65	46.61	5.59
	Low	35	16	50	7,007	6.65	46.61	1.08
Farm Management Technology		-191	427	236	7,007	6.65	46.61	5.06
	Low	-264	492	228	7,007	6.65	46.61	4.88

Note: Economic welfare values are MIROC climate model only, measured as changes from climate baseline scenario. Used 5% discount rate, evaluated from 2015–2050, with 2015 as reference year for present value estimates.
** - average cereal areas from 2015–2050.*
*** Incremental R&D investment of CGIAR and NARS in the East and Asia Pacific region, applied to average cereal areas from 2015-2050.*
Source: Authors' estimates and Rosegrant et al. (2017).

Benefit-Cost Analyses

The benefit-cost analyses (BCA) of the different irrigation development scenarios are presented in Tables 16, 17, and 18. Table 19 presents the BCA for cereal technology development, including new varietal development and farm management. The net benefits from irrigation were estimated with the use economic surplus approach. This framework is based on Marshallian theory of economic surplus that arises from shifts over time of supply and/or demand curves , and has been used extensively in the economic analyses of agricultural policies (Bullock & Salhofer, 2003), including investment in irrigation (Wittwer & Barnerjee, 2004) and other public infrastructure projects and economic returns to agricultural research and development (Norton & Davis, 1981; Alston, Norton, & Pardey,1995), and impacts of new technology (Cuyno, Norton, & Rola, 2001; Krishna & Qaim, 2008) . Economic surpluses were evaluated for 2015–2050, with construction phase starting in 2016, increasing linearly and continuing to 2030 when the targets of 70% and 90% development are achieved. Newly irrigated lands are brought into cultivation as new irrigation systems are completed within 3–5 years of construction and benefits in terms of additional production start to accumulate annually. Five percent discount rate was used in the analysis to bring all the producers' and consumers' welfare changes (benefits and costs) to the 2015 reference year (year$_0$).

Producers benefit the most from irrigation development through positive shifts of production with relatively smaller declines in prices, higher for the 90% development target and for efficiency-based allocation. Consumers are also better off in all scenarios, but with much lesser degrees than producers. Total net economic benefits for 35 years (2015–2050) is estimated to be US$17.8 billion for the efficiency-based allocation and 90% irrigation target. A much lower benefit of US$6.0 billion is projected to the equity-based allocation and 70% development target.

The cost components of the analysis were based on construction costs schedule by type of irrigation system—national or communal; reservoir or non-reservoir; and deep or shallow tubewell irrigation. These are NIA's best estimates of per hectare construction costs of new irrigation systems for 2015, and are used for planning and capital budgeting purposes. When the potential mix of irrigation types was considered and converted to 2015 US dollar equivalent, the cost of irrigation development was estimated to be US$3,500 per hectare. This brings the total cost of irrigation development under the 70% target where a total of 390,000 ha is to be irrigated to US$1.4 billion. For the 90% development target, 1 million ha to be irrigated with a total cost of US$3.5 billion.

The final benefit-cost ratios (BCRs) show the society's benefits from irrigation development can compensate for all the corresponding costs of development. As expected, the 90% development target has the higher BCR values of 5.08 and 4.98 compared to 70% development target's 4.55 and 4.40 ratios. What is unexpected though are the relatively small differences between the efficiency- and equity-based allocations with 4.55 and 4.40 for 70% target; and 5.08 and 4.98 ratios for 90% target. There is essentially no incremental cost to a regionally equitable irrigation investment strategy.

Tables 17 and 18 show that control of the construction costs of irrigation is critical to preserve the high BCR for irrigation development. Historically, irrigation costs have been significantly higher than initial estimates for projects, and irrigations costs have increased substantially as the less costly irrigation systems are completed and any additional systems need to be built in more difficult regions (Inocencio & Barker 2006; David & Inocencio 2012). This cost escalation needs to be avoided to keep the returns to irrigation investment high.

Conclusions

Three broad strategies in the agricultural water sector can be used to address the challenge posed by climate change: (1) increasing the supply of water for irrigation through investment in infrastructure; (2) conserving water and improving the efficiency of water use in existing systems through water management and policy reform; and (3) improving crop productivity per unit of water and land through integrated water management and agricultural research and policy efforts, including crop breeding and water management for rainfed and irrigated agriculture (Rosegrant 2015). In this paper, we analyzed in detail the first strategy for the Philippines, investment in irrigation, together with a brief comparison with the third strategy of increased investment in productivity enhancement.

Population and climate change are putting pressure on both the demand and supply sides of food security goals. Total population is projected to increase by 37% to 139 million in 2040, increasing total demand for rice from 13.1 million mt to 17.8 million mt. With climate change, yields are projected to be 2.6% lower in 2040 compared to the no climate change case, which would result in 0.8% lower production.

Since irrigation development can serve as a primary tool for countering the negative impacts of climate change and in achieving the vision of a population free of hunger and poverty in 2040, and has a long gestation process, there is a sense of urgency on choosing whether and how to develop and allocate the remaining 1.29 million ha of irrigable land of the country.

This paper analyzed two rates of development (70% and 90% of development); two criteria (efficiency- and equity-based allocation) of development to the regions; simulated their projected impacts on rice yields and production, consumer prices and consumption, and nutrition and food security; and estimated their economic profitability. These results were compared with investment in varietal and seed technology research development and in farm level technologies.

Results of the simulations show that on all the comparative indicators, the 90% development target dominated over 70% target. At the lower irrigation cost estimate of US$3,500/ha, irrigation development has a higher positive impact compared with the investment in varietal and seed development and farm level technology. If the costs of irrigation per hectare of new area increase to the levels shown in Tables 17 and 18, the varietal and seed and farm level technologies have higher rates of return than irrigation, and it would be preferable to shift some of the potential investment in irrigation to these other development strategies.

The differential effects for the efficiency- and equity-based regional allocation, however, were not substantial—less than 1% difference for all the productivity, consumption, and nutrition and food security indicators. Rather than broadly targeting regions by overall irrigation performance, investment allocations should be determined by project-by-project cost-benefit analysis.

If investment costs per hectare of new irrigation can be controlled, faster irrigation development would make a major contribution to agricultural development and food security in the Philippines. In addition to the expansion of irrigated areas, future analysis should assess the potential for water use efficiency gains in existing systems and crop water productivity gains in reducing water scarcity and increasing food production and improving food security. Improvements in the irrigation sector can be made at the technical, managerial, and institutional levels. Further research should explore the potential for irrigation system improvements as a complement to irrigation system expansion.

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Box 1.
Description of Adaptation Technologies and Irrigation Development

Climate Change Adaptation Technologies		
Varietal traits technologies	Heat tolerance	Using improved varieties that allow the plant to maintain yields at higher temperatures
	Drought tolerance	Using improved varieties that allow the plant to have better yields than regular varieties because of enhanced soil moisture uptake capabilities and reduced vulnerability to water deficiency
	Enhanced nutrient -use efficiency	Varieties showing enhanced yield response to soil nutrients, such as but not limited to nitrogen, phosphorous and potassium which are found in inorganic fertilizers.
Farm management technologies	No-till	Minimum or no soil disturbance, often in combination with residue retention, crop rotation, and use of cover crops
	Integrated soil fertility management	Combination of chemical fertilizers, crop residues, and manure/compost
	Water harvesting	Channeling water toward crop fields through macro- or micro-catchment systems or by using earth dams, ridges, or graded contours
	Precision agriculture	GPS-assisted delivery of agricultural inputs, as well as low-tech agricultural practices that aim to optimize management of crops (this includes effective plant spacing and use of appropriate planting windows)
Irrigation Development		
70 % development		Construction of new irrigation systems to achieve Irrigation development up to 70 percent of total irrigable area
90 % development		Construction of new irrigation systems to achieve Irrigation development up to 90 percent of total irrigable area

Source: Constructed by authors and based on Rosegrant and others, 2014.

Appendix A

Table A1. *Irrigation Development, 1964–2015*

Years	National Irrigation System	Communal Irrigation System	Private or OGA* Irrigation	Total
		------------------------------ 000 ha	---------------------------	
1964	218	126	52	396
…	…	…	…	…
1973	350	162	104	616
1974	355	182	111	648
1975	396	203	119	718
1976	436	226	126	788
1977	456	249	133	838
1978	464	271	141	876
1979	475	282	149	906
1980	472	310	152	934
1981	492	330	152	974
1982	514	395	152	1,061
1983	505	418	152	1,075
1984	548	430	152	1,130
1985	568	437	152	1,157
1986	596	443	152	1,191
1987	616	406	152	1,174
1988	616	418	152	1,186
1989	621	429	152	1,202
1990	637	448	152	1,237
1991	646	458	152	1,256
1992	647	467	152	1,266
1993	647	474	152	1,273
1994	652	442	175	1,268
1995	652	474	181	1,307
1996	652	489	183	1,323
1997	663	491	181	1,336
1998	679	486	174	1,339
1999	679	495	174	1,348
2000	686	501	174	1,361
2001	689	511	174	1,374
2002	689	524	174	1,387
2003	690	532	174	1,396
2004	690	537	174	1,402
2005	696	543	174	1,413
2006	705	549	174	1,428

2007	706	554	174	1,435
2008	749	554	217	1,520
2009	765	558	217	1,540
2010	767	558	217	1,543
2011	713	496	362	1,571
2012	723	534	370	1,627
2013	740	576	362	1,679
2014	750	596	362	1,708
2015	755	616	361	1,731
Annual growth				
1964–1980				5.7
1980–2000				1.6
2000–2015				1.7

** OGA means Other Government Agencies' assisted irrigation system.*
Source: Philippine Statistics Authority,http://countrystat.psa.gov.ph

Table A2. *Dataset Used for Regression Analysis and Estimates of Rainfed Land Conversion Elasticities*

Year	Luzon			Visayas			Mindanao		
	Irrigated Rice	Rainfed		Irrigated Rice	Rainfed		Irrigated Rice	Rainfed	
		Rice	Corn		Rice	Corn		Rice	Corn
	hectares								
1987	1,191,650	618,010	879,410	262,600	507,910	874,140	397,390	278,340	1,929,100
1988	1,240,650	675,760	898,640	282,790	466,850	881,790	432,590	294,030	1,964,640
1989	1,293,780	661,280	878,920	308,440	475,330	848,190	461,530	296,920	1,962,130
1990	1,277,930	619,200	892,150	282,740	404,230	845,650	449,260	285,360	2,081,760
1991	1,296,580	607,570	841,610	307,710	494,540	743,940	456,140	262,420	2,003,910
1992	1,264,110	595,040	819,850	315,670	440,380	620,770	400,640	182,230	1,890,790
1993	1,222,010	587,770	605,410	341,500	432,450	492,810	453,670	244,950	2,051,120
1994	1,354,220	663,100	564,860	356,580	457,070	458,820	508,580	311,980	1,982,140
1995	1,423,406	618,049	549,007	355,383	432,025	397,809	555,584	374,244	1,745,516
1996	1,464,364	621,789	533,970	401,924	451,117	411,249	618,221	393,721	1,790,504
1997	1,499,566	586,717	567,578	387,743	434,673	396,929	609,578	323,993	1,761,368
1998	1,302,232	439,524	522,384	331,636	320,064	342,098	547,666	228,920	1,489,726
1999	1,566,634	567,861	609,030	431,468	460,708	361,149	666,527	306,641	1,672,029
2000	1,580,184	576,173	550,140	432,500	460,367	369,097	690,670	298,191	1,591,105
2001	1,600,827	576,548	562,013	430,531	456,498	371,192	695,518	305,519	1,553,383
2002	1,560,813	560,553	548,274	440,030	469,651	376,688	705,455	309,816	1,470,494
2003	1,587,105	536,667	515,521	445,246	441,344	383,495	686,187	309,872	1,510,812
2004	1,638,100	543,535	592,693	457,814	463,468	389,817	696,282	327,446	1,544,625
2005	1,645,963	506,151	564,997	450,683	448,428	412,082	695,075	324,121	1,464,709
2006	1,664,509	536,473	666,941	479,242	464,598	419,320	684,135	330,973	1,484,412
2007	1,725,019	552,224	696,261	482,704	476,784	442,996	709,289	326,869	1,509,060
2008	1,793,519	575,526	738,838	523,361	504,563	444,452	715,758	347,250	1,477,731
2009	1,820,214	578,470	764,521	521,479	523,365	425,705	714,070	374,712	1,493,664
2010	1,854,940	527,791	686,516	460,283	458,536	393,154	693,102	359,509	1,419,370
2011	1,841,382	552,805	760,729	508,573	537,369	395,604	722,682	373,831	1,388,279
2012	1,945,575	564,065	783,569	499,194	560,807	390,538	718,416	402,004	1,419,817
2013	2,008,215	556,301	778,229	478,002	526,615	383,609	750,120	426,838	1,401,880
2014	2,020,703	546,104	811,108	485,123	520,912	378,153	747,254	419,576	1,422,171
2015	2,016,375	530,767	788,953	490,291	502,766	368,862	726,520	389,508	1,404,119
2016	2,030,116	512,927	785,783	354,202	428,573	210,541	701,706	390,276	1,360,073

Source: Philippine Statistics Authority. Country STAT Philippines, http://countrystat.psa.gov.ph.

Table A3. *Projection Results for Rice Area, Yield and Production, with and without Climate Change, by Type of Environments, Irrigation Development Targets, and Allocation Criteria, 2010–2050.*

Technology	Area				Yield				Production			
	2010	**2030**	**2040**	**2050**	**2010**	**2030**	**2040**	**2050**	**2010**	**2030**	**2040**	**2050**
	000 ha				mt/ha				000 mt			
Irrigated												
No Climate change	2,814	3,007	3,118	3,245	3.09	3.81	4.25	4.68	8,694	11,460	13,252	15,186
With Climate change	2,814	3,040	3,172	3,321	3.09	3.75	4.14	4.52	8,694	11,388	13,138	15,013
70% development												
Efficiency criterion	2,814	3,489	3,552	3,614	3.09	3.73	4.08	4.40	8,694	13,004	14,506	15,910
Equity criterion	2,814	3,487	3,550	3,613	3.09	3.73	4.09	4.40	8,694	13,003	14,507	15,910
90% development												
Efficiency criterion	2,814	4,077	4,117	4,180	3.09	3.61	3.96	4.26	8,694	14,703	16,292	17,826
Equity criterion	2,814	4,067	4,108	4,170	3.09	3.61	3.96	4.27	8,694	14,679	16,267	17,800
Rainfed												
No Climate change	1,415	1,460	1,478	1,491	2.04	2.45	2.68	2.90	2,889	3,577	3,967	4,322
With Climate change	1,415	1,479	1,509	1,535	2.04	2.41	2.61	2.80	2,889	3,560	3,946	4,290
70% development												
Efficiency criterion	1,415	1,404	1,395	1,362	2.04	2.40	2.58	2.72	2,889	3,362	3,596	3,707
Equity criterion	1,415	1,395	1,386	1,354	2.04	2.40	2.58	2.72	2,889	3,343	3,576	3,686
90% development												
Efficiency criterion	1,415	1,241	1,239	1,209	2.04	2.32	2.50	2.64	2,889	2,877	3,094	3,188
Equity criterion	1,415	1,237	1,235	1,205	2.04	2.32	2.50	2.64	2,889	2,870	3,087	3,179
All (irrigated and rainfed)												
No Climate change	4,230	4,467	4,596	4,736	2.74	3.37	3.75	4.12	11,583	15,037	17,219	19,507
With Climate change	4,230	4,519	4,682	4,855	2.74	3.31	3.65	3.98	11,583	14,948	17,084	19,303
70% development												
Efficiency criterion	4,230	4,893	4,947	4,976	2.74	3.34	3.66	3.94	11,583	16,366	18,102	19,616
Equity criterion	4,230	4,882	4,937	4,966	2.74	3.35	3.66	3.95	11,583	16,346	18,083	19,596
90% development												
Efficiency criterion	4,230	5,319	5,356	5,388	2.74	3.31	3.62	3.90	11,583	17,581	19,386	21,014
Equity criterion	4,230	5,304	5,342	5,375	2.74	3.31	3.62	3.90	11,583	17,549	19,354	20,979

Note: Values are averages for the 4 climate models = HGEM, GDFL, IPSL and MIROC, except for the No Climate Change.
Source: Authors' estimates

Table A4. *Rice Production and Import Dependency Ratios, 1995–2015.*

Year	Production	Dependency Ratio*
	million mt	
1995	7.03	3.69
1996	7.53	10.51
1997	7.52	8.93
1998	5.71	27.95
1999	7.86	9.77
2000	8.26	7.31
2001	8.64	8.71
2002	8.85	12.11
2003	9.00	9.12
2004	9.67	9.55
2005	9.74	16.02
2006	10.22	14.62
2007	10.83	14.53
2008	11.22	18.11
2009	10.85	14.17
2010	10.52	18.73
2011	11.13	6.09
2012	12.03	8.11
2013	12.30	3.20
2014	12.65	8.06
2015	12.11	11.07
Average		11.45
Maximum		27.95
Minimum		3.20

** Defined as the portion or percentage of consumption from imports.*
Source: Philippine Statistics Authority, s http://countrystat.psa.gov.ph