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ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE: REVIEW OF FOOD SECURITY- WATER- ENERGY NEXUS

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ABSTRACT

The food security concerns, which are very intricately linked with water and energy, are getting amplified by climate change, and it requires maintaining optimal balance between synergies and tradeoffs generated in the food production processes. In agriculture, adaptation to climate change by productivity enhancing interventions is identified as the best option. A review of the future demands for food, water and energy has indicated that the food production system is operating outside the safe space and requires large scale adoption of technologies with lower water and energy foot prints. An overview of the productivity enhancing; and water and energy saving potential of climate smart technologies such as micro-irrigation, laser levelling conservation tillage etc, has indicated that their out – scaling, through mainstreaming in the government development programmes, would help turning down the heat by the adaptation led mitigation. The contribution of green revolution technologies which have been promoted through public policies in irrigation sector has been analysed. The first order assessment for the 1990-2010 period indicted a virtual mitigation of green house gas emission by 237 MtCO$_2$e and saving about 56.5 Mha land from getting deforested. The outcome on sustainability front in respect of water resources is questionable, as the projected degree of development (DD) for surface water (0.938) and groundwater abstraction ratio (GWAR)(1.0) for 2050 were extremely high. To address the water resources sustainability issue, reallocation of water in agriculture through diversification, relook at water and energy subsidy and more incentives for adoption of water smart technologies, are advocated.

INTRODUCTION

Universal food security is on top of the agenda of sustainable development as underlined in the 'Future We Want' (UN, 2012). The food security concern is very closely linked with water and energy security. Out of the four dimensions of food security, availability, access, utilization and stability, the first and third are directly influenced by access, affordability and safety of water (Bizikova et al, 2013). Water is required not only to produce food, but is needed along the entire food supply chain; and energy is required to produce and distribute water and food. This nexus decides the extent to which water energy and food security would be simultaneously achieved in a sustainable manner (Table1). It should be understood that, there are synergies as well tradeoffs in food, water and energy interactions during the production process. The sustainable development and management of water and energy for food production requires that synergies and tradeoffs are optimally balanced.

Table 1: Nexus between, water, energy and food system (WEF)

Sector	Food	Water	Energy
Food	Limiting factor for nutrition, overall socioeconomic growth and human development	Increased pressure on water resources to produce food and other agro inputs (seeds, fertilisers, agro chemicals etc.	Increased consumption in irrigation, and other post production processes
Water	Limiting factor for food production agro- inputs and food supply chain	Reduction in per capita water availability Limiting factor for human development	Limiting factor for power generation from hydro, thermal, nuclear, and bio energy
Energy	Limiting factor for food production; agro- inputs and food supply chain	Limiting factor for groundwater and surface water access; utilization; treatment; and transportation	Limiting factor for human development and economic growth

A major challenge for achieving the food security goal ,as enshrined in the "Future We Want" (UN,2012), is the climate change, which is projected to adversely impact agriculture, because it is a highly weather dependent enterprise. The global food system was already facing the difficult challenge of increasing food production to meet demand of growing population with changing consumption patterns requiring more water and energy; and the impact of climate change on crop productivity is an additional strain on the system (Beddington et al 2011).The key impacts of climate change on agriculture will be transmitted through water in terms of increased irrigation demands in response to increased temperatures and decreased rainfall, particularly during winter season; degradation of water quality; and increased flooding risk (GOI, 2010).The overall impacts on food production will be adverse. According to Indian Network for Climate Change Assessment Report of 2010 (MOEF, 2010), rice, which is a major food crop in India, would suffer yield loss of 4-20 % under irrigated condition and 35 to 50 % under rainfed condition as early as 2030. Except for the states of Andhra Pradesh, Tamil Nadu and Karnataka, where yield of rain-fed rice is likely to go up by 10-15%, rice yields will go down by 15-17% in Punjab and Haryana and by 6-18% in all other regions (CRIDA, 2013). Irrigated wheat and maize yields may decline by 5-10 % by 2050. Rain-fed agriculture, which covers 60% of all cultivated land in India, will be particularly hard hit. These projections are much more alarming than the earlier projections and tally with Cline's estimates of 30 to 40 % decline in yield (Cline, 2007). The only difference is that what was expected to happen in 2080 may happen in 2030.

Objectives

This paper aims at addressing the following issues

1) Outlook of demands for food, water and energy by 2050

2) Food security and broad adaptation options in agri-water sector to remain in safe operating space;

3) Agro-technologies for climate change adaptation and their nexus with water and energy

4) Impact assessment of the out scaled green revolution technologies (GRTs) and development policies on mitigation and adaptation to climate change

DEMAND FOR FOOD, WATER AND ENERGY:

Food

Food security connotes access to healthy food and nutrition which in turn is dependent on a healthy and sustainable food system.

There are various projections of increase in demand of food commodities. According to one scenario (Kumar, 2015), at 7% growth rate in GDP, though the demand for food grains will grow only by about 50 per cent, but rise in demands for fruits, vegetables and animal products will be more spectacular, the range being 100-300 per cent (Fig.1).

Water

While talking of water future in view of the increased demands on account of increasing population, changing life style, additional stress due to climate and the prevailing all round depletion and degradation of water resources, we have to answer the following questions:

1) How much water we need to produce for meeting the food requirement at a future date, say 2050?

2) How much production can be sustainably achieved at today's water productivity at projected water availability in 2050?

3) If there is a gap between the demand for water at today's water productivity to produce food required in 2050 and the projected water requirement for this purpose, how is it going to be met?

4) To what extent can gains in efficiency and water productivity (economic output per drop) enable higher levels of growth?

There are clear indications that our water demands are waiting to explode and the water supply side is not keeping pace with

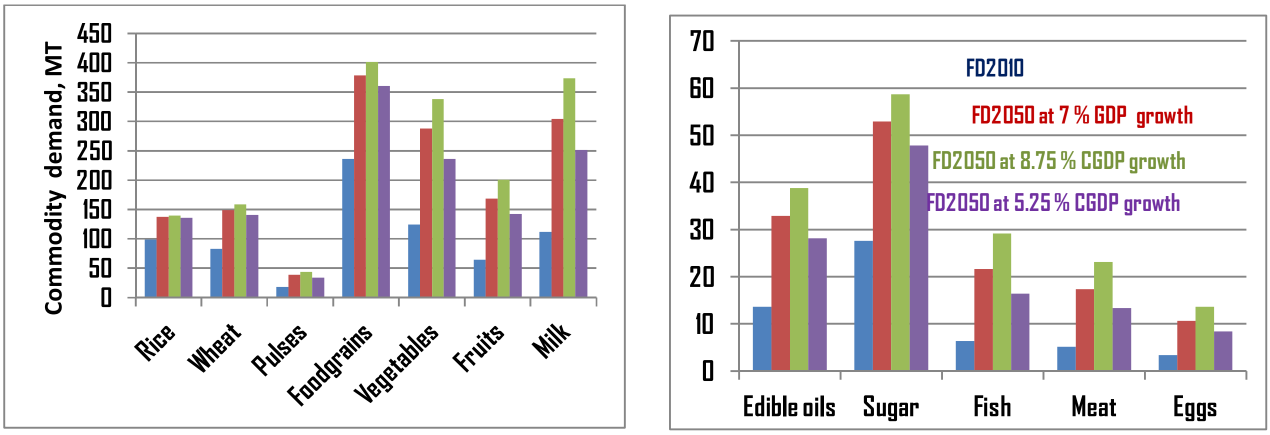
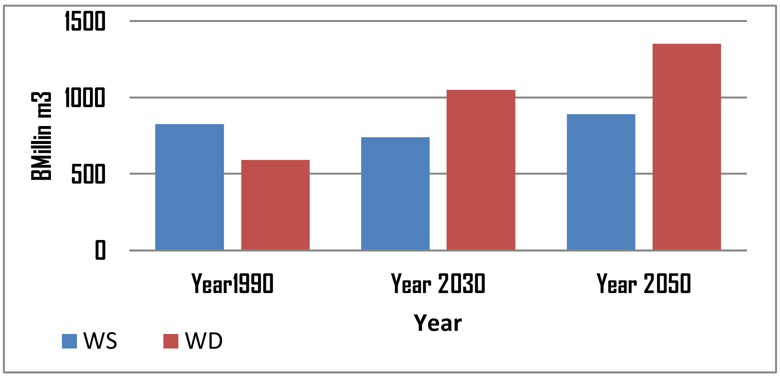


Fig. 1: Demand for various food commodities (FD) in 2010 and projections for 2050 at 7%, 8.75 % and 5.25 % growth in GDP (Personal communication from P. Kumar, 2015).



WS=Dependable water supply including rainfall at 80% dependability, WD=Water demand (irrigation, Industry, drinking, energy)

Fig. 2: Water supply and demand in India under A1B Scenario (Ahmed and Suphachalasai, 2014)

the growth in demand. The water requirement to meet the food demand of 2050 would be about 735 Km^3 as compared to 619 km^3 and the total demand excluding minimum environmental flow in the rivers would be 1108 km^3 against the total utilizable water availability of1123 km^3 (Chakraborty et al,2012) . The 2030 Water Resource Group (2012) has estimated a much higher total demand of 1498 Km^3 in 2050.As per projections of Asian Development Bank, under A1B climate change scenario, India may suffer a negative water balance of 300 BCM by 2030 and 400BCM by 2050 (Ahmed and Suphachalasai,2014). The estimated water demand supply gap by 2030WRG (2009) are much higher, as they have placed it at 750 BCM by 2030 itself. The positive side of the story is that a large basket of technologies, to trigger productivity growth at reasonable cost, is available. Another positive side is that government seems to have realised the importance of water to India's food and nutrition security.

Energy

Climate change will lead to increase in food and water related energy demands. The situation will be further worsened by

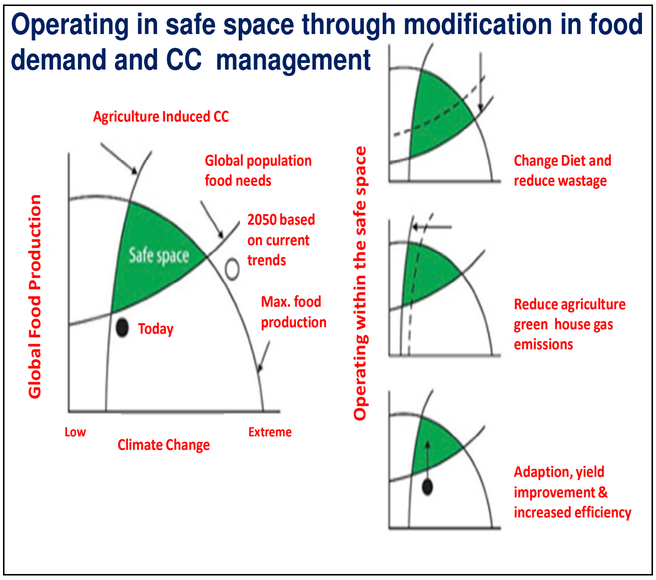


Fig. 3: A safe operating space for interconnected food and climate systems (Beddington et al, 2011).

high subsidy on energy which encourages wasteful water use, leading to depletion of water tables and higher energy consumption. Higher temperatures pronged droughts, as number of consecutive dry days for 10 years return period will go up from 139 to 142 by 2050(,2014) , will increase demand for irrigation .The estimated energy demand in agriculture sector is projected to increase from 21 Mtoe in 2011 to 74 Mtoe in 2050, in the reference energy scenario (REF) (TERI, 2011).

MEETING THE CHALLENGE OF CLIMATE CHANGE IN AGRICULTURE

A sustainable food production system can be maintained, only if use of all the nature's resources (water, land, biodiversity and nitrogen etc) remain within the scientifically defined boundaries and operate within safe space, as outlined by (Rockström et al., 2009). When applied to food system, the concept of operating in safe space, implies (i) modifying the food demand by change of diets and waste reduction ,and (ii) reduction in green house gasses from agriculture through adaptation by yield improving and efficiency increasing measures (Fig.3) (Beddington et al,2011). The reduction in emissions of greenhouse gases in agriculture will, to some extent, turn down the heat. In this paper only adaptations, which can be implemented at the level of crop production system, are discussed

Adaptation to climate change

The impact of rise in green house gasses (GHGs) under climate change is addressed through two distinct but complementary approaches- mitigation and adaptation. In agriculture the opportunities for adaptation, which connotes adjustments to moderate the impacts of climate change, are higher than mitigation. The adaptation requirements depend on the vulnerability in terms of loss in production and/ or income from agriculture (Howden et al, 2010) under the given set of biophysical as and socio-economic factors. As the degree of climate change becomes high, the efficacy of the adaption measures goes down and so do the benefits requiring change from incremental adaptations to systems' adaption; and finally to transformational adaptations.

Enhancement of agricultural productivity without putting excessive additional green house gasses into the atmosphere is one of the keys to adaptation led mitigation. This essentially means reducing the water and energy footprints along the entire food chain. To begin with, this process has to start with crop production where water foot prints of important crops are much higher than the global average (Table 2).

Table 2: Average water and energy foot prints of crops in India

Crops	Global average water foot prints, (m^3/t)@	Average water foot print in India (m^3/t)@	Average energy foot print in India* (MJ/t)
Paddy	1673	2070	6317
Wheat	1827	2100	5322
Maize	1222	2537	4847
Potatoes	287	291	1690
Sugarcane	3048	6026	888
Rapeseed	2271	3398	7574
Seed cotton	4029	9321	19785

Source: Mekonnen and oekstra (2010) @ ; IASRI (2013)*

The guiding principles for building resilience in water resources systems are based on limiting water as renewable supply, adaptive allocation, transparent water markets and maintenance of environmental flows (Box 1).

Box-1.Broad Adaptation Options to Sustainability of Agricultural Water Use

- Altering crop varieties /species to suit altered thermal regimes and resistance to other biotic and abiotic stresses
- Altering irrigation and drainage practices and methods to respond to changed atmospheric and root zone environment.
- Practicing conservation farming (tillage, residue management, land shaping) to harvest and conserve water.
- Diversification and reallocation of water and land resources
- Improvement in weather forecasting, enhanced use of weather advisories and insurance of climate risks through risk transfer mechanism to minimize production risks of the farmers.
- Transparent water markets
- Policies to incentivize optimal mix of options

Minimizing economic and environmental tradeoffs often remains an issue in observance of these principles

Agro-technology –water and energy nexus and resilience in water resources systems

There are number of technological, economic, regulatory and policy based options which may be used to increase the resilience of water resources (2030 WRG, 2009). The objective criterion for selection is, that the technologies should lead to improvement in soil health, and help maintain ecosystem services. Development and adoption of the appropriate agro-technologies, those would minimize tradeoffs and increase synergy between, food and nutrient security; water and energy sectors, is a challenge. But there is very strong empirical evidence to show , that increasing land and water productivity though various agro-technological interventions and their mainstreaming in public development policies is the key to minimizing the projected water demand and supply gaps(Schipper, 2009; 2030 WRG, 2009; Chakraborty et al, 2012; Iglesias and Garrote, 2015).

There being a very close nexus between water, energy and food production systems, adoption of different technologies, gives rise to differential GHG emissions. Collectively, these can be termed as climate smart agricultural technologies (Agarwal,2008).The important water smart technologies include improved irrigation techniques (irrigation scheduling, laser levelling, micro-irrigation, system of rice intensification, alternate wetting and drying(AWD),deficit irrigation etc).

Some of these technologies such as laser levelling, micro-irrigation and reduced tillage have been out scaled in sizeable areas. Laser levelling ,which has been extensively promoted in Indo-Gangetic Plain, was found to save water to the extent of 20-30 %,increase yields by 15-20 % and the reduction in energy used in pumping was a bonus (Jat et al,2006).Similarly micro irrigation which has so far been extended over 4Mha, proved to be a 'triple wins' intervention as it was estimated to have increased production by3.483 Mt, reduced water use by 0.73Mham, and effected GHG reduction of 5.555 CO2e, Mt (Table3) at average efficiency of 30 % (Joshi et al,2015

Introduction of zero–till drill has made a revolutionary change in seed bed preparation and seeding of crops by reducing the cost and time required for sowing .A special feature of this technology, which is hugely significant for climate change adaptation, is its energy saving. The water productivity of zero tillage system in rice wheat could be higher by 15-37 %, while the net global warming potential is lowered by 26-31 % as

Table 3: Water saving, production increase, food grain increase, and emission reduction from due to existing 3.87Mha area under micro irrigation (Tyagi et al, 2014)

Parameters	Increase in water saving productivity/Food grain availability, and reduction in emissions at efficiency		
	20 %	**30 %**	**40 %**
Saving in water, Mha-m	*0.488*	*0.733*	*1.47*
Increase in production,(Mt)	2.522	3.483	4.644
Increase in food grain availability, (kg/cap/yr)	2.08	3.13	4.16
Reduction in GHG emission,CO2e,Mt	3.704	5.555	7.605

Table 4: Simulated yield, irrigation, global warming potential and net benefits resource-conserving technologies in Modipuram (Pathak et al, 2011)

Treatment	Rice+ Wheat Yield (t/ha)	Rice+ Wheat irrigation (cm)	Irrigation WP (kg/m^3)	GWP (CO2 e. kg ha−1)	Net benefit (USD/ha)
Puddling + TP rice &CT in wheat	12.2	271.4	0.449	5853	563
DS rice after ZT and DS after ZT in wheat	11.1	188.7	0.588	4408	651
TP rice after ZT &DS+NT in wheat	11.6	229.9	0.505	4752	629
CT-Conventional tillage DS-Drill seeded, TP-Transplanted, ZT-No till, WP-Water productivity, GWP-Global warming potential					

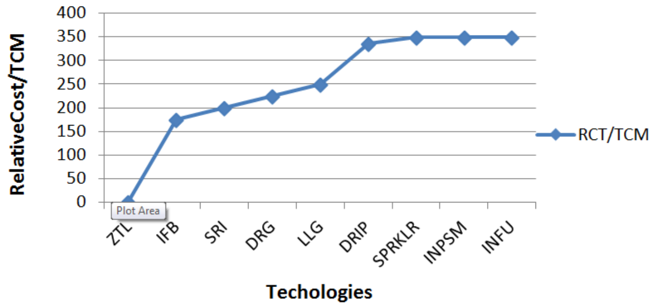
compared to conventional tillage systems (Table 4) (Pathak et al, 2011). An increase of 28 % in water productivity in wheat has been reported from Bihar (Upadhyaya and Sikka,2016. It is apparent that higher water productivity (lower water foot print) is associated with lower warming potential and adaptation led mitigation.

Some other adaptations like adjustment in crop areas, reallocation of water or introduction of tolerant cultivars have been found to be useful(Howden et al,2010; Iglesias and Garrote,2015),but may generate conflict between productivity (income) and environmental sustainability goals, as is happening in northwest India's rice-wheat system and groundwater decline.

No single technology can reduce the water demand supply gap, and therefore adaptation to climate change requires adoptions of multiple technologies. The optimal technology mix varies with location and socioeconomic situations of the adaptors. Decision making prioritization tools, like cost curve, payback period curve and quantitative modelling, which now have become available, could be used in deciding the portfolio of technology actions (2030WRG, 2009; Ahmed and Suphachalasai, 2014).

Relative cost of water saving and productivity increasing technologies

The water savings technologies have cost attached to them and these cost differentials help us order of priorities in which ,the technologies are chosen for implementation. Incremental cost to achieve a unit saving in water has been suggested by 2030 WRG (2009) as one of the tool to plan implementation of technologies. The cost curve that was developed by them for this purpose indicate that incremental cost per unit of water saved can vary from less than rupee for cubic meter saved/generated to more than 100 rupees. Amongst the on-farm agro-technologies, practices like zero tillage, integrated balanced fertilizer use or system of rice intensification, increase not only crop yields, but reduce the overall cost of cultivation. Therefore such interventions bridge the water demand and supply gap with no direct cost to be assigned to water savings resulting from their implementation and incremental costs are shown as negative. Some other technologies like improved irrigation methods, save water by way of improved efficiency as well as increased yields (consequent reduction in irrigated area requirement).Technologies like improved germplasm results only in increased yields with no direct water savings. But the potential of these technologies to bridge the demand and supply gap is much large. For example, estimates by 2030 Water Resource Group (2009) indicated that yield increasing technologies could reduce water demand by 50 BCM as compared to only 15 BCM by agricultural efficiency improvement .The relative incremental costs of some of these technologies are shown in Fig.5. It must be appreciated that cost curve is a only a tool which can help decide the choice of a given technology or a combination of technologies to achieve the desired target water saving, provided the technology is suitable for application.



ZTL-Zero till, IFB-Irrigation-fertilizer balance, SRI- System of rice intensification, IRDRG- Irrigation –drainage, INPSM- Integrated plant stress management LLG-Laser levelling, INFU- Increased fertilizer use, TCM-Thousand cubic meters.

Fig. 5: Relative cost (RCT) of generating additional water through some agricultural water demand management technologies (Chakraborty et al, 2012).

Impact Assessment of Out-Scaled GRTs and Development Policies on Mitigation and Adaptation to Climate Change

The Government of India has promoted development of agriculture by incentivising green revolution policies (GRTs) (improved seeds, irrigation and fertilizers) with policy focus on subsidies on water, electricity, fertilizers and implements. The role of these development policies in combating climate change has been recently evaluated by Joshi et al (2015).The first order assessment indicated that these policies were highly successful in reducing the potential GHGs intensification, which has been termed as virtual mitigation(Fig.6). The adaptation led mitigation limited the increase in green house gas emissions between the base year (1990) and the target year of (2010) to only by 12 $MtCO_2e$ (6.6 %) as compared to the potential increase of 430 $MtCO_2e$ (137.6 %).The virtual mitigation was of the order of 237 $MtCO_2e$.The incremental adoptions of GRTs between1990-2010 resulted in production and productivity increases, and lowered the food grain production foot print (tCO_{2e} / t_{FG}) from1.196 in 1990 to 0.907 in 2010. Additionally, it avoided the deforestation of 56.6 Mha of additional land, which otherwise would have been put under the plough to reach food grain production of 232 Mt, achieved in 2010.

Impact of irrigation sector policies on GHG emission balance

The productivity of rainfed agriculture in India hovers around 1 t/ha as compared to 3 t/ha in the case of irrigated agriculture (Ministry of Agriculture, 2012). If we consider contributions to productivity and benefits of avoidance of the forestland conversion to cropland, irrigation (surface and groundwater) has contributed to net virtual mitigation of the order of 87.32 $MtCO_2eq$ (Table 5). However, if we do not consider these benefits, there has been a net addition of 7.64 $MtCO_2eq$ due to irrigation development.

Irrigation has played positive role so far as productivity increase is concerned. The productivity of rainfed agriculture in India hovers around 1 t/ha as compared to 3 t/ha in case of irrigated agriculture which is indicative of the major role irrigation played in *adaptation led mitigation*. But the

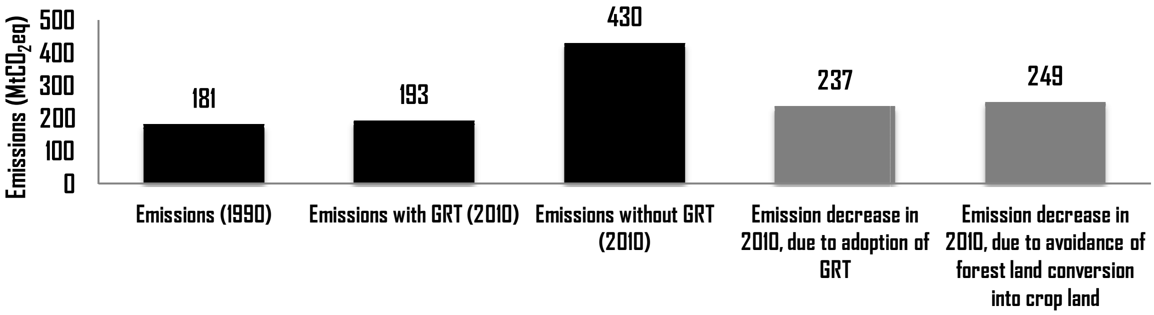


Fig.6: Estimated GHGs emissions from land under food grains with and without incremental adoption of green revolution technologies in India

Table 5: Intensification (IIF) and Mitigation (MI) indices for different GRTs (Tyagi et al, 2014)

Technology	With AFC	With NAFC	Intensification Index (IIF) (%)		Mitigation Index (MI) (%)	
	Mitigation	**Intensification**	**IIF_{AFC}**	**IIF_{NAFC}**	**MI_{AFC}**	**MI_{NAFC}**
All GRTs	(-) 107.40*	(+) 141.80	2.80	46.10	97.20	53.90
Fertilizers	(-) 12.26	(+) 35.22	5.52	50.25	94.48	49.75
Irrigation (SW+GW)**	(-) 87.32	(+) 7.78	8.63	41.57	91.37	58.43
Irrigation (GW)	(-) 41.20	(+) 15.72				
Micro-irrigation						
- Current area (4Mha)	(-) 2.15	(+) 1.25				
- Potential area (40Mha)	(-) 22.24	(+) 12.97				

*(+) = Increase in emissions/intensification; (-) = Decrease in emissions/mitigation

**SW=Surface water; GW=Groundwater, AFC=Avoidance of forest land conversion, NAFC= No avoidance of forest land conversion

irrigation and power sector policies of subsidy on energy and water and absence of regulations on ground water abstraction, have led high stresses on the water resources systems. As seen from Table 5, the degree of development in surface water (DDS) and abstraction ratio in groundwater (GWAR) were already high in 2010 and enter the extreme range by 2050.

Table 6: Sustainability indices of water resource development in India

Item	Level of development (BCM)		
	2000	**2010**	**2050**
Surface water	360 (690)*	404	647
Groundwater	210 (396)*	260	396
Degree of stress			
DDS	0.522 (High)	0.586 (High)	0.938 (Extremely high)
GWAR	0.530 (Normal)	0.657 (High)	1.00 (Extremely high)

CONCLUDING REMARKS

The land productivity, water and energy nexus offers both opportunity and challenge to improve food security minimize GHGs emissions though adoption of water smart technologies.

Government policies which were responsible for intensification in agriculture sector, which had positive impact on adaptation, also hold benefits for mitigation. Policies which led to incremental adoption of agronomic technologies might not have achieved absolute mitigation, but they did minimize the intensification of emissions (virtual mitigation).

Expansion of irrigation has been helpful in adaptation to climate change, while also holding potential for mitigation. However, with the current functioning, the sustainability of irrigation systems remains threatened and the government should rise up to the occasion to plug the policy loop holes and strengthen water governance. The agriculture sector's adaptive capacity and resilience might remain constrained or even diminish, if the production systems become unsustainable.

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