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Adaptation: An Agricultural Challenge

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Abstract: Agriculture is quite sensitive to climate change and to date it has been impacted in many ways. In turn, adaptation to lessen the impacts has attracted increasing attention. Here we discuss private and public roles in adaptation, as well as procedures for the evaluation of adaptation projects. Additionally, we discuss adaptation realities and limits that constrain the practical ability of adaptation actions to cope with climate effects.

Keywords: climate change; adaptation; agriculture

1. Introduction

Adaptation is not a new enterprise for agriculture as farmers have adapted to local climate for centuries. But the motivations for adaptation are entering a new era. The Intergovernmental Panel on Climate Change (IPCC) has amassed evidence that climate change is here today affecting the way we live [1]. They also assert that climate change will continue at an accelerating rate [2]. This raises the adaptation challenge for agriculture.

In considering this challenge, the IPCC calls the next 25 years the era of committed climate change [1] as all of their future scenarios exhibit about 1 °C of warming by then. This reflects a lag in climate action, as well as a delay between mitigation intentions and the actual realization of reductions. Inevitable climate change also reflects (1) momentum in emissions caused by income and population growth; (2) long-lived, expensive capital facilities that will influence emissions for years to come; (3) lagged physical responses such as the time for the ocean to come into equilibrium, and; (4) the long atmospheric lifetime of some greenhouse gasses.

This inevitable extent of climate change has large implications for agriculture. First, the 1 °C of committed climate change virtually mandates agricultural adaptation during the next 25 years (for discussion see Rose and McCarl (2008) [3] and McCarl (2015) [4]). This adaptation would address the need to develop practices and management systems that maintain a productive agriculture for avoiding food security issues. In the past agricultural adaptation, once achieved, would last for a long time, but today adaptation needs to be continual as climate change proceeds. Furthermore, the ability to adapt is limited in places by financial, human, and physical capital, as well as by lifestyle and culture barriers [5]. Moreover, many farmers learn farming practices and potential adaptations from their elders, but additional forms of learning will be needed if climate change alters the best enterprise mix. For example, lands that were: (1) traditionally cropped may be best moved into livestock; (2) mainly devoted to wheat may be more productive in corn, and; (3) producing corn may be desirable to move into sorghum. And the shifts in feed supply and livestock incidence may also be desirable. Collectively such dramatic enterprise shifts may well shift into unfamiliar situations, raising needs for extension and other forms of information dissemination.

Addressing this adaptation challenge requires actions such as: (a) the early identification of climate change effects that merit adaptation efforts; (b) the identification of adaptation alternatives and dissemination of related information; (c) the identification of who will and will not do particular types of adaptations, and; (d) the identification of factors limiting adaptation including possible funding or other support needs. In this paper, we will discuss these issues and draw implications for agricultural adaptation research, development, extension and public support.

2. Agricultural Sensitivity to Climate Change

Climate change is altering temperatures, rainfall patterns, regional climate variability and the incidence of extreme event incidence [2]. Such changes influence agricultural productivity water needs, production costs and the incidence of pests and pathogens [1,6–9]. Additionally, post production processing, storage, packaging, transportation, refrigeration and retailing are also affected [10]. These effects are not geographically uniform being widespread and complex [1]. For example, climate change may damage agriculture in hot areas, but benefit it in cold places. Due to such geographic diversity, climate change has been projected to have little impact on total United States production [11–14] with damages in the south [15] being offset by benefits in the north [16]. But climate change may threaten agriculture and food security of geographically small countries located near the equator [17,18].

2.1. Crop Yield

The effects of changes in temperature, precipitation and carbon dioxide on crop yield vary across regions and crops [19–22]. Lobell and Field (2007) [20] indicated that climate change (temperature and precipitation) had negative impacts on maize and wheat yield at a global scale, with most of the impacts driven by temperature. They also stated that the climate change offset the impact of the increasing carbon dioxide during 1980–2001. Attavanich and McCarl (2014) [22] and Ainsworth and Long (2005) [23] worked with the free air carbon dioxide enrichment (FACE) experimental data, and found that the yield of soybeans, cotton and wheat responded positively to elevated carbon dioxide, but that corn and sorghum did not show any significant response.

Studies have also begun to examine the effects of extreme weather. McCarl et al. (2008) [24] found that the increased variability of temperature decreased crop yield. Schlenker and Roberts (2009) [25] found the incidence of extreme heat decreased the yield of corn and soybeans. Attavanich and McCarl (2014) [22] found that droughts, precipitation intensity, and hot days had yield decreasing effects, as well as the fact that growing CO_2 concentrations enhanced C3 crop yields under drought (C3 crops refer to the crops with the reduced pentose phosphate pathway or the C3 pathway of photosynthesis that do not have growth directly stimulated by increased atmospheric carbon dioxide concentrations [26]).

Additionally, the cumulative rates of technical progress are being affected on a regional basis, particularly in the low latitudes [27]. Carbon dioxide also has effects on yield growth increasing rates for C4 crops like cotton and wheat [22] (C4 crops refer to the crops using the C4 dicarboxylic acid pathway of photosynthesis that have growth directly stimulated by increased atmospheric carbon dioxide concentrations [26]).

2.2. Agriculture Water Use and Supply

Agriculture irrigation water use is dependent upon precipitation, temperature and soil moisture, which are all affected by climate change [28,29]. Increases in temperature enlarge crop respiration and evapotranspiration, in turn increasing irrigation water use [13]. In some regions (Southern Europe, North America and part of Asia), studies have projected a more than 20% increase in water demand under most climate scenarios [30].

Climate change also alters water supply [29]. Many studies have shown that it regionally reduced river flows, as well as diminished ground water recharge [1,31]. Climate change is expected to alter water seasonality, meltwater from glaciers and water demands for non-agriculture and environmental protection [29,32].

2.3. Pests and Pathogens

Pest and pathogen incidence is being changed, affecting crop and livestock performance and pest treatment costs [6,33,34]. Studies have shown effects on the growth and distribution of weeds [33,35]. Invasive species have moved poleward causing increased crop losses [36]. Pests have experienced greater winter-survival, and migratory insects are arriving earlier [36]. On the livestock side, studies have found greater incidence of pathogens and diseases [34,37,38].

2.4. Livestock Performance

Increased temperature has been found to alter livestock mortality, yield, reproductive efficiency and other performance [37,39,40]. Again, this is not regionally uniform with increased temperature benefiting livestock in colder areas, but damaging them in hot areas [37]. Hahn et al. (2001) [41] reported that nearly 5000 head of cattle died due to heat waves in 1995 and 1999 in the United States. Additionally, Hahn et al. (2005) [42] found that changes in climate reduced summer season milk production and conception rates in dairy cows in warmer areas.

Climate change also alters feed supplies through impacts on forages and crops. Reilly et al. (2003) [7] asserted that the grass growth would be altered by climate change. Also, as discussed above, climate change can reduce grain and oilseed production, which is used as the feed of livestock.

2.5. International Trade

Climate change will alter regional comparative advantage and trade [43]. International trade is one of the possible adaptation strategies. However, in studies the net effect of international trade was relatively minor in terms of the net effects on the U.S. [7]. But for other countries climate change can be quite damaging [17,44], and trade again is an important adaptation method [17].

3. Observed Adaptation

Agriculture has always adapted to climate with regionally specific adapted systems being observed across the world. However, the pace of climate change is much faster than that in recent history. In fact, global temperatures have increased by about one degree centigrade since the mid-1970s [45]. This and other associated changes in precipitation and temperature has altered agricultural yields as shown in a number of econometric studies [19,22,24,25]. Consequently, observations of recent management practices revealed that adaptation strategies have been undertaken. In this section, we review evidence on observed and projected adaptations regarding crop management, water usage, weed and pest control, and livestock as climatic circumstances are changing.

3.1. Crop Management

The most discussed climate change adaptations for crops are changes in crop timing, crop mix/production locations and input usage.

- Reilly et al. (2003) [7] documented changes in the weighted centroid of U.S. crop production for corn, soybeans and wheat.
- Park, McCarl and Wu (2016) [46] examined how crop mix changes in response to temperature and precipitation through econometric analysis. Adams et al. (1999) [13] found climate change caused crop mix to change in a modeling study.
- Cho and McCarl (2017) [47] found that crop production was shifting to higher latitudes and elevations under climate change, while Fei, McCarl and Thayer (2017) [16] found this in a modeling study.
- The United States Environmental Protection Agency (EPA) indicated that the average crop growing season increased almost two weeks since the year 2000 [48]. Sacks and Kucharik (2011) [49] indicated that soybeans and corn were being planted earlier than before in the U.S.

3.2. Water Management

Substantial adaptation has occurred in irrigation practices and facilities with observed actions being.

- Alterations in the amount and timing of irrigation, water collection technologies and water transfer infrastructure construction [50]. Ngigi (2016) [51] mentioned smallholder irrigation development, micro-irrigation systems, greenhouses for smallholder farmers, rainwater harvesting and management, energy sources for pumping water, overall farm water management and climate/weather/technology information dissemination and capacity building. Geerts and Raes (2009) [52] discussed deficit irrigation (DI) as an adaptation strategy, while Keplinger et al. (1998) [53] and Keplinger and McCarl (2000) [54] evaluated and discussed irrigation suspension in dry years. Deressa et al. (2009) [55] addressed irrigation choice versus other adaptations.
- Means III et al. (2010) [56] listed five water planning approaches to address the uncertainties of climate change (e.g., classic decision analysis, scenario planning, robust decision making, real options, and portfolio planning). Basically, these methods used probability or scenarios to manage climate change uncertainty [56].
- Many countries that have incorporated climate change into their water management planning process. Arnell (2011) [57] discussed this in reference to England, while Huq et al. (2004) [58] discussed it for Bangladesh and Mali.

3.3. Weed and Pest Control

Climate change can enhance weed and pest damage on agriculture and causes farmer adaptations.

- Chen and McCarl (2001) [6] showed that farmers increased pesticide treatment costs in response to changes in: growing yearly average temperatures; warming winters; changing rainfall patterns, and; droughts.
- Howden et al. (2007) [50] discussed altering pest related management using crop diversification and species resistant to pests and diseases, developing integrated pest and pathogen management systems, upgrading quarantine and monitoring management.
- Rhodes (2016) [59] showed adjustments involving the costs of fungicides, insecticides and herbicides along with the use of pest-resistant genetically modified organisms (GMOs), again with the adaptation extent differing on a regional basis.
- Smith and Menalled [35] discussed the superiority of weed management as opposed to weed control such as herbicides and tillage. They stated integrated weed management referred to actions that not only control weed problems, but also reduce weed invasion and emergence, prevent weed reproduction, change crops less sensitive to weed problems, control crop residues, manage fertilizer, add organic matter, and minimize weed competition with crops. Furthermore, they stated that weed management concentrated on figuring out and preventing the causes of weed problems before they became difficult to cope with.

3.4. Livestock

Livestock producers have been seen to adapt through shifts in the livestock species they raise, as well as the breeds used and the management of the animals.

- Seo et al. (2009) [60] found that species incidence shifted with climate in Africa. They pointed out that beef cattle were replaced by goats and sheep in warming regions, and in wetter regions cattle and sheep shifted to goats and chickens. In a follow-up study, Seo et al. (2010) [61] found that climate change stimulated species shifts in South America.
- Moving to a more diversified production system is an identified adaptation practice [50]. Such adaptations have been found in studies in Africa and Australia [62–64].

- Breed changes within livestock species is another adaptation. Zhang et al. (2013) [65] found that in hotter regions of Texas more heat-tolerant cattle (*Bos indicus*) were raised relative to traditional breeds (*Bos Taurus*). However, Howden et al. (2008) [66] pointed out that usually the more heat tolerance breeds exhibited, the lower the productivity of livestock breeds was. Additionally, there were quality differences leading to lower prices [67].
- In terms of management, strategies like adjusting the stocking rate, varying the season of grazing and altering pest management have been observed [68]. For example, Mu et al. (2013) [38] found that cattle stocking rates decreased with less precipitation or an increasing summer temperature-humidity index (THI). However, they found this effect was regional with colder areas increasing stocking rates.
- Land use change has been observed between cropping and grasslands [47,69]. Again, this varies by region with higher latitudes more likely to move into cropping and lower latitudes more likely to move out.

3.5. Insurance

An alternative observed adaptation involves the use of insurance [70]. Panda et al. (2013) [71] and Falco et al. (2014) [72] discussed the importance and incidence of crop insurance in a climate adaptation context. Surminski and Oramas-Dorta (2014) [73] observed increased incidence and role of flood insurance again under climate change. In terms of crop insurance, the 2014 U.S. Farm Bill moved more toward insurance [74]. Additionally, in recognition of changing yields (to which climate change is a contributor) the U.S. crop insurance program is adopting a trend-adjusted program yield which is more dependent on recent yields [75]. In general, climate change raises issues for insurance providers as distributions of crop yields and water availability are changing [24,76]. This means insurers have difficulty setting rates and may withdraw from risky markets with greatly altered coverage and premiums [77,78].

4. Adaptation Roles

Adaptations can occur through human actions or natural, ecological change. Natural adaptations result from ecosystems adapting through autonomous mechanisms, such as altered bird migrations; species invasions; and shifts in ranges of fish, animals, insects, trees, and plants. Human adaptations involve practice and land use shifts as discussed above. Here we will further discuss roles of different parties in implementing human adaptation.

Human adaptations have been characterized as being autonomous or planned [1,79]. Autonomous adaptations are those undertaken by individuals in their own best interests without any external incentives. Planned adaptations are generally public (government, NGO and other groups) actions to resolve problems that are not sufficiently addressed by autonomous actions. To economists, the planned activities are public actions that address a public good issue, while the autonomous ones are private actions. From hereon we will discuss these as public and private adaptations.

Private decision makers implement autonomous adaptation for their own benefits, and these activities are "without directed intervention of public agency" [1]. Following McCarl (2015) [4] and McCarl et al. (2016) [80], a list of possible private agricultural adaptation actions are as follows:

- Altered agricultural management, machinery investment, processing industry types and locations and resource supply/use. They may be supported by public involvement providing subsidies or altering input cost, in turn incentivizing adaptation actions.
- Alterations in the crop and livestock types present in an operation.
- Changing land allocation between cropping, grazing and other uses plus the geographic location of enterprises.
- Altered locations and capabilities of processing and transportation facilities in conjunction with regional shifts in agricultural product outputs.

- Increasing the stock of adaptation information on enterprises, practices, and so forth, through with interactions with extension, other communication vehicles or formal education.
- Development of private institutions to facilitate adaptation (e.g., altering available forms of insurance and provision of adaptation financing).
- Increasing trade with other regions or countries to correct for any production reductions or to sell surpluses.

On the other hand, what are called planned or public adaptations are primarily implemented by public efforts, and cope with public good issues like market failures, information failures, and resource limits [80–82]. The adaptation actions undertaken in this context generally are options that do not allow private individuals to capture the full benefits of their implementation. Consequently, without public intervention there is an insufficient level of private adaptation investments in such actions [83]. Again following McCarl (2015) [4], McCarl et al. (2016) [80] and IPCC (2014) [1], broad classes of public adaptations are:

- Direct capital investments in major infrastructure facilities for resource supply (dams and irrigation water dissemination), and means for product movement (roads, airports, bridges, ports), along with other infrastructure investment.
- Research and development investment creating climate-tolerant crop and livestock varieties plus new production practices appropriate for the altered climate (e.g., improved irrigation techniques or more generally climate smart agriculture).
- Dissemination of adaptation information through extension, formal education or other communication vehicles.
- Redesign, development and support of institutions to facilitate adaptation (e.g., altered forms of insurance or extreme event early warning).
- Public assistance in implementing adaptation (providing financing, facilitating labor or enterprise movement, providing equipment or adding adaptation aspects to public policy programs).
- Altering regulations and norms like technical standards, regulations of environment.
- Implementing mechanisms that reduce or share risks like subsidized insurance or provide emergency response.
- Providing incentives for adaptation practice adoption.

Some of these adaptation actions can involve both private and public actors such as research and development in technology, the development of new agricultural practices, and facilities, processing infrastructure relocation and education on adaptation, as well as more general actions to deal with climate change.

5. Public Financial Needs for Adaptation

As stated above, adaptation involves private and public actions. Generally, the private actions do not need financing as they will be privately beneficial. However, the public efforts require funds and this has led to international climate adaptation finance groups. A number of aspects of financing merit are discussed.

5.1. Needed Levels of Financing

United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation funding as "financial assistance from Parties with more resources to those less endowed and more vulnerable," especially in developing countries. A number of studies have estimated the magnitude of adaptation funding needs. In 2016, the United Nations Environment Programme (UNEP) Adaptation Finance Gap report suggested that, in developing countries, the adaptation cost for climate change could be range of USD $140–300 billion per year in 2030s, and USD $280–500 billion per year in 2050s [84]. They also said "to meet finance needs and avoid an adaptation gap the total finance for adaptation in 2030s would have to be approximately six to 13 times greater than international public finance today" [84]. In terms of agriculture, global estimates have been done by McCarl (2007) [85] and Parry (2009) [86] with the estimates being about USD $8 billion per year. Furthermore, the adaptation deficit is likely growing in agriculture as Food and Agriculture Organization of the United Nations (FAO) estimates indicate that current agricultural adaptation actual expenditures are about USD $244 million [87,88].

5.2. Commitments to Climate and Adaptation Financing

In 2014, the contribution of governments and intermediaries to funds financing of climate mitigation and adaptation was about USD $148 billion, which was an 8% increase over 2013 levels and a 10% increase over 2012. Estimates of the adaptation share ranged from USD $23 billion to USD $26 billion in 2014, or 17% of the total [89]. Most of that financial support (nearly 90%) was invested to developing countries [89]. A brief review of the major mechanisms and their activity follows.

5.2.1. UNFCCC Funds

In the 15th UNFCCC Conference of the Parties (CoP 15), 2009, developed countries committed to provide USD $100 billion annually by 2020 for climate activities in developing countries. This funding was supposed to come from "a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance", and shared between adaptation and mitigation strategies.

Today there are three UNFCCC funds that provide financing to developing countries:

- the Special Climate Change Fund (SCCF)
- the Least Developed Countries Fund (LDCF)
- the Adaptation Fund (AF)

The Global Environment Facility (GEF) and the Green Climate Fund (GCF) manage the first two funds listed above, and the third one is supervised and managed by the Adaptation Fund Board (AFB).

The Green Climate Fund (GCF) has raised USD $10.3 billion in pledges from 43 governments, including nine developing countries as of March 2017 [90]. The Global Environment Facility (GEF) financing amounts to nearly USD $7 billion in 2015. About 55% of that is invested through the LDCF and about 37% through the SCCF [91]. The available funds for the AFB as of 31 March 2017, are USD $175.47 million [92].

5.2.2. Multi-Lateral Development Banks

The Multi-lateral Development Banks (MDBs) finance adaptation and mitigation activities in developing countries and emerging economies through normal lending and the Pilot Program for Climate Resilience (PPCR). In 2015, more than USD $4.5 billion was committed to climate adaptation efforts from the member banks [93]. Of that, 90% was committed to public projects and 10% to the private ones.

The financial breakdown of the MDBs funding activity in 2015 was estimated as 71% to investment loans, 13% to grants, 7% to guarantees and 6% to policy-based loans/budget support. Expenses for lines of credit, equity investments, and advisory services were small. MDBs Funds by sector are: 27% for water and wastewater systems; 24% for energy, transport and other built environment/infrastructure, and; 18% for crop production and food production [93].

5.2.3. Official Development Assistance

Country-level Official Development Assistance (ODA) provides funds through three types of ODA adaptation actions: activities addressing the risk of climate change; activities reducing the vulnerability of the target community or ecosystem to climate change, and; activities possibly lightening the vulnerability of communities of ecosystems to climate change [94].

The Organization for Economic Co-operation and Development (OECD)'s Development Assistance Committee (DAC) members committed USD $9.3 billion on average per year in 2010–2012 for bilateral adaptation-related ODA, amounting to 7.1% of the total [95]. Of the projects categorized as adaptation-related aid, 29% have adaptation as the principal objective and the rest have adaptation as a significant objective but are "mainstreaming" adaptions into broader development efforts [58].

The largest amounts of financial support from ODA addressed water supply and sanitation (USD $2.5 billion on average per year in 2010–2012), and the next biggest recipients were those pursing environmental research, education, policy and administration (about USD $2.1 billion), and agriculture, forestry, fishing and rural development (about USD $2 billion).

6. Adaptation Project Evaluation

Lending activity typically involves a process where applications are submitted then evaluated with some selected for funding. In the evaluation of potential adaptation projects, we feel there are several concerns that are relevant. The current funds have a number of items guiding their evaluations. Here we cover some of those mentioned in adaptation funds documents and then later discuss some additional items which we feel are keys to effective project evaluation.

6.1. Existing Evaluation Procedures Used by the Adaptation Fund

There are many documents which reveal project evaluation criteria. Namely, Brann (2012) [96] and Adaptation Fund Board [97,98] indicated.

- Fund objectives and desired impact: Adaptation funds are to be allocated so as to increase resilience at the community, national and regional levels to climate variability and change. The desired outcomes are: (1) Reduced exposure at the national level to climate-related hazards and threats; (2) Strengthened institutional capacity to reduce risks associated with climate-induced socioeconomic and environmental losses; (3) Strengthened local-level awareness and ownership of adaptation and climate risk reduction processes; (4) Increased adaptive capacity within relevant development and natural resource sectors; (5) Increased ecosystem resilience to climate change and variability-induced stress; (6) Diversified and strengthened livelihoods and sources of income for vulnerable people in targeted areas, and; (7) Improved policies and regulations that promote and enforce resilience measures [96,98].
- Criteria to be evaluated related to those proposing the project are: (1) Financial Integrity and Management—the ability to record funds disruption, secure independent audit, manage and disperse funds efficiently with safeguards, produce forward-looking plans and budgets, and legally administer the process; (2) Institutional Capacity—Demonstrated transparent procurement procedures; capacity for monitoring and evaluation; ability to identify, develop and appraise projects; and competence to oversee project; (3) Transparency and Self-Investigative Powers—demonstrated competence to deal with financial mismanagement and other forms of malpractice [96–98].
- Project Review Criteria to be evaluated: (1) government endorsement; (2) identified concrete adaptation activities; (3) economic, social and environmental benefits, particularly with reference to most vulnerable communities; (4) cost-effectiveness; (5) consistency with relevant national strategies; (6) meets relevant national technical standards; (7) no duplication of funding sources; (8) presence of learning and knowledge management component, and; (9) justification of the basis for project cost [96,97].
- Project Submission Tips: (1) explain how the project is truly an adaptation project, as opposed to a "business as usual" development project; (2) show that climate change is the primary cause of the problem that the project will address; (3) offer adaptation measures that are suitable and adequate for addressing the identified climate threats; (4) meet the Fund's requirements for cost effectiveness, and; (5) specify the social, economic and environmental benefits of the project.

6.2. Additional Considerations

We believe there are relevant criteria beyond those discussed above, as well as a few of the above criteria that need augmentation. In particular, within the climate change mitigation context there has been discussion regarding desirable project characteristics with common mention of additionality, permanence, uncertainty and leakage (see the discussion of these concepts in McCarl et al. (2016) [80]). Generally, these concepts are also relevant in an adaptation context, and we also choose to cover co-benefits, transactions costs and equity concerns. We discuss each of these items below.

6.2.1. Additionality

The concept of additionality has two meanings within the adaptation context. The first is whether or not the available financial resources are net increasing over traditional development funds or are diverting traditional development funds. Lemos and Boyd (2010) [99] discussed this issue.The second meaning of additionality is the one used in regard to mitigation within the Kyoto protocol, which indicates the projects funded should be those that would not have been implemented in the absence of funding [100]. In particular, this additionality construct reflects the desire that investments in adaptation really stimulate additional adaptation actions that are beyond what would have happened without those investments. This implies that project proposals could be required to provide information allowing one to apply additionality tests, such as those mentioned in Greiner and Michaelowa (2003) [101]. The project activities are judged to be additional if: (1) there are barriers to the project in the without project case; (2) project developers can show that funding will overcome any barriers; (3) the costs of the project exceed benefits under the reference case; (4) the net present value or internal rate of return of implementing the project is insufficient to cause autonomous private investment; (5) the internal rate of return to the project is less than a threshold; (6) the payback period is too long, and; (7) the project adaptation benefits are significant compared to the without project case.

One difficulty with the additionality criteria is that conditions are not homogeneous. Cases will exist where judgements of non-additionality exclude people who could gain in an adaptation sense from implementation adapt and, in fact, meet some of the criteria; however, at a more aggregate level the region does not. One might want to incentivize practice adoption in a region but will not have information on what are termed "without project" reactions. Also, applying discounts based on historical regional uptake of the adaptation strategy would make the non-additional actors already using the practice most likely to apply with those not using the practice receiving lower incentives. Feng (2012) [102] discusses this issue in a mitigation context.

6.2.2. Uncertainty in Impact

While project adaptation impacts may be relatively clear, there will be uncertainty in how many in the target population may participate and how long the adaptation will be successful (i.e., the use of salt tolerant crops in low-lying areas may avoid issues with small amounts of sea level rise, but would eventually cease to function under enough sea level rise to cause inundation). In the mitigation context, Kim and McCarl (2009) [103] provides a procedure for placing a lower confidence interval on potential following a suggestion by Canada during the Kyoto Protocol discussion [104]. Such an approach could be used in an adaptation context.

6.2.3. Leakage and Maladaptation

Another mitigation project evaluation concern is leakage. Mitigation leakage occurs when greenhouse gas (GHG) emission reduction in one place stimulates added emissions somewhere else [105]. In the adaptation context, this involves cases where an adaptation action by one party raises the climate vulnerability of others now or in the future. This has been called maladaptation. We will consider two examples. First, suppose a major city that has river running through it sees a flood originating upstream and acts adaptively so as to divert the water before it reaches the city.

However, other parties that reside in the place where the water is diverted is flooded, raising their vulnerability. Second, suppose a coastal city raises levees or seawalls in an effort to adapt, in turn resulting in population increases in the protected area. Then suppose in the future that we have enough sea level rise to overtop the structures. Consequently, this adaptation action can raise the amount of future assets at risk. The extent of project-caused maladaptation could be one evaluation criteria. Those proposing the project could be required to provide documentation on the expected effects project implementation on other parties currently and parties in the future.

6.2.4. Permanence and Sustainability

Another potential evaluation criterion involves permanence or sustainability where one considers the amount of time during which the adaptation is effective and does not assume that the adaptation benefits are eternal. This may also involve the concern that the adaptation effectiveness phases out over time and one needs to consider some criteria like the net present value of adaptation benefits. For example, a project involving developing crop varieties that perform well in the face of low amounts of temperature change may create varieties that lose their effectiveness under larger temperature changes. Kim et al. (2008) [106] provided a procedure to discount project benefits based on sustainability concerns. This raises a need in project applications for discussion of the sustainability of the project.

6.2.5. Co-Benefits

Projects are commonly argued to have co-benefits. In the case of adaptation projects, generally the main objective involves correction of reduction of future risk arising from climate change. However, such projects may also lead to benefits to the extent the region currently may not be fully adapted to the climate correcting what is called an adaptation deficit [87]. In addition, climate related benefits might arise in the form of GHG emission reductions reducing future vulnerability. More generally, projects can have other economic and noneconomic benefits such as providing employment, facilitating industry growth, improving income distribution, reducing poverty, enhancing water quality, improving biodiversity, and bolstering human health [5]. These items are not all easily converted into monetary terms. Generally, this implies that any analysis of project performance is multi-metric, with part in monetary terms and other parts not, and some in precise quantitative terms and others not. It also implies that the project documents and evaluation need to reflect benefits that are not strictly regarded as adaptation ones so as to not penalize valuable projects.

Many authors have argued that the total spectrum of benefits should be part of an evaluation (e.g., see Brouwer and Van Ek (2004) [107] and Viguié and Hallegatte (2012) [108]). However, some degree of caution may be needed as full consideration of co-benefits imposes a large burden on those proposing the project, forcing them to both identify and potentially quantify the full range of co-benefits. Furthermore, there is an issue when only part of the projects covers co-benefits. Such partial coverage could bias the evaluation toward projects where co-benefits can be easily identified as opposed to other projects where the identification and quantification involves a major effort. Elbakidze and McCarl (2007) [109] raised the argument in a mitigation context that perhaps co-benefits should be neglected because of the burden they impose and the substantial effort needed to identify and quantify them across all projects. (The principles and standards for water project evaluations [110] call for the omission of co-benefits based on the argument that local employment and other benefits under a full employment economy would be offset by a loss in such benefits elsewhere.)

6.2.6. Transactions Costs

Part of the stated adaptation funds criteria that we covered above involves administrative costs where there are limits placed on them. However, it is also important to consider the mechanism via which incentives for implementation of adaptation get passed through to adaptation implementing parties relative to the actual amount of financial incentive that is passed through. It is also worthwhile considering whether there are inflated estimates of the cost of equipment and contractor services in implementing infrastructure revisions. Project documents are currently required to have some accounting of administrative costs and this should probably cover procedures for and costs of passing incentives through to adaptation implementers.

6.2.7. Equity Concerns

Finally, the adaptation fund objectives and procedures explicitly contain language that favors projects that "diversify and strengthen livelihoods and sources of income for vulnerable people" [111]. This implies that project documents need to identify how benefits will be spread among various parties, particularly vulnerable ones.

7. Realities and Limits to Adaptation

Those implementing adaptation actions should realize that adaptation simply cannot eliminate all climate change vulnerability [86]. Broadly speaking, some climate change damages may be irreversible in a realistic timeframe, may be far too costly to eliminate and may just not be technologically feasible to eliminate. Furthermore, there will be factors that limit regional abilities to implement potential adaptation strategies as discussed in IPCC (2014) [1] (Chapters 16 and 17). Generally following the list in Klein et al. (2014) [94] as modified and rephrased by McCarl et al. (2016) [80], these include:

- Knowledge, awareness, and the technology available.
- Physical and biological constraints that limit basic feasibility.
- Financial constraints such as available funds.
- Human and equipment resource constraints such as the availability of trained personnel, experienced contractors and construction equipment.
- Social and cultural constraints such as the consistency of societal values, world views, and cultural norms and behaviors with the adaptation possibilities.
- Governance and institutional constraints such as property rights, zoning, and applicable regulations.
- Economic constraints such as local state of development and regional infrastructure.
- Competing values on behalf of those decision-makers choosing adaptation strategies which lead to other actions being preferred or a lack of belief in the need for adaptation.
- Lack of larger-scale coordination where for example local water management adaptation is constrained by multi-country or -region agreements such as an international water compact.

These limits can make implementation of some strategies simply impossible or can require supporting forms of local, national or international public action (such as provision of financing, direct involvement in infrastructure development, enhancement of education, conduct of research and development plus extension, and or technology transfer) to facilitate implementation.

8. Conclusions

Climate change impacts are widely apparent and further impacts are virtually inevitable. Consequently, adaptation actions have attracted increasing attention. Furthermore, relative to mitigation, adaptation actions generally have much more immediate effects and, in cases, lower costs. Agriculture is quite vulnerable to climate change and a wide array of adaptation activities are occurring that reduce the negative effects of climate change or exploit opportunities. Part of the adaptation actions will happen autonomously without public intervention, and others need to be implemented or facilitated by public actions. A number of funds have arisen and herein we discuss procedures and criteria that might be used in evaluating the economic consequences of proposed adaptations. However, there still exists a large gap between the current level of finance and the total need. The estimates of financial needs for agriculture alone is about USD $8 billion per year and is much more than current expenditures, indicating that adaptation is expensive and that the adaptation gap is growing. In addition, it is important to recognize that adaptation cannot overcome all climate change effects.

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