CLIMATE RISKS TO AGRICULTURE/ FOOD SECURITY IN THE GMS COUNTRIES AND EARLY WARNING SYSTEMS IN THE CONTEXT OF THE FOOD-WATER-ENERGY NEXUS

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Abstract

The Greater Mekong Subregion has undergone a rapid economic growth over the past decade with positive impacts on the human development and negative impacts on the environment and natural resources. The growing demand for energy in the region and high fuel prices during 2008 has seen several countries declaring ambitious biofuel strategies from which they retreated covertly later on. This has set a debate on nexus between food, water, and energy in the region. Though the biofuels fever has died down sooner than expected, there are chances for reemergence of debate over food-water-energy due to several traditional and non-traditional pressures discussed in this paper that include increasing energy demand, population growth, urbanization, changing life styles, and climate change. Early warning systems can play a crucial role in averting situations like 2008 fuel and food prices. However, there are several bottlenecks to be overcome that include lack of infrastructure and capacity for implementing such EWS. In addition to EWS, this paper discusses some traditional off-the-shelf interventions such as general improvement in resource use efficiency in agriculture, water and energy sector, increasing energy supply through renewable sources, and creating an East-Asian Energy Community or a grid that could ease the food-water-energy nexus in the region to a greater extent.

1. Introduction

The well-being of countries in the Greater Mekong Subregion (GMS)--Cambodia, Guangxi Zhuang Autonomous Region and Yunnan Province of the People's Republic of China (PRC), the Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam–is very much linked with the Mekong River as it influences the livelihoods of a large proportion of the population in these countries directly or indirectly. The economies in the GMS are predominantly agrarian with 63% of the total population dependent on agriculture (FAO, 2011) contributing to 22.6% of total GDP in the subregion (World Bank, 2011) which signifies the importance of stable agriculture production to the livelihoods of majority of the population in the GMS.

The subregion has witnessed rapid economic growth in the past decade with both positive and negative consequences. The positive consequences are increased income levels and better progress in human development; the negative consequences include rapid degradation of natural environment; heavy pressure on natural resources, such as water, land, and forests; and heavy demand for all forms of energy. Despite the development gains, including steady increase of food supply over the past several years reaching a current level of 2,551 calories (kcal)/capita/day, a wide disparity in the food supply situation also exists between countries, with highest food supply in PRC (2,981 kcal/capita/day) and least in Cambodia (2,268 kcal/capita/day) and the Lao PDR (2,240 kcal/capita/day), and within the countries (World Food Program, 2004). During recent years, the global rising food prices have become a cause of concern (ODI, 2008), which was attributed to the cumulative impact of increasing population pressure; dwindling natural resources, such as land and water due to such pressures as rapid urbanization, industrialization; and introduction of biofuels that directly compete for land and water resources. These factors could be characterized as "traditional pressures" in the subregion.

Climate change brings another dimension, as a "nontraditional" pressure. Available climate projections indicate impacts on crop yields, while changes in seasonal Mekong River flows (Kingston *et al.*, 2011) might complicate the food-water-energy conflict in the GMS. This necessitates a review of current patterns of growth and alternative pathways that could reduce vulnerability to climate change while mitigating or moderating the traditional pressures, thus leading to sustainable development. This can be achieved through developing an early warning system (EWS) that keeps track of the food-water-energy nexus dynamics in the subregion and warns policy makers to take pragmatic steps to avoid catastrophic consequences. However, developing a EWS requires greater understanding of the variables underlying this food-water-energy nexus.

This paper evaluates climate risks to agriculture in the GMS, evaluates the traditional stressors that are already

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active in the subregion, helps understand the opportunities and difficulties in developing a EWS for the food-water-energy nexus, and provides a way forward in terms of policy suggestions.

2. Understanding Factors Operating on the Food, Water, and Energy Nexus

Understanding the system and different factors that determine the food-water-energy nexus is a pre-requisite for developing an effective EWS in the subregion. From the point of the nexus, the EWS constitutes the actors and the many traditional and nontraditional pressures that determine the demand and supply of food, water, and energy in the GMS.

2.1. Traditional Pressures

Rapid economic growth. The GDP of GMS economies grew at a rate of 7.3% in 2010 (International Monitory Fund, 2011) with various implications for such resources as land, water, and energy.

Growing population. The population in the subregion grew at an average rate of 0.94% during 2005–2010. Though this is less than the global average (1.16%) and that of Asia (1.08%), the populations of Cambodia, Myanmar, and Viet Nam grew at more than 1% during this period (United Nations, 2011a). In short and medium terms, the population growth rates in terms of total fertility rates in these countries are projected decline (until the 2050s); however, in long-term projections (to 2100), all the countries have positive growth rates, implying increasing population pressure on various natural resources.

Urbanization. Urbanization creates demand for land, water, and energy. The urbanization in the GMS in 2010 was 3.19%, higher than in less developed regions (2.39%) and in more developed regions (0.5%) of the world. With current policies in place, the GMS countries are projected to urbanize at the same rate until 2020 when it should start declining (United Nations, 2011b).

Energy demand. Fuelling economic and population growth has led to rapid increase in demand and consumption of primary energy in the GMS. All the countries in the subregion are net importers of energy with the PRC being the world's largest importer of primary energy. The demand for energy is set to increase until 2030 and beyond, and future energy needs are expected to be mainly met through fossil fuel sources. To avoid climate change implications, countries in the region should seek alternative energy sources, such as biofuels, that may have implications for land and water, and hence for food.

2.2. Nontraditional Pressures

Climate Change. Climate change is known to bring some additional pressures to the traditional pressures discussed above and could be more significant than expected. Most importantly, the past climate trends in the GMS suggest a significant increase in rainfall events leading to heavy runoff losses, and projections suggest an increase in rainfall and floods with implications for water and related sectors.

Among the above discussed factors, this paper focuses on two important pressures, energy and climate change. Energy demand is chosen because all other factors (economic growth, urbanization, and population growth) are manifested in terms of energy demand, and because of the implications of biofuel production (Worldwatch Institute, 2007; Prabhakar *et al*., 2009; Prabhakar *et al*., 2008; Elder *et al*., 2008). Also, energy and climate change are recognized as the most significant threats to global food security in the long run (FAO, 2009a).

3. Climate Risks to Agriculture and Food Security

Agriculture has multiple interactions with climate change. It is impacted by climate change (either negatively or positively), and it can influence climate change (both negatively through greenhouse gas emissions and positively by providing an opportunity to sequester carbon). This section reviews different observed and projected trends of climate change in the GMS for deriving implications in terms of food security and the food-water-energy nexus. Although emphasis is given to country- and GMS-specific literature, other literature that covers some GMS countries was included. The later part of this section discusses how agriculture in the region can impact the climate change.

3.1. Observed Climate Change

Few things must be kept in mind before making conclusions about the past impacts of climate change in the GMS. Some countries in the region have well established climate research programs while others are either in advanced development phase or beginning to establish research programs with external support. In most of the GMS countries, the density of meteorological observatories and the quality of data in terms of time series are limited. Hence, conclusions on the historical observations have to be made with caution.

Climate change is a global phenomenon with uneven distribution of its impacts across different geographical locations. Climate change in GMS countries is manifested in various forms (Parry *et al*., 2007; Asian Development Bank, 2009) and the countries in the region have already started showing signs of climate change (Asian Development Bank, 2009) with differences among countries.

Significant increase in the annual number of hot days and warm nights and significant decrease in cool days and cool nights were reported in Southeast Asian countries (Manton *et al*., 2001). Trends in extreme temperatures were consistent across the region. Extreme rainfall trends were less spatially consistent than were those for extreme temperature.

The number of rain days (with at least 2 mm of rain) has decreased significantly throughout Southeast Asia. The proportion of annual rainfall from extreme events has increased at most stations. A regional study based on 20-year rainfall data obtained from 16 locations in Bangladesh, Indonesia, Thailand, and Viet Nam has identified positive rainfall trends in peninsular Thailand and negative rainfall trends in Sumatra and Java islands of Indonesia (Egashira *et al*., 2003). The variability in rainfall was, however, higher in the dry season than in the wet season. In the GMS, the past trends indicated an increase in precipitation during the early monsoon season and increase in runoff (Costa-Cabral *et al*., 2008; Jianchu *et al*., 2009).

PRC. Since there is scant literature on Guangxi and Yunnan, general literature from the PRC has been cited here. In general, there has been a clear observation of climate change in the PRC. The past 100-year meteorological records indicated a warming of 1.1 °C manifested in terms of warmer winters, with 2007 as the warmest year in the recorded history (State Council of the People's Republic of China, 2008). Changes in terms of distribution of rainfall across the PRC were reported with distinct trends of increased precipitation in western and southern PRC and decreased precipitation in northern and northeastern PRC. Increase in heavy precipitation events was observed in the southern PRC, which has implications for the GMS since a large proportion of water in the Mekong River originates from Yunnan Province, mostly from snowmelt in the Tibetan plateau and precipitation. There is a high probability of association between accelerated glacier melting and increased surface temperatures in this region (Barnett *et al*., 2005) which puts this region as one of the most critical regions in the world in terms of climate change impacts on freshwater availability.

Cambodia. The meteorological data availability in Cambodia is relatively poor due to the war and destruction of meteorological observatories. To date, Cambodia has 38 meteorological observatories that record temperature and rainfall, 23 observatories that record evaporation, and 14 stations that record wind speed (Ministry of Environment, 2002). From the limited available data for the period of 1980-2000, no discernable trends were observed in temperature and rainfall (Ministry of Environment, 2001).

Viet Nam. In general, climate observations are reported to be in conformity with the regional and global trends. The monthly mean temperatures have increased by 0.07 to 0.15 °C per decade (Ministry of Natural Resources and Environment, 2003). However, these observations are not uniform throughout the country with some observatories showing a different trend from the national trend. The temperatures recorded at A Luoi and Nam Dong stations in 1974–2004 showed an increasing trend (NCAP, 2007). The temperature recorded at Hue station indicated a slight declining trend during 1991–2004 with no clear trend over 1928–1990. In most locations, the January temperatures (winter season) were observed to have become warmer when compared to the July month (summer season). The annual rainfall at A Luoi and Nam Dong has increased by 800 and 600 mm, respectively, during 1974–2004 with relatively stable rainfall before the 1990s. The rainfall has increased during the rainy season (August-December and April-May) and decreased during drier periods (June-July) with significant drought risks during drier periods and floods during the rainy season. At Hue, the trends were more complex with increasing trend of rainfall after 1996. At this location, rainfall showed a decreasing trend during January-March with values crossing the 100 mm drought threshold in most years after 1986.

Thailand. Known as the rice bowl of Asia, any changes in temperature and precipitation patterns in Thailand could lead to negative impact on the food security of the region. The observed maximum and minimum temperatures showed an increasing trend in Thailand during 1951–2002 (Greenpeace, 2006). From a long-term perspective, based on principal component analysis of temperature data available between

1951–2003, the minimum temperatures have been reported to increase at an unprecedented rate since the early 1950s, consistent with the global and hemisphere average patterns (Limsakula *et al*., 2008). The minimum temperatures changed quicker than the maximum temperatures leading to narrowing down of diurnal temperature ranges in Thailand. Maximum temperature increased significantly at Nan, while the increases at Prachuap Khiri Khan were not significant (Manton *et al*., 2001). Temperature changes in other parts of Thailand are not consistent with the above observations. The northern provinces of Thailand, which include Chiang Mai, Chiang Rai, Lampoon, and Lampang, Phrae, Phayao, Nan and Pitsanulok, did not show any long-term trends (Kwanyuen, 2000).

Summer monsoon rains are a critical factor in Thailand's water resources and agriculture planning and management. Consequently, understanding the variability of the summer monsoon rains over Thailand is important for instituting effective mitigating strategies against extreme rainfall fluctuations. The observed rainfall pattern in the Chao Phraya Delta, which is considered the rice bowl of Thailand, has shown a declining trend over 1952–1991 (Kwanyuen, 2000). The reduction in rainfall was prominent in the river basins of Kok, Ping, and Nan rivers and no changes were observed in the Salawin, Wang, and Yom basins. The sub-basin level observations were consistent with the basin level observations indicating little spatial variation in rainfall trends in these basins. At Nan, the number of rainy days has decreased significantly, and the proportion of total rainfall from extreme rainfall has increased significantly (Manton *et al*., 2001). Prachuap Khiri Khan showed a significant decrease in rainy days. There was a significant increase in extreme minimum temperature at both stations, partly owing to a peak in 1998. The number of warm nights increased and the number of cold nights and cool days decreased. Prior to the 1980s, there was weak relationship between summer monsoon and El Niño– Southern Oscillation (ENSO). However, recent studies have indicated a negative relationship between ENSO and the summer monsoon (Singhrattna *et al*., 2005). This increasing influence of ENSO during recent decades has been attributed to Walker circulation over the Thailand-Indonesia region. In some models, a clear influence of climate change on Walker circulation has been established (Power *et al*., 2007).

3.2. Projected Climate Change

General circulation models (GCMs) are used to simulate future climate change scenarios resulting from the accumulation of greenhouse gases (GHGs). The most common GCMs employed in generating simulations are coupled GCMs (e.g., CSIRO global coupled ocean-atmosphere-sea-ice model), HadCM2 model, ECHAM4/OPYC3 model, and First Generation Couple General Circulation model (CGCM1) of the Canadian Center for Climate Modeling and Analysis. The outputs of these GCMs (e.g., monthly mean values of climate variables) are used to derive local impacts of climate change. More recently, multi-model ensembles became more prominent tools in providing more reliable climate projections than the single model approaches (Tebaldi *et al*., 2007).

Climate projections in the GMS have been difficult because most GCMs have shortcomings in representing the ENSO phenomenon, which is the strong source of variability in Southeast Asia. The projected climate change over Southeast Asia is a general warming trend (Parry *et al*., 2007; Allison *et al*., 2009), following the global mean projections (an increase in temperature of 2.5 ^{o}C up to 2099) with likely increase in precipitation (Christensen *et al*., 2007). There is high confidence in most of the climate change scenarios in the region that extreme rainfall events and winds associated with tropical cyclones will increase. There is a general tendency for models to project higher rainfall and more extreme floods in the GMS (Nijssen *et al*., 2001; Jianchu *et al*., 2009).

The conformal cubic atmospheric model (CCAM) was employed to study the impact of climate change in the lower Mekong basin (Chinvanno *et al*., 2006). CCAM is the second-generation regional climate model developed for the Australasian region, with a resolution of 0.1 degree (about 10 km × 10 km). Three levels of simulations were carried out with varying levels of carbon dioxide concentrations. The model simulations showed increased precipitation throughout the GMS, with a range of 0–500 mm per annum, and a potential high intensity of rainfall with the same duration as in the current climate. The Mekong basin would be warmer by 0.79 ^{o}C, with greater increase toward north of the basin (Eastham *et al*., 2008). The runoff would increase in most climate change scenarios projected in 2030 due to combination of high intensity of rainfall during the rainy season and accelerated melting of glaciers. The dry season runoff would remain the same across the basin, including in the Tonle Sap catchment in Cambodia. This has potential implications for increasing flood intensity during the rainy season and drought intensity during the dry season with negative impacts on agriculture.

The MIKE11 model was used to simulate flow and salinity intrusion from December to June (dry season) for the medium-term (mid-2030s) and long-term (mid-2090s) scenarios using data derived from the SRES B2 climate change projection (Khang *et al.*, 2008). Models have projected +20 to +45 cm rise in sea level with a reduction in Mekong River flow by -15% to -29%. Medium- and long-term scenarios showed that the 2.5 grams per liter (g/L) saline front is likely to shift upstream by 10 km and 20 km in the main river channels, and up to 20 km and 35 km in the paddy fields, respectively. The individual country variation in the projected climate change is discussed below.

Three GCMs (UK 89, UKMO and GISS) were employed to construct temperature and precipitation scenarios over Thailand (Thailand Environment Institute, 1999). All models showed an increase in temperature, high in the central, northern and western regions (3.0–3.5 ^{o}C) and less increase in northeast (2.5 ^{o}C). Models predicted an increase in rainfall by 20% (Bachelet *et al.*, 1992; Greenpeace, 2006). The United Kingdom Meteorological Office Hadley Centre projected a warming of 1.74−3.43 ^{o}C by 2080 (Parkpoom *et al.*, 2008). Studies also indicated that the climate change could reduce the rainfall and reduce the runoff in Chao Phraya River basin with negative impact on its catchment areas (Ministry of Science, Technology and Environment, 2000). Results from an ensemble of 20 models revealed that Thailand will warm under both low and high GHG emissions scenarios during 2040–2069 compared to the mean temperatures observed during 1972–2003 (Felkner *et al.*, 2009). The magnitude of temperature increase under the high emissions scenario will be 40% higher than that in the low emissions scenario during 2040–2069. Daily precipitation will increase throughout the year under the low emission scenario and there will be less precipitation in the second half of the year, coinciding with the growing season of the rice crop, in the high emission scenario.

3.3. Projected Climate Change Impacts on Agriculture

Projecting climate change impacts on agriculture involves complex interactions between climate, agriculture systems, and crop management. In order to obtain relevant impact projections, the climate predictions of GCMs are utilized by dynamic crop simulation models (e.g., Decision Support System for Agrotechnology Transfer), and land management decision tools. Agro-ecological models are often employed to take advantage of the high resolution of dynamic crop models while still being able to handle large-scale computations with relatively good accuracy.

Climate change is expected to threaten the rice crop, the most important staple food crop in the GMS region, due to heat-induced spikelet sterility or increased crop respiration losses during grain filling (IRRI, 2006). Most of the rice crop being currently grown is at the threshold level of congenial temperatures for rice growing. In Southeast Asia, the hottest months are before the onset of the monsoon season, March-June, which coincides with the final stage of dry season rice crop. These areas are already experiencing high temperatures, 36 ^{o}C and above. Any warming in these areas would mean significant reduction in rice yields (Wassmann *et al.*, 2009). The HadCM3 global climate model using future climate scenarios projected by the Intergovernmental Panel on Climate Change (IPCC), indicated global and regional yield decline of crops such as wheat, rice, maize and soybeans (Parrya *et al.*, 2004). The A1FI scenario[2] with large increase in global temperatures exhibited the greatest decreases both regionally and globally in yields by the 2080s. The contrast between the yield change in developed and developing countries was largest under the A2A–C scenarios. Under B1 and B2 scenarios, developed and developing countries exhibited less difference in crop yield changes, with the B2 future crop yield changes being slightly more favorable than those of the B1 scenario. In Asia, the reduction in crop yields was as high as 30%. Introducing carbon dioxide (CO_2) fertilization effects reduced the negative impact of high temperatures, especially in mid- and high-latitude areas for temperate cereals and South Asia, due to deep penetration of the monsoon in summer and a lengthened growing season. Similar benefits of CO_2 fertilization were observed in Southeast Asia.

Projected climate change scenarios suggested that the decline in yields of major crops would be: rice, 1.4% (Lobell *et al.*, 2008); wheat, 10%–95% (Fischer *et al.*, 2005); and soybeans, 10% (Lobell *et al.*, 2008). The agroecological zone models projected that the attainable wheat yields would decline substantially in the range of 10%–95% by the 2080s when compared to 1990 in Southeast Asia (Fischer *et al.*, 2005). The reduction in wheat yields is due to increasing temperatures, especially during the panicle initiation and flowering stages. The favorable area under wheat would either be reduced or move northward in the

[2] The IPCC A1FI scenario stands for fossil fuel intensive scenario characterized by rapid economic growth, a global population that peaks in mid century and declines thereafter; A2 family of scenarios represent a heterogeneous world, B1 family of scenarios describe a convergent world, and B2 family of scenarios represent emphasis on local solutions economic, social and environmental sustainability. For more description on IPCC SRES Scenarios, please refer to IPCC report on Emission Scenarios, Summary for Policy Makers (IPCC, 2000).

subregion, with expansion of area under subtropical and tropical crops replacing the wheat. Under various climate scenarios, the area covered by the cool, temperate wheat mega-environments could expand as far as 65°N (Ortiza *et al.*, 2008). Rising sea level can threaten crop production in many areas of Southeast Asia. The Mekong River Delta in Viet Nam and Cambodia is already facing the negative impacts of sea level rise and related intrusion of water into rice growing areas during the dry season (Wassmann *et al.*, 2007).

A global study on prioritizing adaptation needs for food security in 2030 was carried out by generating hunger importance ratings for all crops and region combinations (Lobell *et al.*, 2008). Climate change impacts were obtained from outputs of 20 GCMs and production changes for 2030 were expressed as relative to the average of 1980–1990. The study indicated a significant reduction in yield of rice and soybeans; 5% of the models projected a reduction in soybean yields by 10% or more and 50% of models projecting soybean yield reduction by 5% in Southeast Asia. Most of these reductions were attributed to the large dependence of historical production variations on temperature combined with the large projected warming overwhelming the large uncertainties in precipitation changes. Higher reduction in crop yields in climate change scenarios would mean greater impact of GHG mitigation. GHG mitigation in Southeast Asia could bring significant increase in cereal yields up to 130% compared to crop yields in 2000 in wheat, maize, rice and other coarse grains with most of the increments coming from the developing countries (Tubiello *et al.*, 2007).

The GMS is highly vulnerable to climate change impacts. Studies have indicated increased rainfall intensity in the subregion with implications for floods (Chinvanno *et al.*, 2006) and water scarcity during dry seasons due to reduced runoff and seawater intrusion (Khang *et al.*, 2008). The model projections on impact of future climate change on crop production were not uniform across the subregion and there is greater uncertainty (Eastham *et al.*, 2008). However, food scarcity may increase due to population pressure. Sea level rise could reduce the area under triple cropping of rice by 70,000 ha while the single crop area would increase by 38,000 and 179,000 ha for the near- and long-term scenarios, respectively (Khang *et al.*, 2008).

In Thailand, rice yields could drop by 57 % in Roi Et Province but increase by 25 % in Surin Province (Ministry of Science, Technology and Environment, 2000). The four climate models also demonstrated that climate change could increase temperature during the flowering period of crops by 1–7 ^{o}C.

This would reduce flowering and harvesting periods as well as crop yields in general. A study based on ensemble-mean of 20 well recognized global climate models following the IPCC SRES scenarios along with the DSSAT model revealed the complexity of climate change impacts on rice crop in Thailand (Felkner *et al.*, 2009). The DSSAT simulations projected yield reductions of 30%–50% in both low and high GHG emission scenarios. The yield reductions were either moderated or even improved when farmers' response to rainfall change was incorporated through an economic model.

3.4. Agriculture Impact on Climate Change

Agriculture is also a contributor to climate change as an important emitter of GHGs. Rice lands occupy nearly 60 million ha in the GMS (FAO, 2011) and are a significant GHG emitter. A range of methane emission values are reported depending on microclimatic conditions, agronomic practices, and cultivars (IPCC, 1996). Taking median values, 50 grams per square meter (g/m^2) for the PRC and 19 g/m^2 for Thailand, the region has potential to emit 12–30 million tons of methane in a single season. This range would double if there are two crops per year, and emissions from related manure management, etc., that are used for paddy cultivation are additional to these estimates. Thus, methane emissions are significant in the region and any policy intervention that aims to address climate change in the region cannot ignore these emissions.

From the above discussion, the following broad conclusions can be made that have implications for designing EWS for the food-water-energy nexus:

1. Significant observed climate change trends have been reported in the GMS in terms of warming and precipitation.
2. Climate change has specific implications for agriculture and food security, mostly through the impact on the rice crop and on freshwater availability.
3. There is great uncertainty in estimates of projected climate change impacts in the region. Most importantly, in the estimates of Mekong River flows and their impacts in various months of the year.
4. Agriculture also contributes to GHG emissions in the region and limiting these GHG emissions would have complementary impact on the water demand situation in the region.

4. Food-Water-Energy Conflict

In view of the climate change effects of fossil fuel use, many countries, including those in the GMS, are seeking alternative sources of energy, one of which are biofuels, i.e., oil obtained from biomass sourced from traditional food crops (e.g., corn, cassava, sugarcane, oil palm) or crops that have traditionally been known to provide oil for industrial purposes (e.g., jatropha). As a result, some countries in the region have rushed to set national targets of producing biofuels. The PRC has set a target of 15% share of biofuels in total transportation energy; Thailand has set a target of meeting 20% of vehicle fuel consumption by 2012 (Elder *et al*., 2008); and Viet Nam has set a target of producing 500 million liters of fuel ethanol and 50 million liters of biodiesel by 2020 (Asia Pacific Economic Cooperation, 2008). The PRC is currently the largest producer of bioethanol in Asia and the Pacific and a global leader in biofuel production, with roughly one million tons of fuel produced annually (Weyerhaeuse *et al*., 2007). About 1% of total transport fuel in Asia came from biofuels in 2004 (Worldwatch Institute, 2007).This was despite reports questioning the possibility of achieving national biofuel targets without causing food-fuel-water conflict, environmental degradation, and negative impacts on food security (Worldwatch Institute, 2007; Prabhakar *et al*., 2008).

Many crops grown for food purposes (e.g., oil palm, corn, cassava, and sugarcane) were quickly converted to first generation biofuel feedstock. It is expected that the subregion will continue to promote first generation biofuels before the second generation biofuels are fully commercialized. Even though countries like the PRC have adopted policies to discourage use of food or feed crops for biofuels, concerns persisted that these policies might be difficult to implement and that biofuels would still directly or indirectly compete with food and feed (Prabhakar *et al*., 2009). The factors that have led to the food-fuel-water conflict are elaborated below.

4.1. Conflict for Water

Producing crops require inputs, such as land, water, fertilizers, and pesticides. These inputs are essential for crops that are grown for commercial purposes where certain assured output (feedstock for biofuel) is expected in return. Biofuel crops fall under the category of commercial since they are produced for the market and are expected to return high-value commercial outputs such as feedstock for oil. Initially, there were efforts to produce biofuel from corn and food crops like cassava in the PRC but soon the Government banned using any food crops for producing fuel, fearing food-fuel conflicts (Macartney *et al*., 2007). Even after the focus was shifted to jatropha (Weyerhaeuse *et al*., 2007), the competition for land and water cannot be ignored since for optimum results jatropha requires fertilizers, land, and water. Jatropha can be cultivated without additional irrigation in areas receiving a rainfall of 600 mm or above. Under practical conditions, the rainfall is intermittent and variable, such that the crop may not produce satisfactory economic yield. Irrigation is required for such contingencies as mid-season water stress and in critical periods of the crop season, such as flowering. Expecting farmers to irrigate only during critical stages of the crop can be considered as an ideal scenario, especially as farmers often tend to over-apply fertilizers and water, expecting good returns when they have huge stakes to produce crops like jatropha as is happening with most cash crops globally. More often than not, farmers apply certain amounts of fertilizers and water even if the crop does not require them. The PRC Government has set a target of producing jatropha in an area of 1.03 million ha of wastelands in southwestern provinces, including Sichuan and Yunnan that fall in GMS. Expecting wastelands to produce an economic output from jatropha is questionable. The argument for this is that wastelands have remained wastelands because they are not fit for cultivation, either because of the poor fertility or lack of irrigation facilities (Elder *et al*., 2008; McGahey, 2008). From this logic, growing biofuels on wastelands without using external inputs, such as water and fertilizers, is doubtful. Considering the practical scenario explained above, even if 50% of farmers require water for 50% of jatropha's water requirements (i.e., 300 mm), the total water requirement amounts to an additional 3 million liters per ha or 3 trillion liters of water for 1 million ha, the target set by the PRC. This may affect the water available for the countries downstream in the GMS.

4.2. Conflict for Land with Implications for Food

An important question concerns the extent of wastelands that can be brought into cultivation without substantial investments and environmental consequences and the alternative cost of bringing these lands into cultivation for food crops. From this point of view, if bringing wastelands into cultivation is economically feasible, food production should be the main competitor for wastelands rather than biofuels, since most parts of the region have reached a plateau in crop yield gains (vertical expansion) and there is a need for horizontal expansion of agriculture to feed the millions beyond 2050 (FAO, 2009b). Allocation of these wastelands to sustainable food production makes more sense than converting them to biofuel production with environmental consequences, particularly at a time when global food prices have risen at rapid rate partly due to diversion of crops, such as corn, raised on premium agricultural land to feed cattle in countries like the PRC. This argument is even more valid in the Lao PDR and Cambodia where high rates of hunger and food poverty exist today, and for achieving relevant MDG goals rated as "unlikely" in the Lao PDR (United Nations Development Program, 2011) and "slow" in Cambodia (Royal Government of Cambodia, 2010).

4.3. Do Biofuels Pose any More Threat to Food and Water?

The initial expectations and gains made under biofuel production and consumption could not be sustained because of a combination of factors listed below:

1. The global economic depression during 2008–2009 further reduced the demand for oil.
2. The steady decline in global crude oil prices reached a level that is a disincentive for biofuel companies to produce fuel for the domestic market.
3. Reduced emphasis on biofuels has been made by the European Union in its revisions of energy policy.
4. Pressure from environmental activists made some players realize that biofuel targets cannot be achieved without substantial impact on food security and environmental health and made them covertly retreat from those targets.

However, the demand for energy is never-ending and, depending on global economic growth, developmental path, and energy choices made, there is a probability that global crude oil prices will rise in the medium and long term. According to the United States Energy Information Administration's latest projections, global energy consumption will rise from 505 quadrillion British thermal units (Btu) in 2008 to 619 quadrillion Btu in 2020 and 770 quadrillion Btu in 2035, mainly with demand from developing countries, notably the PRC and India, surpassing that from members of the Organisation for Economic Co-operation and Development (OECD) by 2015 (US Energy Information Administration, 2011). Most of this demand is said to be driven by long-term economic growth. The result will be sustained upward pressure on oil prices, which would allow ethanol and biodiesel producers to pay much higher premiums for corn and oilseeds than was conceivable just a few years ago.

Resource-use efficiency also requires greater attention in the GMS and has close linkage with the issue of biofuels and the food-water-energy nexus. Hence, biofuels are still at the center stage of policy discourse.

4.4. The Food-Water-Energy Nexus and Resource-Use Efficiency

Resource-use efficiency is especially important in agriculture for food and in energy production and utilization. Further, resource-use efficiency in one influences the other; for example, poor efficiency in energy could have implications for agriculture and poor efficiency in agriculture could influence the biofuel energy sector.

The 2008 global food price crisis was argued to have been caused or worsened by diversion of crops to biofuel production, though other factors, such as increasing population, changing consumption trends, and weather abnormalities, may have also contributed. During this crisis, many countries took extreme steps, such as restricting food exports to allay fears of food insecurity, including in some cases, measures to restrict biofuel production from food or feed-based crops; however, it was not clear how effective these measures were (Katz, 2008; MacInnis *et al*., 2008).

A simple indicator for efficiency of combined inputs is to measure the productivity of major crops grown in these countries. The productivity of rice and nitrogen use efficiency levels in the GMS (Table 1) exhibit wide variation; rice yields in the GMS increased at an average rate of only 2.7% per annum during 1990–1999 as against an increase in N fertilizer

Table 1: Productivity Levels of paddy in the GMS

Country	Productivity (tons/ha)	Nitrogen (N) fertilizer use rate (Kg N/ha)	Estimated N use efficiency (kg rice per kg N)
Cambodia	2.8	17 (FAO FertiStat, 2001)*	164.7
PRC	6.6	250 (Zhao *et al.*, 2009)	26.4
Lao PDR	3.6	55 (FAO FertiStat, 2001)	65.5
Myanmar	4.1	91 (Win, 2006)	45.1
Thailand	2.9	62 (FAO FertiStat, 2001)	46.8
Viet Nam	5.2	130 (Soong, 2006)	40.0

* This figure was crosschecked with other references, such as USDA, (2010), which states that Cambodia has the "lowest rates of fertilizer use rate in rice in Southeast Asian countries".

Source: FAO ProdSTAT (2011).

use of 15% (Mutret *et al*., 2002), which shows stagnation in yields despite of steady increase in input use.

While reasons for poor input use efficiency in each GMS country are different, improving nitrogen use efficiency would mean increase in crop yields, reduced resource use, and hence reduced pressure on land and water resources. The same logic applies to other inputs used in agricultural production systems.

5. Understanding EWS in the context of Food-Water-Energy Nexus

For the purpose of this paper, EWS in the context of food-water-energy nexus can be defined as a collection of dependent and independent variables that lead to detection and assessment of impending problems based on feedback connections operating between demand and supply of food, water, and energy. A EWS can be as simple as a collection of indicators that can provide an early warning to policy makers and other development planners at various levels. It can also be complex, employing dynamic simulation models that can quantitatively represent the real world based on the conditions defined/assumed within the model (the system).

Due to complex feedback connections and dependencies operating between food-water-energy, some of which was discussed in the previous section, most often it is difficult for most decision makers operating at specific sector level to project/expect impacts of changes happening in other sectors. The ramifications of lack of understanding on interconnected nature of different sectors have become more evident with the global food price crisis of 2007-08 and subsequent repetition of the same in 2010-11. Several arguments have been put forward to explain reasons behind increase in global food prices which include reduced grain yields due to poor weather in Australia, changing diet patterns such as increased meat consumption in developing Asia, cultivation of biofules on agricultural fields, rising oil prices, low stocks, export restrictions, depreciation of United States Dollar, low interest rates, and investor speculation (Headey, 2011; Lagi *et al*., 2011). Among all these reasons, researchers have concluded that at least land conversion to biofuels, export restrictions and investor speculation have strong influence on global food prices Table 2, some of which are more intuitive than others (Headey, 2011; and Lagi *et al*., 2011). For example, possible impact of land conversion to biofuel use on food security has long been discussed in the policy and scientific literature. However, none could emphatically project that it could lead to global food crisis of the magnitude or none could help in taking preemptive measures ahead of the food crisis. The experience from 2008 food crisis couldn't help project and prepare for another one in 2010-11.

One may argue that an early warning system that considers various interconnected factors underlying events such as food crisis 2008 could have avoided the catastrophe. Examining the lessons from the existing examples would help validate this argument. Some examples of EWSs for policy decisions are European Union proposal for building a EWS for energy that simulates the supply and demand situation in the region (European Union, 2009); it includes early warning for long-term energy conditions as well as for oil shortages in short time scales. The Crop Weather Watch Group (CWWG), India aims to provide early warning of an impending drought and help take preemptive measures. The flood mitigation and management center of Mekong River Commission collects data on Mekong river flows and provides early warning to the countries in downstream. However, these early warning systems suffer from several limitations. The CWWG has failed to warn impending crop losses and couldn't take advantage of recovering monsoon in 2004 drought. Several other drought monitoring tools being implemented in the region including west-Asia drought monitor based on USDA drought monitor and it is not clear from the literature on the success of these drought monitors in avoiding the impending drought events. The currently available early warning systems are highly specialized in nature and are narrowly defined in the scope. For example, they are either limited to only energy or only water or only food sector and don't consider the impacts of decisions taken in other sectors. In other instances, they are limited to hazard-

Table 2. Role of different factors behind food crisis

Reasons put forward for global food price crisis	Marco Lagi *et al*., 2011	Headey, 2011
Adverse weather (Drought in Australia)	No evidence	
Land conversion to biofuel use	Strong evidence	
Shifting investor speculative focus from mortgage and stock markets to commodity markets	Strong evidence	
Change in dietary patterns in developing countries	No evidence	
Export restrictions/trade factors		Strong evidence

mitigation approach (drought or flood forecasting) and end with projecting a physical event.

An effective EWS can be built using dynamic simulation models since they can consider the element of time and related dynamics in determining the status of outcomes that could be useful to policy makers. The use of simulation models in the public policy research is not new. Some examples are:

- The general algebraic modeling system (GAMS) has provided a good tool in understanding environment and economics in a single framework.
- The Asia-Pacific Integrated Model (AIM) has provided a tool to simulate the impact of climate change on natural environment and socio-economics in Asia and the Pacific.
- Computable general equilibrium (CGE) models have been used for understanding the economy-wide impacts of policies.
- Multi-regional input-output (MRIO) models have been employed to understand and forecast material flows across different regions.

All the above simulation models are largely used for research purposes that have partially contributed to development of policies rather than for providing real-time early warning for preemptive response. Partially, this could be attributed to the limited understanding of natural, socioeconomic, and institutional systems.

5.1. Prerequisites for Development of an EWS

Development of EWS is dependent on various factors related to the system in question and it has to do with how best the EWS can represent the real world.

Determinants of an effective EWS are:

1. How the system is defined (components of the system),
2. Understanding of relationships and feedback connections between different actors/components of the system,
3. The precision with which these dynamic and static forces are quantified and represented in the model, and
4. Interpretation of the outcomes of the model as against what it actually means, with implications for the institutions that use the EWS for policy purposes.

5.2 What an EWS should be Able to Do

A EWS for the food-water-energy nexus should be able to:

1. visualize demand and supply situation of food, water, and energy in the region on a short-, medium-, and long-term basis;
2. give projections on prices of food, water, and energy on an immediate and long-term basis so that countries can make preventive and proactive strategies;
3. help policy makers at various levels to plan appropriate crops, water usage, and water conservation practices, and how energy is produced and consumed at the regional and national scales;
4. help in appropriate allocation of resources for food and energy production while keeping in view such constraints as environmental health, climate change, food prices, and sustainability of resources employed; and
5. help develop a set of standard operational procedures to be invoked in a situation like the 2008 energy and food crisis.

5.3 Opportunities and Challenges for Developing an EWS

From the above discussion, it can be concluded that several factors determine the food-water-energy nexus in the GMS and that there are both opportunities and challenges for developing an effective EWS for decision making in the subregion.

5.3.1. Opportunities:

The main opportunity for developing and implementing a EWS in the GMS comes from three integrating factors operating in the subregion:

1. *Institutional system.* The Mekong River Commission (MRC) integrates nations in the subregion through its significant impact on the way other institutions set policies and processes in managing resources.
2. *Growing economic integration*. Countries in the subregion are increasingly integrated in terms of economic activities (e.g., trade of goods and services).
3. The Mekong River. The Mekong River acts as a single, most important integrating factor, providing the opportunity to develop the EWS around it.

5.3.2. Challenges:

1. *Complex nature of the food-water-energy nexus.* This is largely brought by the uncertainty in climate projections, future growth patterns, and changing food preferences of the people that can introduce

many "unknowns" that influence the effectiveness with which the EWS can work.

2. *Poor availability of data*. Real time and quality data are often a problem in the subregion and can greatly influence the effectiveness of a EWS. Such approaches as integrated river basin level resource management using water balance models could be useful to avoid water shortages. These are data-intensive approaches and lack of quality data hinders their adoption and effectiveness.
3. *Attitudinal factors of stakeholders*. As with any other EWS, different actors in the region may not trust the EWS and may not consider it as a decision-making tool. Thus, there is a need for capacity building of different stakeholders.
4. *Poor development of regional coordination mechanisms for the use of certain common natural resources*. As an example of both the solution and problem, disputes related to how the water in the Mekong River should be equitably used by various countries on upstream and downstream has not been resolved. Development of a EWS may help resolve this problem since stakeholders in the region would be able to visualize how downstream users are affected by overexploitation by upstream users, leading to amicable allocation of water resources to individual countries.

5.4 Simple Representation of an EWS

Figure 1 shows an oversimplified schematic representation of the concept behind an EWS for food-water-energy nexus in the region. This idea need to be further refined since it does not capture all the complexities operating in the food-water-energy nexus. The proposed EWS consists of integration of three modules, one each for food, water, and energy production and demand (in the figure they are shown as a single diagram for simplicity). Each module will feed into the other module based on allocation of resources following constraints set by the decision maker. The output in the diagram can represent either the quantitative or health status of resources, prices of products, or their combination.

This module need to be integrated with a climate and weather early warning system that can inform the policy makers and local natural resource managers and cropping experts to decide and strategize various operations according to the climate and weather forecasts. However, for this to work satisfactorily there is a need to strengthen climate and weather forecasts in the region.

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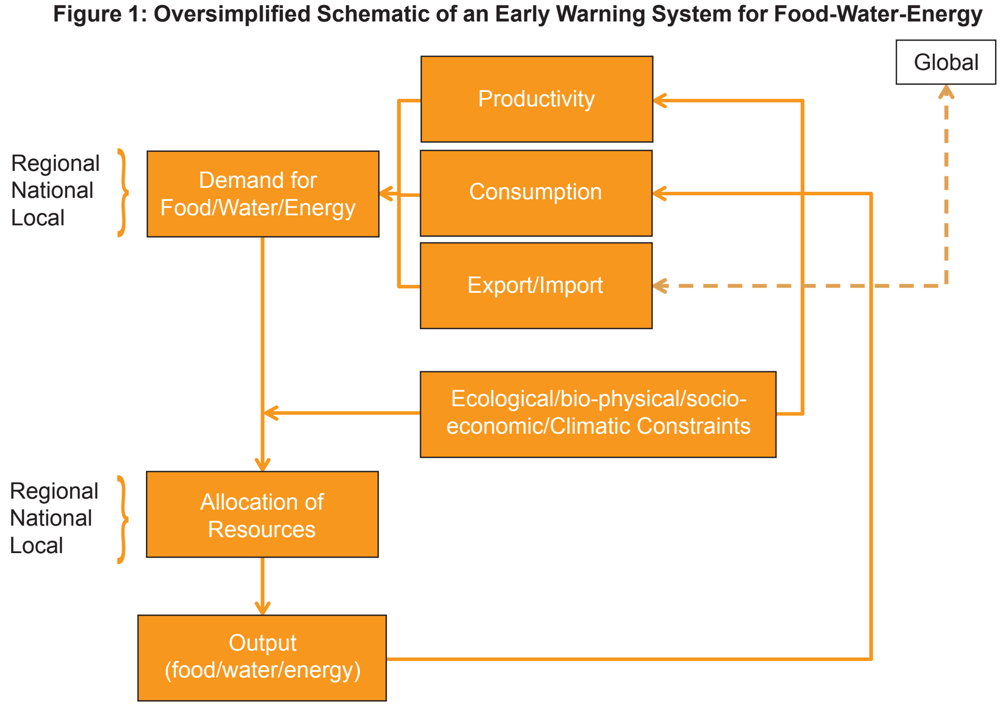
Figure 1: Oversimplified Schematic of an Early Warning System for Food-Water-Energy



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6. Policy Suggestions for Avoiding Food-Water-Energy Conflicts

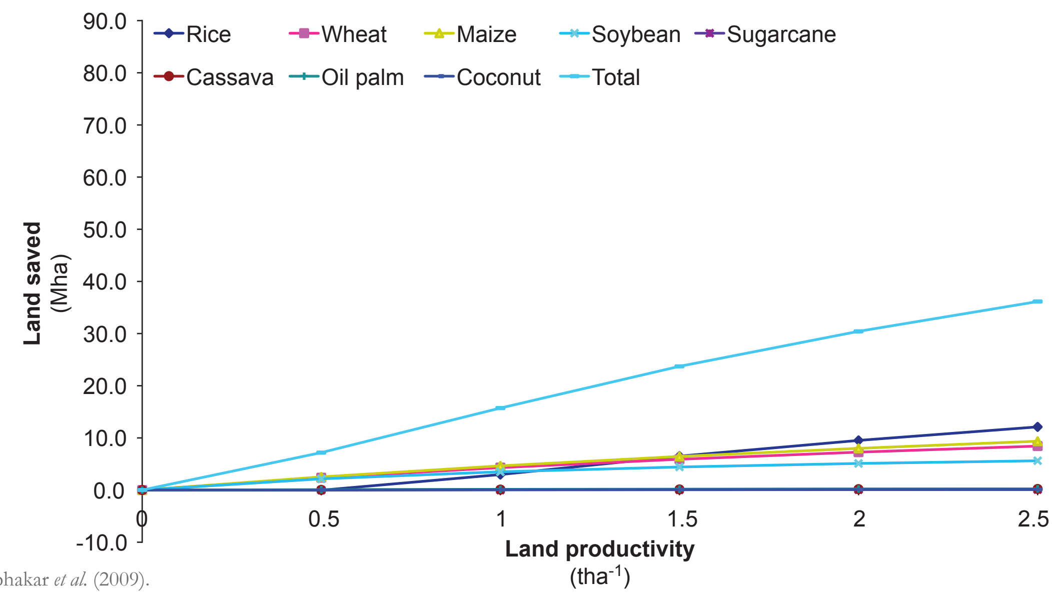
While developing an EWS for food-water-energy could provide several benefits, we are far from the point of developing such EWS that satisfies the criteria discussed above. Hence, it would be logical to promote some of the off-the-shelf policies that could reduce the food-water-energy conflict.

6.1. Improving Resource Use Efficiency in Agriculture and Water

Increasing the use efficiency of water, land, and other resources in the subregion could reduce pressure on these resources and make them available for other competing users. This can be achieved through few example practices listed below:

- Identification and promotion of agro-technologies that provide synergistic advantage in terms of improved productivity, profits, and climate benefits. Introduction of such practices as the system of rice intensification, organic agriculture, and conservation tillage practices are known to reduce water use and provide both mitigation and adaptation benefits (Prabhakar *et al*., 2010). Simple strategies, such as increasing the productivity of crops, can ease pressure on the land (Figure 2).
- Moving from local watershed-based approaches to integrated river basin level water management approaches and harmonizing the available water with land-use practices in the subregion could drastically increase overall water-use efficiency.
- Reducing vulnerability to weather fluctuations through assured irrigation facilities would provide insurance against vagaries of weather. Despite the huge irrigation potential in the GMS, actual utilization of this potential is not significant (Tu *et al*., 2004). Expanding the area under irrigation could reduce the weather-linked agricultural risk, provide assured income to farmers, and avoid fluctuations in food production.
- Moving to full-life-cycle assessment of benefits and costs of producing biofuels has been suggested for fully accounting the environmental costs involved in biofuel production and consumption (Prabhakar *et al*., 2009). There are suggestions to go beyond these methodologies and include new innovative methods, such as system perturbation analysis (SPA) (Worldwatch Institute, 2007), which examines geographic system balances of resources and the resulting effects rather than comparing well-to-wheel trajectories; or graphical pinch analysis (Tan *et al*., 2009), which helps in solving the source-sink problems while allocating the limited resources in production processes, enabling optimal use of resources.
- Market distorting policies, such as subsidies, affect the way the benefits from biofuels are assessed and promoted. For example, countries

Figure 2: Land Saved from Agriculture by Increasing Land Productivity in the People's Republic of China, Thailand, and Viet Nam



Source: Prabhakar *et al.* (2009).

where inputs are subsidized for agriculture do not differentiate whether these inputs are used for agriculture for food or for fuel. Targeted subsidies could be more effective.

- Improving the weather and climate forecasting systems in the region could help in strategic planning in agriculture and water sectors and avoid undue sudden shocks and hence improve overall productivity of these resources. Establishing dense weather stations, capacity building of ground staff, strengthening data archival systems, and strengthening weather and climate models suitable for the region are necessary.

6.2. Improving Energy Use Efficiency

Energy use efficiency in the subregion is presently low. For example, in the PRC, energy utilization efficiency (GDP output per unit of energy consumption) is around 20%–40% that of developed countries, depending on the GDP description (exchange-rate converted GDP or PPP-converted GDP) (Li *et al*., 2005). This indicates a huge potential for improving energy efficiency. Realizing this potential, the PRC Government has placed great importance on structural reforms and economic development patterns with a focus on energy conservation (National Development and Reform Commission, 2009). This strategy includes enhancing the share of service industry in the overall GDP, implementing rigorous standards for manufacturing industries, and promoting the concept of a circular economy, which has implications in terms of GHG emissions while maximizing the energy use efficiency. As a result of these policies, energy intensity dropped by 19.06% over the 11th 5-year-plan period. However, the prospects for improving energy intensity in the 12th 5-year plan may not be high in view of progress already achieved; speculation has been that maintaining high targets on energy intensity could even cost the country more (Fuqiang, 2011). For improving energy intensity in other GMS countries, there is a greater need for analysis and policy focus.

6.3. Increasing Energy Supply from Renewable Sources

The PRC has recognized the domestic potential for renewable energy and has invested in use of its renewable resources. The country has set a non-fossil fuel target of 15% of its primary energy consumption by 2020 (National Development and Reform Commission, 2009). Currently, the PRC produces about 24 million kilowatts of wind energy, which is only second to the United States, as a result of rapid investments in wind energy in the past 5 years. However, the literature suggests even great potential for expansion of renewable energy in the country (Meisen *et al*., 2009), with huge potential in hydro-, wind, and solar power (Meisen *et al*., 2009). Harnessing this potential could reduce demand for biofuels and the pressure on land and water resources. RE production and utilization in other GMS countries is still in nascent stages and need a greater fillip through promoting a combination of demand and supply side policies.

6.4. Creation of an East Asia Energy Community/ Grid

There have been several proposals for establishment of an East Asian energy community or a grid, in view of the different supply and demand situation for energy among the countries in East Asia. Such a network would greatly benefit countries in the GMS as they can use the already well-developed economic cooperation and trade ties in the subregion easing burden on natural resources in some of the countries.

Acknowledgements

This paper has partially benefited from the work carried out under the Environmental Research and Technology Development Fund Project S8-3-4 of Ministry of Environment, Government of Japan and the APN funded Project CRP2009-02NMY-Pereira.

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