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Past and Future Trends in Crop Production and Food Demand and Supply in the Lower Mekong Basin

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Executive Summary

The regional Climate Change and Adaptation Initiative (CCAI) of the Mekong River Commission (MRC) addresses the shared adaptation challenges to climate change impacts of the Lower Mekong Basin (LMB). The study described in this report provides an overview of the expected changes in crop production and food demand and supply in the LMB. This explorative outlook uses existing data sets, and the established and well-tested AquaCrop model and Food Balances Sheets. Analyses were undertaken at the 15 BDP sub-area level.

Results show that under climate change crop yields will decrease as a result of higher temperatures and changing rainfall patterns. For the dominant crop, rice, yields are projected to reduce by a few percentages for the near future (2026-2035) for most sub-areas. For some sub-areas yields will reduce more, especially under the RCP8.5 and the more distant future. Other crops included in the analysis (maize, cassava, sugarcane) will also experience decreasing yields for most sub-areas, but less pronounced than rice.

Current and future food intake were analysed using Food Balance Sheets (FBS) for each of the 15 sub-areas. Under changes in climate and population, food security will decrease and will fall below the daily recommended intake levels. Especially for the component “fat” shortages will be substantial, but also energy and protein will fall below accepted levels. The FBS were used to explore potential potential adaptation options (interventions). A total of six interventions were explored and results show that the one that includes a mix of actions is the most effective.

The study concludes that: (i) result are indicative as data accuracy should improve, (ii) food balance sheets are an excellent tools to be used in interactive stakeholder involvement, (iii) the tools can be applied in smaller pilot studies, and (iv) actions can and should be taken to improve food security.

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1 Introduction

1.1 Background

The population of the Lower Mekong River Basin (LMB) has been estimated at 60 million people [*MRC*, 2010a]. About 75 per cent of the basin's population lives in rural areas. About 60% of the economically-active population has water-related occupations that are vulnerable to changes in water availability and water quality [*MRC-BDP*, 2011].

With more than 20 % of the population living below the poverty line - and 15% undernourished – the agriculture and fisheries sectors are vital for food security. Agriculture is the single most important economic activity, providing livelihoods for approximately 60% of the basin population while Mekong fisheries are among the largest inland fisheries in the world, and provide most of the proteins for the basin population.

There is growing concern about the potential impacts of climate change on natural ecosystems, socio-economic characteristics and food security in the LMB. In response to this the Mekong River Commission has launched the regional Climate Change and Adaptation Initiative (CCAI) with its mandate to address the shared adaptation challenges to climate change impacts of the Lower Mekong Basin. Whilst climate change impacts are already being felt among farming and fishing communities within the basin, these impacts are expected to significantly increase in the future, and poor communities and households are most vulnerable to such impacts due to their relatively limited livelihoods assets. It is thus important for the CCAI to provide a more informed understanding about the impacts of climate change on food security in the LMB.

1.2 Rationale

The Climate Change and Adaptation Initiative (CCAI) is a collaborative regional effort of MRC Member Countries (Lao PDR, Cambodia, Thailand and Vietnam) to support processes of adapting to the new challenges posed by climate change in the Lower Mekong Basin (LMB). The main focus is a basin wide integrated approach to adaptation planning consistent with Integrated Water Resources Management principles and within the Framework of the 1995 Mekong Agreement. The specific aim is to make adaptation a permanent part of development plans and planning process, and to have tools as well as institutional and specialist capacity in place to implement them.

The CCAI focuses on the following Outcomes: (1) climate change impact and vulnerability assessment, adaptation planning and implementation in priority locations within the LMB; (2) building knowledge and capacity at different levels (institutional, technical and managerial capacity); (3) regional adaptation strategy supporting national frameworks; (4) regional partnership and collaboration. A number of CCAI approaches are designed specifically to ensure the sustainability of its outcomes with the objective of guiding climate change adaptation planning and implementation through improved strategies and plans at various levels and priority locations throughout the LMB.

The CCAI is developing its first "Status of Climate Change in the Lower Mekong Basin" report. An important component of the Status Report will be the impact of climate change on the agricultural sector and the projected food situation in the LMB.

Analyses on changes in crop production and food demand and supply have clear transboundary dimensions. Changes might be important in the context of imports and exports of agricultural products. Irrigation is an important consumer of water and changes in irrigated areas can have basin-wide consequences.

A clear overview of expected changes in crop production and food demand and supply in the LMB is missing. Earlier initiatives are were often local specific, encompassing only climate change, often based on old climate scenarios, and, often based on different and not comparable approaches and assumptions. However, these initiatives are all very valuable in itself but there is a need to explore the impact of climate change and other changes over the entire LMB using homogenous approaches and assumptions and based on the latest IPCC scenarios. Obviously, previous studies were used as base for the study presented in this report.

1.3 Concept definitions

Food security is a multi-dimensional issue that includes the following four dimensions: food availability, food accessibility, food utilization, and food systems stability. "Food security exists when all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [*Thomas*, 2006].

The scope of this assessment, as described in this report, is on food availability and food utilization and studies the impacts of climate change and other changes. Moreover the study explores possible adaptation options on these dimensions of food security.

1.4 Objectives

The overall objective of this study is to provide a clear overview of the expected changes in crop production and food demand and supply in the LMB. This explorative outlook will be obtained by using a generic approach, combining crop modelling and food balance sheets, taking into account climate change but also other changes expected in the LMB that affect the food production and demand.

The specific objectives of this work are:

- To provide an explorative outlook on crop production under climate change, using crop modelling.
- To provide an explorative outlook on food requirements and production under climate change.
- To integrate the predictions on crop production and food requirements into food balance sheets.
- To explore the impact of a set of adaptation options using the food balance sheets.

The analysis should serve the CCAI in setting out the way forward in climate change adaptation actions and projects throughout the region.

2 Changes and trends: data and literature

This chapter provides a review of studies carried out in the LMB on how climate change and drivers affect food availability and food demand and summarizes the past trends and predictions that were reported.

Climate change can have a significant impact on food production, through direct changes in weather patterns affecting temperature, rainfall and wind in terms of intensity, duration and frequency, and indirect effects affecting riverflows, water for irrigation, pests and diseases. Many of those impacts can be expected to affect the Lower Mekong Basin [*MRC*, 2010a].

So far, most climate change studies in the LMB have been based on the fourth assessment report of the Intergovernmental Panel on Climate Change [*IPCC*, 2007] and the IPCC Technical Paper on Climate and Water [*IPCC*, 2008]. The projected weather pattern changes point to increasing variability, e.g. less rain during the dry season and more rain during the wet season and more frequent extreme weather events, although with regional differences within the basin [*Eastham et al.*, 2008]. Seasonal water shortages and floods may become worse, as may saltwater intrusion into the Mekong Delta due to storm surges and sea level rise [*Wassmann et al.*, 2004; *Van Cong*, 2010; *ARCC*, 2013].

Impacts of such changes are expected to affect natural ecosystems and agriculture, both the subsistence production systems as well as the commercial crop cultivation are vulnerable [*ARCC*, 2013]. This will exacerbate the challenges of satisfying increasing food demands from growing populations [*Hoanh et al.*, 2003; *Johnston et al.*, 2010]. Planned developments in the LMB over the next 20 years in combination with climate change will affect the hydrology, the environment and people’s livelihoods. In some areas this will exacerbate the challenges of dealing with climate change and in other areas developments can counteract climate change impacts [*MRC-BDP*, 2011].

The impacts of climate change on food production can be both direct, through changes in temperature, rainfall and CO2 that affect crop growth and yield, as well as indirect by for example water availability for irrigation, pests, diseases, etc. The following sections summarize previous work carried out in the LMB that studied these effects of climate change.

2.1 Direct effects of climate change on rice production

Rice is the primary staple crop in the region. Rice production in the LMB can be categorized into four types of production systems; lowland rain-fed, irrigated, deep-water, and upland [*Heft-Neal et al.*, 2013]. Lowland rain-fed is the primary production system, in which the yields depend mainly on rainfall, are highly variable and significantly lower than in irrigated systems. Irrigated rice systems, in turn, benefit from higher yields in the wet season as well as a second production cycle during the dry season. The deep-water production system is practiced in areas of the central plains in Thailand and is subject to a long annual flood season. Yields in this system are low and account for a low percentage of rice production on the regional scale. Upland rice produces the lowest yields and has become significantly less common over the past 40 to 50 years [*Heft-Neal et al.*, 2013].

Being the primary staple crop in the LMB, rice has been subject of several climate change impact studies. These impact studies can be distinguished between: (i) Laboratory experiments, (ii) Field-level experiments, (iii) Crop modeling assessments, and (iv) Statistical assessments. Overall, no general consensus has been reached on how climate change may affect the rice production in LMB. Clearly the impact will be different in each region, and will depend on the dominant factors (positive and negative) in each regions affecting yield. There is however a general concern that the expected higher variability in temperatures and rainfall may cause a risk to rice production.

Eastham et al. [*Eastham et al.*, 2008] indicated that by the 2030s, climate change may not affect rice productivity, and that there could be increased productivity in some areas in northeast Thailand as well as in the central part of Lao PDR. However, they also warned that the variability in water cycles driven by climate change is likely to impact rice production in the near future.

Mainuddin et al, [*Mainuddin et al.*, 2011, 2013] examined the impact of climate change on rice production in the lower Mekong Basin, and evaluated some widely used adaptation options, and their implications for overall food security by 2050. Climate change data used in the study are the future climate projection for two IPCC SRES scenarios, A2 and B2, based on ECHAM4 General Circulation Model downscaled to the Mekong region using the PRECIS (Providing Regional Climates for Impact Studies) system. In general, the results suggest that yield of rainfed rice may increase significantly in the upper part of the basin in Laos and Thailand and may decrease in the lower part of the basin in Cambodia and Vietnam. Irrigated rice may not be affected by climate change if increased irrigation requirements are met. Negative impact on the yield of rainfed rice can be offset and net increase in yield can be achieved by applying widely used adaptation options such as changing planting date, supplementary irrigation and increased fertilizer input. Analysis of the projected production, considering population growth by 2050, suggests that food security of the basin is unlikely to be threatened by the increased population and climate change, excluding extreme events such as sea level rise and cyclones.

Table 1. Summary of previous studies on the impact of climate change on rice production in the LMB countries.

Publication	**Area**	**Approach**	**Outcome**	**Comments**
Eastham et al. [*Eastham et al.*, 2008]	Mekong River Basin	Climate: CMIP-3, selected GCMs, A1B scenario. Crop yields: crop modelling (CROPWAT)	On the basin scale a slight increase in agricultural productivity under the projected climate for 2030. However, food scarcity is likely to increase in parts of the basin as a result of population growth. Food production in excess of demand is likely to be reduced across the basin causing negative economic impacts.	No adverse effects of increased flooding or waterlogging on productivity were assessed. Only one horizon (2030s) and one emission scenario was used.
Mott MacDonald [*Mott MacDonald*, 2011]	Thailand	Climate: PRECIS RCM for dynamic downscaling of ECHAM4 GCM. A2 and B2 scenario. Crop yields: locally calibrated crop model (DSSAT)	Yield increase for rainfed rice. Irrigation shortfalls for irrigated rice increase. In some areas dry season cropping will have to be reduced from current levels. No changes in irrigated dry season rice yields. Increase in inter-annual variability due to increase flood risk.	Study assumes net positive effect on crop growth of CO2 fertilization. Only one GCM used.
Mainuddin et al, [*Mainuddin et al.*, 2011, 2013]	LMB	Climate: PRECIS RCM for dynamic downscaling of ECHAM4 GCM. A2 and B2 scenario. Crop yields: crop modelling (AquaCrop)	Yield increase of rainfed rice in the upper part of the basin in Laos and Thailand and yield decrease in the lower part of the basin in Cambodia and Vietnam. Increased irrigation water requirements of irrigated rice. Negative impact on the yield of rainfed rice can be offset by applying widely used adaptation options such as changing planting date, supplementary irrigation and increased fertilizer input.	Only one GCM used. Net positive effect of CO2 increase assumed on crop yields, parallel to increase in temperature. Possible impact of extreme events not assessed
Pannangpetch et al., [*Pannangpetch et al.*, 2009]	Thailand	Climate: PRECIS RCM for dynamic downscaling of ECHAM4 GCM. A2 and B2 scenario. Crop yields: locally calibrated crop	Decline in rice production for dry season irrigated rice, but no significant change for rainfed wet season rice production. No significant net positive effect of CO2 increase. Increased variability of the annual	Main causes affecting rice productivity are declining of soil fertility and rainfall distribution.

		model (DSSAT)	productivity. Some areas will be critically affected.	
Furuya et al.,[*Furuya et al.*, 2013]	LMB	Climate: SRES-B2. Crop production: economic supply and demand model	Climate change will depress wet season rice production in Cambodia and MRD region and that of dry season rice in the MRD region and NE Thailand. Planted areas of dry season rice in the west side of the LMB and MRD region will reach to the upper limit of the irrigation area for rice cultivation	One single emission scenario. Economically focused approach.
Heft-Neal et al., [*Heft-Neal et al.*, 2013]	Thailand	Climate: A1B and A2 scenario, multiple GCMs. Crop yields: statistical analysis of historic data.	Increase in minimum temperature is a driving factor in yield loss by temperature stress. Maximum temperature is positively correlated with higher rice yields, radiation negatively. Rainfall over irrigated and rain-fed cropland have opposite effects.	Analysis based on statistical modelling
ARCC [*ARCC*, 2013]	LMB (identified hotspot provinces)	Climate: single scenario (A1B) multi-model ensemble (six GCMs) Crop yields: crop modelling (AquaCrop)	General decrease in yield compared to the current situation. Changes in yield are variable but typically were predicted to decrease by 2050 due to higher temperatures during the crop season. Increases in diurnal temperatures can reduce rice yields, especially of rainfed rice.	The study stresses that a decrease in average rice yields of just a few percent per hectare could have dramatic impact on LMB food security and food production.

A recent assessment covering the LMB region on climate change impact on crop production (financially supported by the World Bank) was done using the Hydrologic-Agronomic-Economic (HAE) Model. This model has been developed to assist the governments of Lao PDR and Thailand to develop policy tools for adapting to climate change impacts on the water and natural resources of the Mekong River Basin [*MoNRE*, 2012]. The HAE model is an assemblage of component models that permits assessment of the impacts of climate change on: (i) the hydrological regime; (ii) water usage; (iii) agricultural production; and (iv) economics in the water and agricultural sector.

The HAE model has been constructed on the basis of available data sets, proprietary software packages, and various bespoke interface programs that permit data transfer between component models, and the analysis of model results. It includes crop modelling components to evaluate the impacts of climate change scenarios on crop yields and crop water requirements. For Lao PDR, the FAO crop model AquaCrop is being implemented, while for Thailand the DSSAT has been used [*MoNRE*, 2012].

The crop simulations done for the National Final Report for Thailand, using the HAE Model, indicated a significant increase in the yield of rainfed rice under both the A2 and B2 scenarios [*Mott MacDonald*, 2011]. A small increase in the yield of irrigated wet season rice is indicated under both A2 and B2 scenarios, with an increase in yield variation under the B2 scenario. No changes in dry season irrigated rice yields were indicated.

The authors of the assessment for Thailand [*Mott MacDonald*, 2011] suggest that it would be valuable to verify some of the DSSAT model results against those of other crop models. They stress that further verification should be carried out, especially of the predicted increase in rainfed rice yields. Another study carried out in Thailand [*Pannangpetch et al.*, 2009] predict a decline in rice production for dry season irrigated rice, but no significant change for rainfed wet season rice production in Thailand.

Furuya et al., [*Furuya et al.*, 2010] carried out a study that tried to clarify impacts of water supply changes on producers and consumers of rice using a supply and demand model of rice considering hydrological cycle changes to aid in making agricultural policies and plans. The developed model is extended to a stochastic model and fluctuations of water supplies are analyzed. They show that the production of dry season rice is more influenced by climatic change than in wet season rice, and thus adequate water management is required for dry season rice to reduce production risk faced by producers. However, when considering price risk alone, the wet season rice cultivation is more vulnerable to water supply changes. Rice farmers producing wet season rice in high yielding regions with sizeable production will incur financial damages under a scenario where the variation in the water supply expands.

A more recent study by the same authors [*Furuya et al.*, 2013] showed that climate change will depress wet season rice production in Cambodia and delta region and that of dry season rice in the delta region and NE Thailand. Also, climate change is likely to increase farm prices of rice in Cambodia, Vietnam and Thailand and the authors conclude that climate changes will weigh on the livelihood of rice consumers, especially those of poor rural populations.

Heft-Neal et al., [*Heft-Neal et al.*, 2013] carried out an assessment on the climate change impact of rice production in Thailand, using a purely data-based approach. In summary, the results from their statistical modeling suggested that minimum temperature is a driving factor in yield loss from temperature, that maximum temperature is positively correlated with higher rice yields, radiation negatively so, and that rainfall over irrigated and rain-fed cropland have opposite effects.

Heft-Neal et al., [*Heft-Neal et al.*, 2013] forecast a 12-15% decrease in yields, while another assessment for rice production in Thailand carried out by CIAT [*CIAT*, 2012] forecasts a 0-1.5% increase in rice yield by 2050 under the A1B climate change scenario. According to Heft-Neal et al., [*Heft-Neal et al.*, 2013], this difference is because of the mechanism identified as the driver of climate impacts. The model used by identifies CIAT [*CIAT*, 2012] rainfall as the primary driving force while Heft-Neal et al., [*Heft-Neal et al.*, 2013] identify rising minimum temperatures to be the salient risk factor. This difference stresses the uncertainty of crop modeling under climate change.

Minimum temperature as a driving factor of rice yields is supported by many studies using a wide variety of methodologies. Similar results have been found in studies using statistical models with field-level panel data [*Welch et al.*, 2010] and field experiments [*Peng et al.*, 2004; *Madan et al.*, 2012].

Welch et al. [*Welch et al.*, 2010] collected data from farmer-managed fields to disentangle the impacts of daily minimum and maximum temperatures and solar radiation on rice yields in tropical/subtropical Asia. They used a multiple regression model to analyze data from 227 intensively managed irrigated rice farms in six important rice-producing countries. The farm-level detail, observed over multiple growing seasons, enabled them to construct farm-specific weather variables. The results showed that temperature and radiation had statistically significant impacts during both the vegetative and ripening phases of the rice plant. Higher minimum temperature reduced yield, whereas higher maximum temperature raised it; radiation impact varied by growth phase. Combined, these effects imply that yield at most sites would have grown more rapidly during the high-yielding season but less rapidly during the low-yielding season if observed temperature and radiation trends at the end of the 20th century had not occurred, with temperature trends being more influential. Looking ahead, they imply a net negative impact on yield from moderate warming in coming decades. Beyond that, the impact would likely become more negative, because prior research indicates that the impact of maximum temperature becomes negative at higher levels. The authors stress that diurnal temperature variation must be considered when investigating the impacts of climate change on irrigated rice in Asia.

Previously to this study, also Shimizu et al. [*Shimizu et al.*, 2006] used a purely data-based approach to understand the influence of rainfall variability on the yield of rain-fed paddy rice. Agricultural statistics and rainfall data were collected and analyzed for all 24 provinces in Cambodia for the years 2001 and 2002. Factors such as soil fertility and other natural conditions were removed by comparing the yield and rainfall in one province for different years. Special attention was given to the relation between yields of paddy in the wet season and rainfall, considering factors such as rice varieties, soil fertility, irrigation ratio and the ratio of area damaged by flood, drought, and insect. Although the authors stress that it is not easy to assess those impact factors on yields because they are organically interactive, they conclude that there is no clear relation between yields of rain-fed paddy rice and total rainfall in wet season and total rainfall does not influence yield much if it is over 700 mm in the wet season, owing to the use of supplementary water sources such as small ponds and water ponding in local land depressions in and along the paddies.

Also yield modeling carried out for the USAID Mekong ARCC study [*ARCC*, 2013] indicated for rice a general decrease in yield compared to the current situation in the hotspot provinces studied. Changes in yield are variable but typically were predicted to decrease by 2050 due to higher temperatures during the crop season. Increases in diurnal temperatures can reduce rice yields, especially of rainfed rice. The study stresses that a decrease in average rice yields of just a few percent per hectare could have dramatic impact on LMB food security and food production.

2.2 Direct effects of climate change on other field crops

Besides rice, sugarcane, maize and cassava are the economically most important crops [*MRC*, 2010a]. Not many studies have been done so far on climate change impacts on these crops. As with rice, impacts are likely to be different among the different regions in the LMB, and positive and negative factors may become dominant or outweigh each other.

An analysis by Pannangpetch et al. [*Pannangpetch et al.*, 2009] indicated that sugarcane and maize production in Thailand would not be adversely affected by future climate change. However, the statistical approach followed by Heft-Neal et al. [*Heft-Neal et al.*, 2013] indicated that in Thailand rising maximum temperatures are likely to hurt sugar yields, and above 34^{o}C there is a sharp drop-off in yields. Higher minimum temperatures increase sugar yields, up to 23 ^{o}C, but above this value yields will reduce. The same increasing and then decreasing relationship with radiation was found. Finally, the study showed a positive relationship between sugar yields and rainfall above 40cm, but an insignificant relationship below 40cm.

Above the maximum temperature threshold, Heft-Neal et al. [*Heft-Neal et al.*, 2013] find that losses associated with a one-degree increase in temperature double. Above the minimum temperature threshold, we find that yield changes associated with rising minimum temperature switch from being positive to negative. Consequently, taking into account the differential yield effects over different ranges of temperatures, they predict a 1-2% decline in sugar yields by 2050, relative to baseline yields forecast under current conditions.

Also for maize, Heft-Neal et al. [*Heft-Neal et al.*, 2013] found the yields to be highly sensitive to rising minimum and maximum temperatures. Under the linear model, maize yields are found to decrease steadily each decade with approximately 5-10% losses predicted by 2050. All temperature and radiation covariates are found to be negatively associated with higher maize yields in the linear model and rainfall is not found to be significant. In the non-linear model, we find similar results, where all temperature and radiation variables are found to be negatively associated with higher maize yields. In these specifications, additional rainfall is found to be highly beneficial (+9% in yields) when rainfall levels are initially low. However, at higher levels of seasonal rainfall, additional rainfall is not found to be significantly beneficial. Moreover, rainfall above the upper threshold of 170cm is found to be negatively associated with maize yields. Collectively, this suggests that maize is one of the more robust crops with respect to water shortages.

For cassava, Pannangpetch et al. [*Pannangpetch et al.*, 2009] found that climate change would have a serious negative impact on cassava production in Thailand, resulting in significantly lower yields and total production. However, Heft-Neal et al. [*Heft-Neal et al.*, 2013] found cassava to be the most robust crop to temperature rises (in terms of percentage yield changes). Their models suggest that rising minimum temperatures, as well as maximum temperatures above 23.5 degrees C, will actually increase yields. Rainfall in cassava growing areas is found to be beneficial (2% increase) for the first 160cm, but then slightly negative thereafter.

Under climate change, Heft-Neal et al. [*Heft-Neal et al.*, 2013] forecast higher future yields (up to 5% by 2050) relative to baseline forecasts under no climate change. Both maximum and minimum temperatures are found to be positively associated with yields, although higher radiation levels are found to be negatively associated with yields. In addition, lower levels of rainfall are found to reduce potential cassava yields. However, in most cases the positive temperature effects around found to outweigh the negative effects from reductions in rainfall. The authors find that in cases of extreme water shortages, cassava yields are vulnerable to major losses but compared to rice and tree crops, cassava is relatively robust to water shortages.

2.3 Effect of CO2 and O3 on crop yields

CO2 (carbon dioxide) levels have increased and are expected to continue to do so as a result of the use of fossil energy. It is well known that plants require CO2 for their photosynthesis. Higher CO2 levels will increase photosynthesis and therefore higher biomass production and yields [*Singh et al.*, 2013]. Many field and modeling experiments have investigated this process, because of its relevance for food production under elevated CO2 levels with climate change.

As many factors come into play, there is still a large debate on the net effects of CO2 enrichment. Also for the key crops in the LMB, no conclusions can be drawn, as the effects may depend on crop type, cultivar and local conditions while at the same time many governing processes and interactions are unclear.

Key processes that might counteract the positive impact of elevated CO2 on crop growth are (further detailed hereafter):

1. Acclimation to elevated CO2 has been confirmed in a variety of plant species even under field conditions.
2. Increased ozone concentrations under climate change do negatively affect crop yield.
3. Temperature increase may affect rice yield negatively, as shown in various experiments.
4. Pathogens may also benefit from enhanced CO2.

Several authors have stressed the importance of long-term observations to understand better the acclimation effects of CO2 enhancement in rice [*Ono et al.*, 2013]. So far, few studies have quantified seasonal changes in the effects of elevated CO2 on canopy evapotranspiration, which integrates the response of stomatal conductance of individual leaves with other responses, such as leaf area expansion, changes in leaf surface temperature, and changes in developmental stages, in field conditions [*Shimono et al.*, 2013]. [*Yang et al.*, 2006] conclude that the gradual acclimation of rice growth to elevated CO2 does not occur inevitably, and it could also be altered by environmental conditions (e.g., cultivation technique).

Ozone risks are projected to increase most dramatically, especially in regions with rapid industrialisation and population growth and with little regulatory action, thus causing negative impacts major staple crops such as rice. Experiments with increased ozone show large yield losses (20%), which are not accounted for in projections of global food security [*Long et al.*, 2005a]. These findings suggest that current projections of food security are overoptimistic. For this reason, the fertilization effect of CO2 is less than that used in many models, while rising ozone will cause large yield losses especially in the Northern Hemisphere. Unfortunately, experiments so far have hardly studied the interactive effects of CO2, ozone and temperature [*Long et al.*, 2005b].

Fuhrer [*Fuhrer*, 2009] reviewed risks related to ozone for crop production and reveals that besides uncertainties in climate projections, parameters in models for ozone risk assessment are yet too uncertain and model improvements are necessary to better define the governing processes and identify regions most at risk from ozone in a future climate and to set robust effect-based ozone standards [*Fuhrer*, 2009]

Ainsworth [*Ainsworth*, 2008] has carried out a meta-analysis synthesizes the research on rice responses to rising atmospheric carbon dioxide concentration ([CO2]) and rising tropospheric ozone concentration ([O3]). He stresses that too few studies have been done on the interaction of CO2 and O3 for meta-analysis. On an average, elevated CO2 (627 ppm) increased rice yields by 23%. Modest increases in grain mass and larger increases in panicle and grain number contributed to this response. However, free air concentration enrichment (FACE) experiments showed only a 12% increase in rice yield. The rise in atmospheric CO2 will be accompanied by increases in tropospheric O3 and temperature. Many determinants of yield, including photosynthesis, biomass, leaf area index, grain number and grain mass, were reduced by elevated O3.

The interaction of temperature and CO2 has been studied more widely. Generally, elevated temperature treatments negated any enhancement in rice yield at elevated CO2 [*Ainsworth*, 2008]. Krishnan et al., [*Krishnan et al.*, 2007] studied the impact of elevated CO2 and temperature on rice yield in eastern India by using two crop simulation models for rice. For every 1 °C increase in temperature, the rice models predicted average yield changes of around -7%. But increases in the CO2 concentration up to 700 ppm led to the average yield increases of about 30%. The authors suggest that the limitations on rice yield imposed by high CO2 and temperature can be mitigated, at least in part, by altering the sowing time and the selection of genotypes that possess higher fertility of spikelets at high temperatures [*Madan et al.*, 2012].

Kim et al. [*Kim et al.*, 2013] studied the potential effect of CO2 fertilization using a crop simulation model. This study investigates the effects of climate change on paddy rice production in the temperate climate regions under the East Asian monsoon system using the CERES-Rice 4.0 crop simulation model. Based on calibration and validation under elevated CO2 and various temperature conditions, the model was applied to deliver a simulated forecast of paddy rice production for the region. In these climate change projection simulations for a particular region in Korea, the yield increases (+12.6 and + 22.0%) due to CO2 elevation were adjusted according to temperature increases, which resulted in significant yield decreases (-22.1% and -35.0%). The authors conclude that the potential negative impact on crop production may be mediated by appropriate cultivar selection and cultivation changes such as alteration of the planting date.

Another factor that may counteract the CO2 fertilization effect, is the possible alteration caused by higher CO2 concentrations in the plant-pathogen interactions. Gória et al., [*Gória et al.*, 2013] assessed the effects on rice blast for three rice cultivars which were exposed to elevated CO2 air concentration. They conclude that the disease was more severe under high CO2 concentration. Also Luck et al., [*Luck et al.*, 2011] stresses that plant pathogens affecting rice will have varying responses to climate change. Whilst the life cycle of some pathogens will be limited by increasing temperatures, other climatic factors such as increasing atmospheric CO2 may provide more favourable conditions for certain pathogens.

As a conclusion, the CO2 fertilization effect is still under debate, as several processes may counteract the short-term positive effects on biomass production and yield. These effects are related to acclimation, ozone and temperature increase, and pathogens. Different adaptation strategies (crop enhancement, cultivation practices, etc) may reduce the impact of these factors and promote a net gain of CO2 enrichment.

Based on the discussion above it is clear that there is a lack of consensus and large uncertainties related to the yield-response of increased CO2 levels. It is not disputed that CO2 as well as O3 levels will increase and that CO2 has a positive effect on crop growth and O3 a negative one. The magnitude of those two opposite effects is however not clear and it was therefore decided to ignore in the current study the positive CO2 and the negative O3 impacts on crop growth.

In summary, for the current study neither the positive impact of higher CO2 levels nor the negative impact of higher O3 levels have been taken into accountant.

2.4 Indirect effects of climate change

2.4.1 Streamflow and water availability

Translating changes in rainfall into changes in availability of surface water and groundwater depends on a complex set of hydrological factors. Hydrological models are needed to translate climate change impacts into changes in flow. In large river basins, small changes in precipitation can have significant changes in downstream flow. Such projections are specific to the input of the climate scenario, including both the volume and timing of rainfall, and to other assumptions including land use, but the results illustrate the magnifying effect that hydrological conditions can have on climate impacts [*Johnston et al.*, 2010].

Several assessments have been carried out on the impact of climate change on streamflow and water availability. For example, Eastham et al. [*Eastham et al.*, 2008] modeled hydrological impacts of climate change in the Mekong to 2030 and, based on the assumption of an average increase in rainfall of 0.2 m (13%), projected a 21% increase in overall flow in the river and an increase in probability of “extreme wet” flood events from 5% under historical conditions to 76% under future climate conditions.

Hoanh et al. [*Hoanh et al.*, 2010] carried out a study for MRC, in which the authors confirm that the predicted changes in precipitation and temperature would affect Mekong River flow. Mean monthly flow would increase in both the wet and dry seasons with most pronounced effects for the dry season in the upper parts of the basin (Chiang Saen) and most pronounced for the wet season in the middle reaches (Kratie and Phnom Penh). Due to the complex hydrology, areas where precipitation is predicted to decrease may nevertheless experience higher river flows in the future due to the increase in precipitation and flow from upstream.

This is particularly clear for the downstream delta parts of the Mekong River [*MRC*, 2010a]. The wet season flow is predicted to increase about 15 per cent in the upstream sections down to Phnom Penh after which the increase is smaller due to the lower increase in precipitation. The percentage increase in flow for the dry season is about 30 in the upper parts of the river. The predicted lower increase in precipitation in central Lao PDR and in the southern parts of the basin reduces the increase in dry season flows from Vientiane and downstream to about 15 per cent in the delta region.

Hoanh et al. [*Hoanh et al.*, 2010] further found that the increased flow in the Mekong River will increase water availability in the dry season and increase the risk of flooding in the wet season. The low-lying areas downstream of Kratie to the Mekong Delta, including the Tonle Sap Great Lake area, are particularly at risk of flooding. The area affected by flooding in the future wet year (2048) compared with the extreme wet year experienced in 2000 is estimated to increase by about nine per cent, and the area where the flooding depth is high (more than 2 m) is estimated to increase by almost 40 per cent, meaning that flooding intensity is expected to increase.

Lauri et al. [*Lauri et al.*, 2012] studied future changes on the hydrology in the Mekong River, comparing impact of climate change and reservoir operations. They found that the simulated change in discharge between the baseline (1982–1992) and projected time period (2032–2042) ranges from −11% to +15% for the wet season and −10% to +13% for the dry season. Besides, their analysis shows that the changes in discharge due to planned reservoir operations are clearly larger than those simulated due to climate change. These results confirm that within the coming 20–30 years, the operation of planned hydropower reservoirs is likely to have a larger impact on the Mekong hydrology than the impacts of climate change, particularly during the dry season. On the other hand, climate change will increase the uncertainty of the estimated reservoir operation impacts, and the authors stress that the direction of the flow-related changes induced by climate change is partly unclear.

Another major factor of uncertainty is the divergent trends in snow cover (decreasing) and precipitation (increasing) over the twenty-first century. Cook et al. [*Cook et al.*, 2012] demonstrate how future changes in dry season streamflow in the LMB will depend on changes in snow cover and precipitation, factors that will need to be considered when assessing the full basin response to other climatic and non-climatic drivers. Much uncertainty still exists which is primarily driven by differences in GCM projections of future precipitation. In contrast, there is strong consistency between GCMs in terms of both increased potential evapotranspiration and a shift to an earlier and less substantial snowmelt season [*Kingston et al.*, 2011].

Overall, there is general agreement that rainy-season precipitation, runoff and discharge will increase in the first half of the twenty-first century, although there are significant differences in projected magnitudes of changes in water level and flooded area. However, estimates for dry-season changes differ, with projections of both increased and decreased flow in dry-season months, and depend to a large extent on the big changes to occur over the next decades in reservoir operations. Also most authors agree that climate change is likely to increase already high year-to-year variability of wet and dry season flows, as well as the frequency and intensity of floods and droughts [*MRC-BDP*, 2011].

The projected increased variability in wet and dry season flows will tend to increase the flood and drought risks to crops [*Dinh et al.*, 2012]. To better understand the implications of climate change for rice farming in the Lower Mekong Basin (LMB), Yamauchi [*Yamauchi*, 2013] compared climate and hydrological figures related to rice production for the lower part of the Basin between a baseline period and a climate change scenario. Findings of this study include that the transplanting date of rain-fed rice will be delayed more likely due to insufficient precipitation in the early wet season, which may result in decreasing rice production. Also longer dry spells will be observed during the wet season, raising the drought risk to rain-fed rice. They find that these changes will be generally observed across the LMB, while the extent of the changes varies among regions.

Definitely, water availability is one of the most critical constraints determining the current and future potential for agricultural production [*MRC*, 2010a]. In the monsoonal climate of the Mekong region, with its strongly seasonal rainfall distribution, farmers, who mostly use rainfed production systems, have multiple strategies to cope with rainfall variability. These range from investment in on-farm storage and pumps to cropping patterns that allow for rainfall shortfalls during the rainy season, and to the adaptation of appropriate crop varieties that can withstand temporary crop water shortages. Even so, shortfalls in water supply can have profound impacts on agricultural production, both for individual farmers and on a regional scale. Such events have occurred repeatedly over the last 50 years, with the most recent exceptional drought experienced between 2003 and 2005 when an atypical rainfall pattern, particularly the changes in rainfall distribution towards the end of the monsoon season, had a critical impact on agricultural production throughout the LMB [*MRC*, 2010a](see the box on p. 116.)

2.4.2 Sea level rise

In the Mekong Delta the most important factor related to flooding is expected to be the sea level rise. [*Wassmann et al.*, 2004] found that at the peak of the flood season high discharge from upstream could attenuates the increment in water level, but average sea water level rise would still imply a substantial aggravation of flooding problems in the area. They confirm that rice production will be affected through excessive flooding in the tidally inundated areas and longer flooding periods in the central part of the delta. These adverse impacts could affect all three cropping seasons.

Other attempts to estimate the impacts on the delta region [*TKK and SEA START RC*, 2009] found that the increase in flooding in the Viet Nam delta in an average year for IPCC emission scenario A2 was caused about equally by the increased flow from upstream and sea level rise. During dry years the sea level rise caused most of the changes. Another important factor for the coastal and tidally influenced areas of the delta is changes in the monsoon weather systems affecting the oceanic currents and storms from the sea. It has not been possible to quantify the effects yet.

An important factor for the flooding dynamics in the delta is deposition and erosion. Floodplain sedimentation is a relevant factor for the design of flood protection measures, productivity of agro-ecosystems, and for ecological rehabilitation plans. In the Mekong Delta, erosion and deposition are important factors for geomorphological processes like the compensation of deltaic subsidence as well as for agricultural productivity. Floodplain deposition may counteract the increasing climate change induced hazards by sea level rise in the delta, but will also depend very much on upstream developments, especially reservoir operations which the downstream sediment yield and deposition [*Hung et al.*, 2013].

Another threat due to sea level rise is salt intrusion. Saline water intrusion and sea level rise will affect both irrigated and rainfed rice, with water quality constraints, shorter growth period and higher flood level and duration. In the dry season tidal conditions influence the water levels in the Mekong River system to just upstream of Phnom Penh. The extent of the intrusion of saline water into the Mekong Delta depends on the magnitude of the dry-season flows from upstream and the level of abstractions for irrigation. Currently in the dry season, only a fraction of the delta can be irrigated due to saline intrusion.

Many authors have stressed that the area is sensitive to saline due to increasing sea levels and storm surge intrusion but also due to future changes in river flows [*Eastham et al.*, 2008; *Johnston et al.*, 2010]. Increased diversion for irrigation will reduce the dry season flow in the river which could have an impact on salt water intrusion in the Mekong Delta of Vietnam. Reservoir development will reduce flow, sediments and nutrients arriving in the Mekong Delta and increase saline water intrusion, all factors which will constrain agriculture in various ways. Farmers already perceive a rise in sea level and salinity intrusion and think they are more severe and frequent in coastal villages causing yield loss [*Dang et al.*, 2013].

Recent modelling studies have shown that that large areas of the delta will experience only minor changes in maximum salinity but other areas will experience an increase in maximum salinity concentration of over 50% [*ARCC*, 2013]. At the same time, climate change induced changes in the extent and duration of saline intrusion in the Mekong Delta are highly sensitive to the use of human built water control infrastructure in the delta itself. This infrastructure reduces the hydraulic gradient and thus allow more saline water to intrude [*ARCC*, 2013].

2.4.3 Farm inputs and mechanization

The area under irrigation has expanded gradually in all four LMB countries. Most of the installed irrigation infrastructure is found in northeast Thailand and the Viet Nam delta. The total area under irrigation in the LMB is estimated at four million hectares, comprising 3.5 million hectares in the wet season, and 1.2 million hectares in the dry season [*MRC*, 2010a].

In both northeast Thailand and the Viet Nam delta, land resources have already been brought under intensive production and there is little scope to expand. Modest potential exists in northern Thailand and the Central Highlands but, compared to Cambodia and Lao PDR, the area is small [*MRC*, 2010a].

Irrigation is used in many different agro-environments of the LMB. As well as enabling dry season production (and in some cases a third crop) it also helps stabilize agricultural production during the wet season. Because of the different socio-economic conditions found throughout the basin, the focus of irrigation development and management differs considerably between the four countries. While in Lao PDR and Cambodia food security is still a major concern, the focus in both Thailand and Viet Nam is one of intensifying production.

Diversification in irrigated agriculture has been slow in the LMB. Despite potential returns and lower water requirements, farmers have been reluctant to invest substantially in non-rice production. Access to markets, poor facilities for dry season irrigation, rapidly changing prices and adversity to risk have all contributed to a slow development towards crop diversification, outside the Mekong Delta [*MRC*, 2010a].

There is a general shift towards greater commercialization of agriculture, with even smallholder subsistence-based households engaged in some form of commercial activity [*ARCC*, 2013]. This is confirmed by the increase agricultural exports that have risen rapidly over the last years. Over the long-term, the transition towards commercial agriculture has positive implications for the alleviation of poverty and the provision of food security, as rising agricultural productivity is a major engine of economic development. Yet, in the short term, commercialization of agriculture may cause threats to the rural poor and food security, related with land tenure, and lack of skills to adapt [*Rüdiger and Stefanie*, 2009; *ARCC*, 2013].

2.5 Impacts on livestock

Traditional' small-scale, low-intensity, low-input, and low-output systems are dominant in the LMB, and over 50%of total production [*ARCC*, 2013]. These systems typically raise stock of local genetics and with limited market orientation. Though significantly less in terms of total farm numbers, commercial production volumes are relatively important and increasing.

Small- and medium-scale commercial operations are most vulnerable and have limited capacity to adapt [*ARCC*, 2013]. The presence of commercial livestock production units has increased dramatically in recent decades, a trend highly likely to continue. Higher temperatures will have little measureable effect on individual animals in ‘traditional’ systems but multiplied across villages to regional level the impacts may be significant [*ARCC*, 2013]. Temperatures above the upper critical value for specific animals will impact productivity and increase behavioral problems in intensely stocked systems.

Climatic changes will likely affect the availability and price of local feed sources and ingredients which will have significant impacts on smallholders. Drier dry seasons will likely increase the length and severity of low feed periods for grazing stock and those fed predominantly on local raw feeds - systems already stressed with stock scoring low on body condition. Also negative impacts on feed availability caused by drought and flooding will reduce stock condition and resilience to disease [*ARCC*, 2013].

Another possible impact is through animal health issues. Pathogens will likely be affected in terms of viability outside hosts and rates of proliferation by humidity levels and the quality and quantity of vector breeding sites. Wetter periods increase the likelihood of disease transmission through fomites, increasing the importance of employing effective biosecurity measures.

2.6 Impacts on fishery

The total consumption of fish and other aquatic animals in the LMB is currently estimated (2008) to be about 2.8 Mt (million tonnes), of which 1.8 Mt is from capture, including some stocked and feral fish [*MRC-BDP*, 2011]. The total production of fish in the LMB is about 3.8 Mt, as a considerable amount is produced by aquaculture and exported elsewhere within the MRC countries (but outside the LMB) and to international markets. Current estimates are that total aquaculture is of the order 2.0 Mt, of which more than half is exported outside the basin

Few studies have been carried out on the likely impacts of climate change on the current yield from fisheries. Capture fisheries yield includes a very wide range of species of fish and other aquatic animals caught in many different habitats. Principal habitats in the LMB are (i) river- floodplain wetlands, (ii) rainfed wetlands and (iii) reservoirs [*MRC-BDP*, 2011].

Fisheries are a major source of animal protein in all parts of the basin, especially in Cambodia and Vietnam. Production of capture fishery is static with some signs of overfishing, whereas aquaculture production in the delta is increasing rapidly. The increased population in 2050, together with changed diets, will require considerable increases in production. This requirement may be met by increasing the area under production, or by increasing the area under irrigation (with consequent downstream impacts). Production of capture fisheries is unlikely to increase, whereas aquaculture and mixed use rice-fish systems appear capable of greatly increased production [*Kirby and Mainuddin*, 2009].

Warming in the basin could affect fisheries yields either positively or negatively depending on how dissolved oxygen concentrations and aquatic productivity (food availability) respond [*MRC*, 2010a]. The inextricable link between local water temperature and the life history, physiology and behaviour of most freshwater organisms makes most aquatic organisms, especially fish, very susceptible to even small-scale changes in environmental thermal regimes

Changes to river flow in response to changing spatial and temporal patterns of precipitation in the basin are likely to have the most profound impact on the basin's fisheries resources. The growth of fish in the LMB is strongly linked to flood extent and duration [*ARCC*, 2013]. Increasing flows during the flood season will translate to more extensive and prolonged floodplain inundation, potentially increasing overall system productivity including the fish component but there are also side-effects that may counteract these benefits [*MRC*, 2010a]. Aquaculture could be more vulnerable to climate change than capture fisheries, with flash floods causing a sudden drop in salinity and inviting disease of coastal shrimp ponds in Vietnam [*ARCC*, 2013].

The most critical impact of a changed flow in the Mekong River is probably the potential effect on migratory fish species. Changes in water flow may disrupt the movements of migrating fish that use water conditions to control their development, time their migration, and orient themselves to navigate effectively. In the Mekong River, a number of factors trigger fish migration that may be sensitive to climate change. These include: i) variation in river dis- charges; ii) variation in water levels; iii) first rainfalls after the dry season; iv) change in water turbidity or colour; and v) presence of insects [*MRC*, 2010a]. Black fish, which have limited migrations, appear more 'climate-proof' than migratory fish and upland fish and may be expected to increase in the proportion of fish catches as temperatures increase [*ARCC*, 2013].

The previous sections are based on a combination of international literature and LMB specific information. It is however clear that in order to make more rigorous assessments on the impact of climate change on fish and fishery additional data collection in the region is highly needed.

2.7 Past trends in food supply

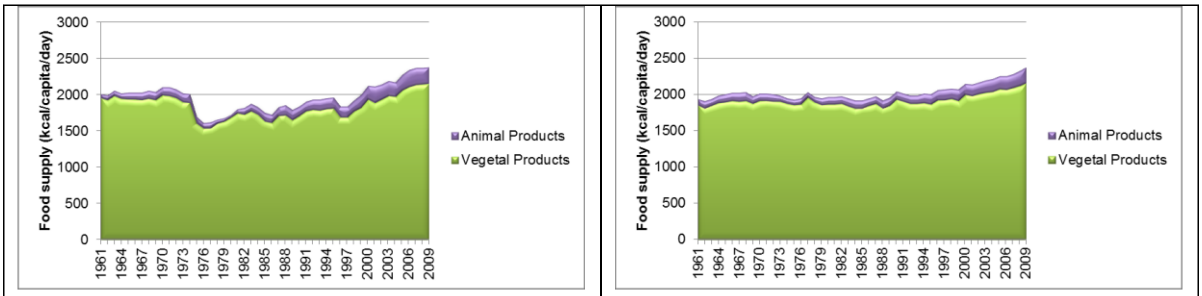
Climate is only one driver of change that will affect the balance between food supply and demand. Rapid economic development and population growth mean that water resources in the region will be shaped by a complex mixture of social, economic and environment factors [*Johnston et al.*, 2010]. Social, demographic and economic drivers are already forcing rapid and visible change in the water resources of the Mekong region. Withdrawals for irrigation regularly cause seasonal water shortages and water use conflicts in some areas. Construction of dams for irrigation and hydropower has significantly changed local downstream flow patterns and productivity of local fisheries.

Quantifying the relative impacts of different drivers of change is not easy, but it is clear the impacts of demographic and economic changes are of at least the same magnitude as, or greater than, the impacts driven by climate change, and will occur in a shorter time span [*Johnston et al.*, 2010]. For example: estimates of changes in crop productivity due to climate change are in the range of 2-30% over a 20-30 year period [*Hoanh et al.*, 2003; *Eastham et al.*, 2008; *MRC*, 2010a]. While in comparison, total agricultural production has increased almost 80% in Vietnam and over 200% in Cambodia over the last 15 years, with even faster growth in specific sectors and regions.

Pas trends in food supply to the population in the four member countries is analyzed based on statistical data collected by the countries and distributed by FAOstat. Table 2 shows that average caloric supply per capita is more or less sufficient given the Recommended Daily Intake (RDI) in the four member countries. Also protein supply is sufficient but fat supply remains on the low site. It is important to realize that these numbers are country averages and large differences can exist within a country and between individuals.

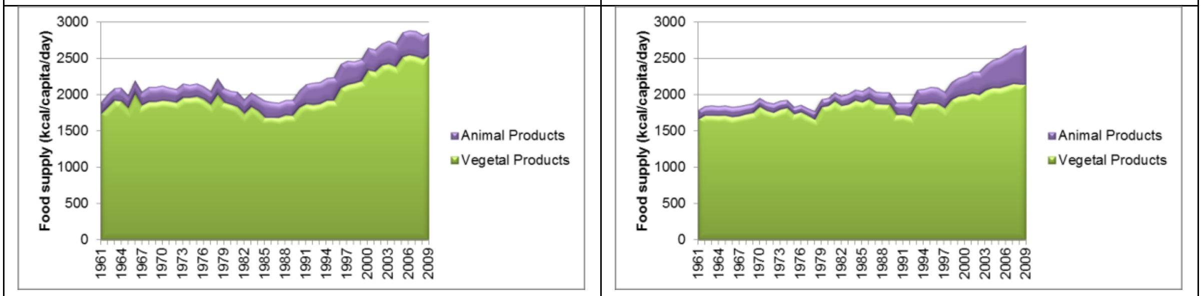
Table 2. Food supply quantities compared to the Recommended Daily Intake (RDI) based on the USDA. Source: country data as compiled in FAOstat.

	Cambodia		Lao PDR		Thailand		Vietnam		RDI
	1961	2009	1961	2009	1961	2009	1961	2009	
Food supply (kcal/capita/day)	2019	2382	1946	2377	1899	2862	1794	2690	2400
Protein supply (g/capita/day)	44	62	49	65	41	63	43	75	50
Fat supply (g/capita/day)	15	37	18	38	31	55	20	69	65



Cambodia

LAO PDR



Thailand

Vietnam

Figure 1. Total food energy supply for the four member countries. Source: country data as compiled in FAOstat.

Increase in food supply has been increasing over the last decades and especially for Thailand and Vietnam a substantial rise in food energy supply has been observed (Figure 1). Interesting is that more than 90% of the total food energy supply originates from vegetal products. From these vegetal products rice is still the dominant crop with around 60% of total crop area. This dominancy of rice is however smaller compared to 1961 when about 80% of the cropped area was rice (Figure 2).

Changes in food supply can have various reasons. The most relevant are: (i) changes in import and/or export, (ii) changes in population, (iii) changes in agricultural production, and (iv) changes in agricultural area. For the LMB all these four factors have played a role in food supply trends. Changes in import and export are displayed in Figure 3 for the dominant crop in the countries: rice. Between 1960 and about 1990 quite some rice was imported in Cambodia, Lao PDR and Vietnam. During the last two decades rice imports were very low and Thailand and Vietnam has been developing as exporters of rice. Thailand exports between 40 and 50% of their domestic production and Vietnam about 25%. For Thailand the export seems to be more or less stabilized, while for Vietnam an upward trend can be seen.

Population growth is an important factor when analyzing food supply per capita. Population has more than doubled in the four member states over the last 50 years (Figure 4) and also more people live in urban areas than ever before in history(Figure 5). It is clear that these changes, combined with climate change put another challenge on food supply capacity of the region.

The harvested area of the member countries is still increasing which explains the increase in total food supply (Figure 6). For Thailand and Vietnam the harvested areas have been more than doubled over the last 40 years, for Cambodia and Lao PDR increase was about 50% over the same period. Also over the last 10 years these grow continues and especially for Cambodia this increase in rice area is over 5% per year since 2000.

Protein and fat coverage per capita has changed as well over the last decades and a clear trends towards more animal based coverage can be seen (Figure 7 to Figure 10). However, vegetal products remain the main source for energy, protein and to a lesser extent fat. From the various animal based products pig meat is still the main source. Only for proteins and then specific for Cambodia fish is an important food product (Table 4 to Table 6)

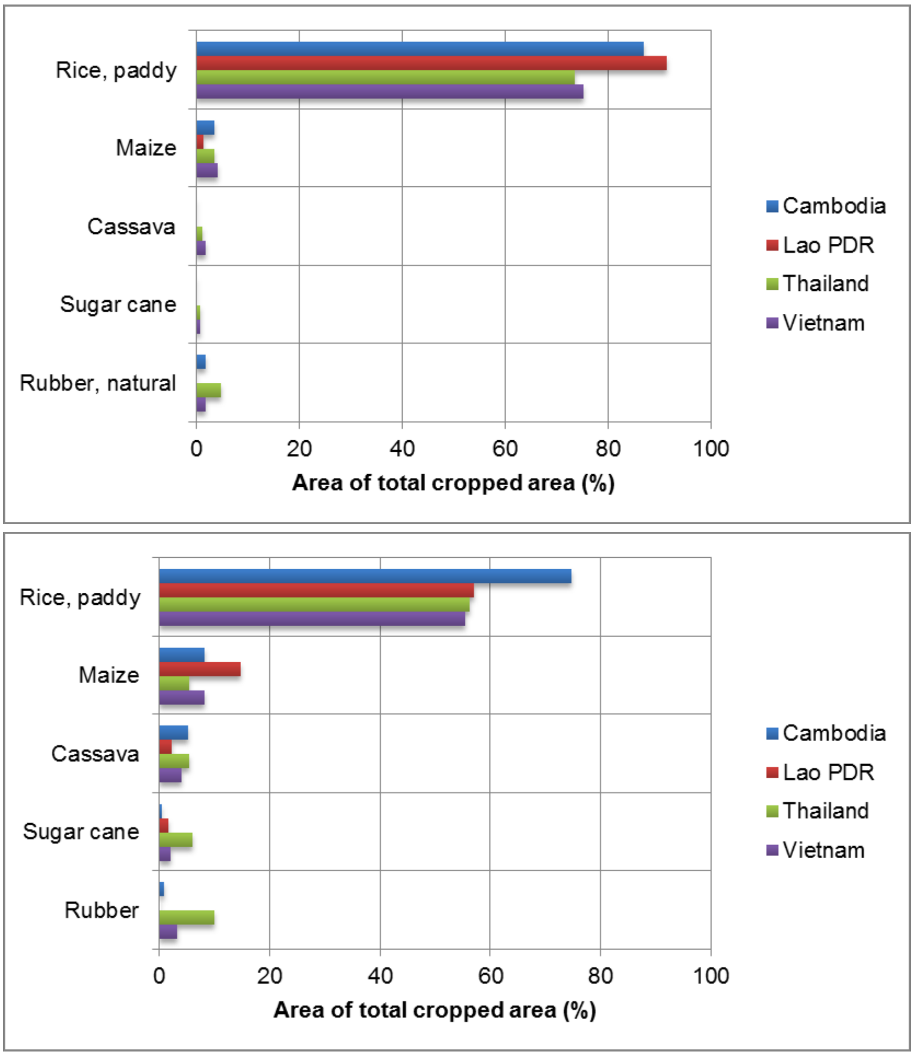


Figure 2. Crop area as percentage of total cropped area for 1961 (top) and 2011 (bottom). Source: FAOstat.

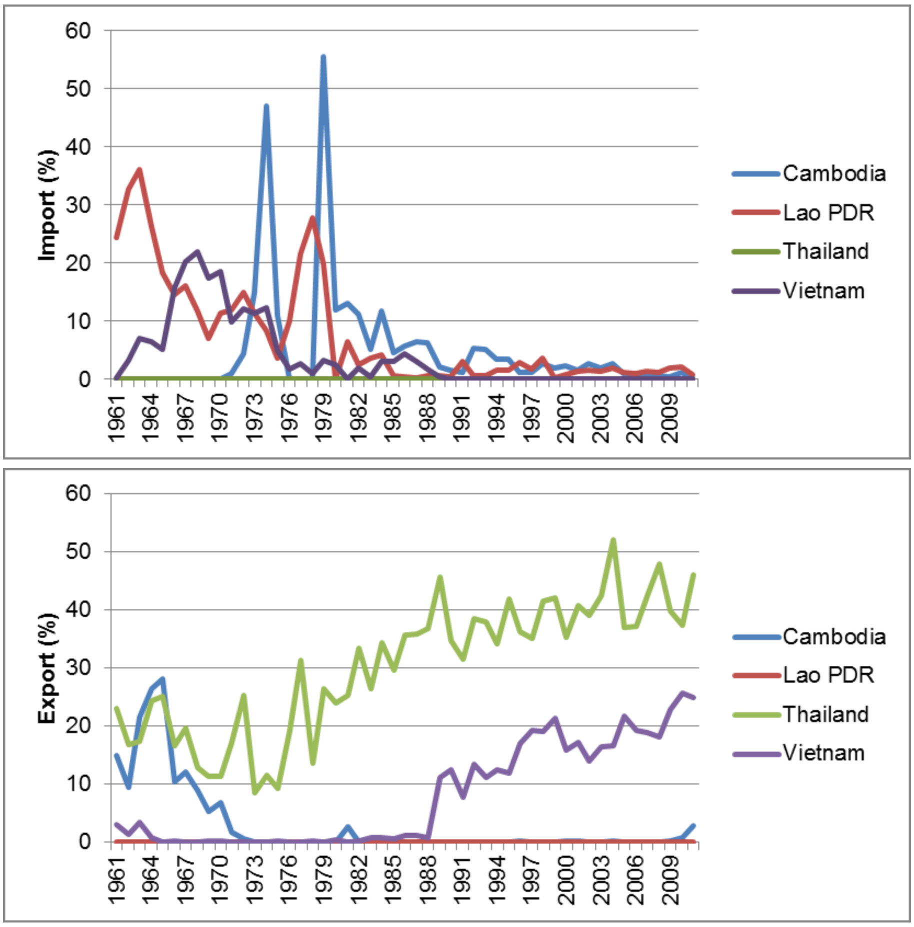


Figure 3. Rice import (top) and export (bottom) as percentage from domestic production. C=Cambodia, L=Lao PDR, T=Thailand, V=Vietnam. Source: Country statistics as compiled in FAOstat.

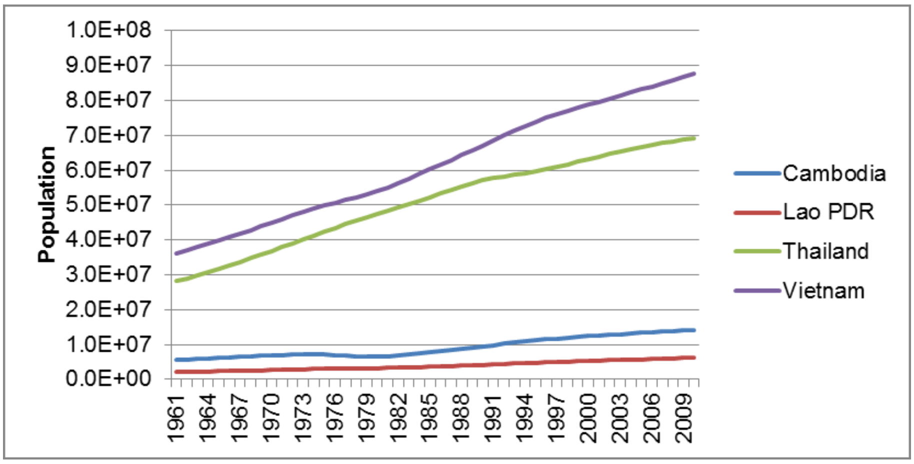


Figure 4. Trends in population growth over the last 50 years. Source: FAOstat.

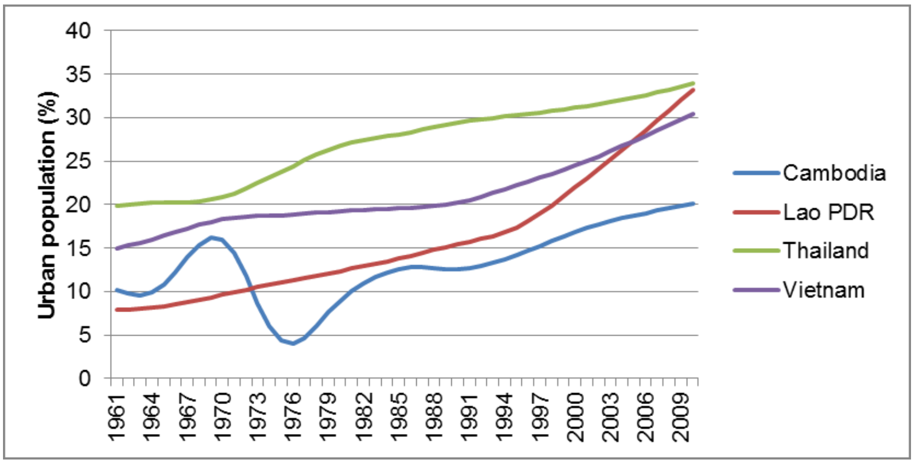


Figure 5. Trends in urban population over the last 50 years. Source: FAOstat.

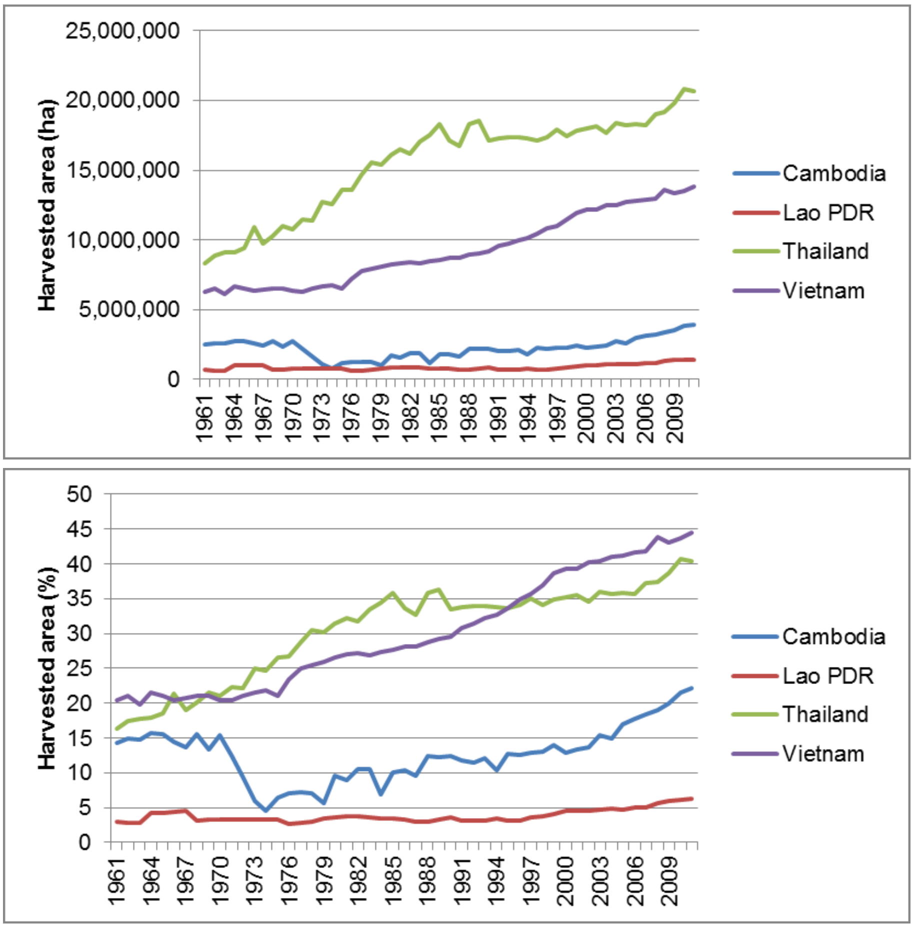


Figure 6. Area harvested in hectare (top) and as percentage of total land (below). Source: Country statistics as compiled in FAOstat.

Table 3. Trends in rice area expressed as % per year. Source: FAOstat

	1961-2010 (%/y)	2001-2010 (%/y)
Cambodia	0.8	5.2
Lao PDR	1.0	3.5
Thailand	1.4	1.4
Vietnam	1.8	1.1

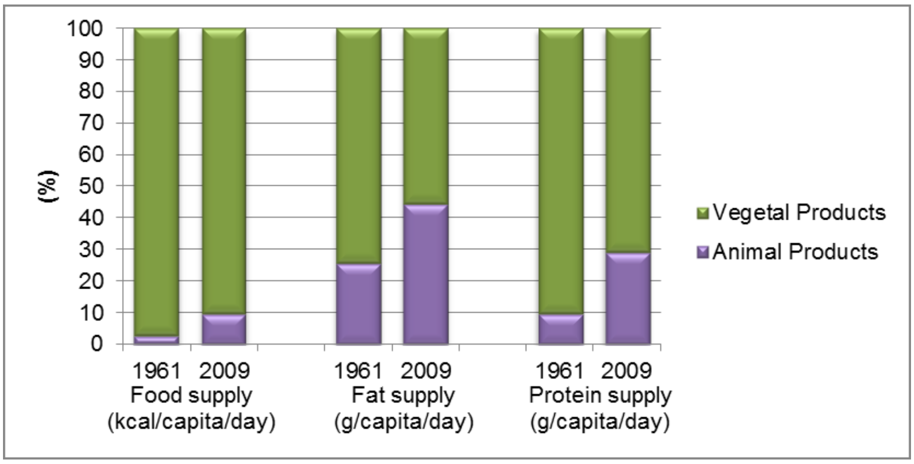


Figure 7. Fraction of food, fat and protein supply originating from vegetal and animal products for Cambodia. Source: FAOstat.

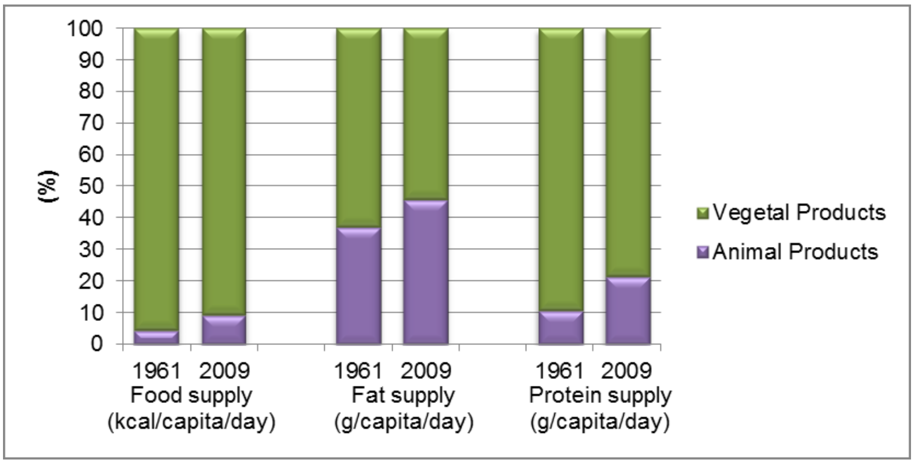


Figure 8. Fraction of food, fat and protein supply originating from vegetal and animal products for Lao PDR. Source: FAOstat.

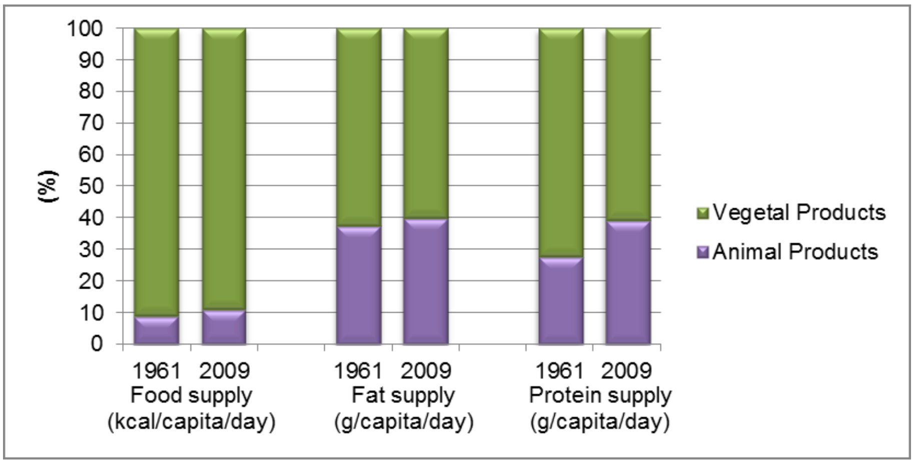


Figure 9. Fraction of food, fat and protein supply originating from vegetal and animal products for Thailand. Source: FAOstat.

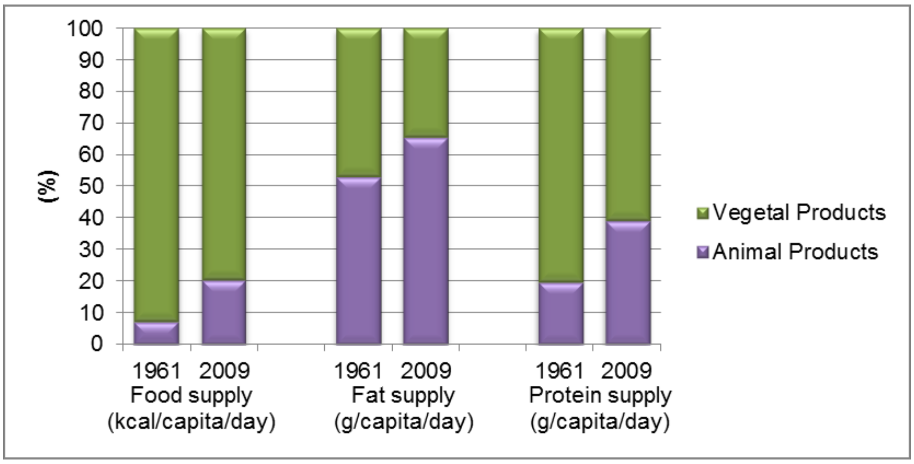


Figure 10. Fraction of food, fat and protein supply originating from vegetal and animal products for Vietnam. Source: FAOstat.

Table 4. Food supply quantity originating from the most important animal sources (kCal/capita/day).

	Cambodia		Lao PDR		Thailand		Vietnam	
	1961	2009	1961	2009	1961	2009	1961	2009
TOTAL	**66**	**240**	**93**	**224**	**180**	**342**	**132**	**559**
Pigmeat	17	88	41	100	45	107	68	342
Fats, Animals, Raw	4	17	10	20	10	9	11	39
Poultry Meat	3	10	7	15	13	53	7	39
Freshwater Fish	5	65	10	33	7	18	7	23
Bovine Meat	11	24	9	32	21	10	6	21
Others	*26*	*36*	*16*	*24*	*84*	*145*	*33*	*95*

Table 5. Fat supply quantity originating from the most important animal sources (g/capita/day).

	Cambodia		Lao PDR		Thailand		Vietnam	
	1961	2009	1961	2009	1961	2009	1961	2009
TOTAL	**4.1**	**16.8**	**7.1**	**17.7**	**11.8**	**22.8**	**10.3**	**46.0**
Pigmeat	1.6	8.5	3.9	9.6	4.3	10.2	6.5	32.9
Fats, Animals, Raw	0.5	1.8	1.1	2.1	1.1	0.9	1.2	4.2
Poultry Meat	0.2	0.8	0.5	1.2	0.9	3.3	0.6	2.8
Bovine Meat	0.8	1.6	0.6	2.3	1.1	0.4	0.4	1.6
Eggs	0.2	0.4	0.1	0.6	3.0	3.4	0.4	0.9
Others	*0.8*	*3.7*	*0.9*	*1.9*	*1.4*	*4.6*	*1.2*	*3.6*

Table 6. Protein supply quantity originating from the most important animal sources (g/capita/day).

	Cambodia		Lao PDR		Thailand		Vietnam	
	1961	2009	1961	2009	1961	2009	1961	2009
TOTAL	**4.4**	**18.4**	**5.5**	**14.2**	**11.9**	**25.8**	**8.6**	**29.4**
Pigmeat	0.5	2.7	1.3	3.1	1.4	3.4	2.1	10.6
Freshwater Fish	0.7	9.8	1.6	5.2	0.9	2.8	1.1	3.6
Marine Fish, Other	0.8	0.3	0.0	0.0	0.8	0.1	2.6	3.3
Poultry Meat	0.2	0.7	0.7	1.1	1.1	6.0	0.5	3.3
Offals, Edible	0.3	0.8	0.4	0.9	0.6	0.5	0.6	2.1
Others	*1.9*	*4.1*	*1.5*	*3.9*	*7.1*	*13.0*	*1.7*	*6.5*

3 Methods

3.1 Introduction

The previous Chapter discussed the existing knowledge, literature and data on the impact of climate change on crop production and food supply. These studies provide an interesting indication of parts of the entire complex system, but an overall inclusive picture is lacking so far. More specifically there is a need for an overview that: (i) is based on the latest IPCC projections, (ii) uses the entire range of climate projections, (iii) is region specific, and (iv) includes all components of the food balance (crops, fish, meat). The tools and approaches as used here (statistics, AquaCrop, Food Balance Sheets) have been applied before and are well tested. The weakest component is the data used. Given the large area and the many components included in this study results should be considered as scoping. Obviously, if more and more accurate data will become available, it is easy to include this in the tools as discussed below.

To study the impact of climate change and other drivers of change on the balance between food production and supply, two tools were used (Figure 11):

1. A water-focused crop model, developed by FAO: AquaCrop, to study the impact of climate change on crop yields in the LMB
2. Food Balance Sheets, a locally-adapted version of the methodology followed by the FAO.

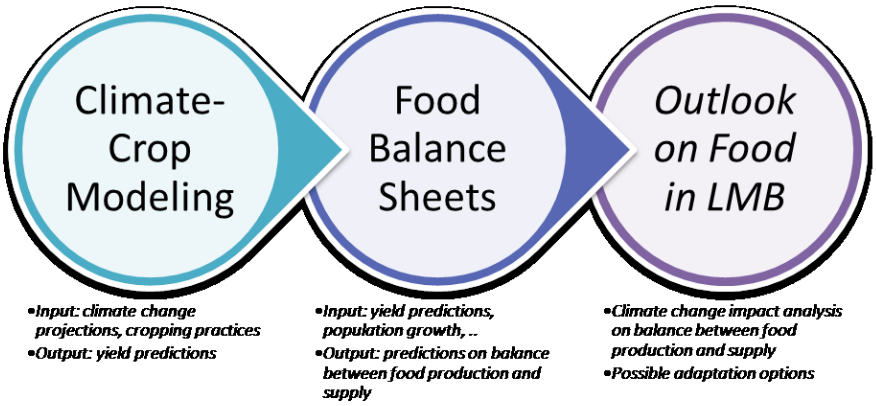


Figure 11. Tools used to explorative outlook on crop and food production and supply in the LMB.

Climate-crop modelling will provide predictions on crop yields of the main crops in the LMB for the different future horizons. These predictions will be one the inputs of the Food Balance Sheets (explained further on) which include projections on population growth and changing diets as economies will develop. Several adaptation options will be explored through the Food Balance Sheets, to assess how they may reduce the gaps between food supply and demand.

The analysis is done for each sub-area of the Lower Mekong Basin, as defined in the Planning Atlas [*MRC*, 2011]. Sub-areas represent the intersection of one or more river catchments with national boundaries. They are numbered sequentially from upstream to downstream, while the letter refers to the country within which the sub-area is located (total 15, see Figure 13).

The sub-areas were defined by the Basin Development Plan Programme of the Mekong River Commission in 2002 for the purpose of aiding basin development planning. Sub-area reports (2002 and 2011) include inventories of the status and use of water related resources, the formulation of sub- area scenarios and development strategies, and the identification of projects. The activities are implemented in a bottom-up and participatory process, led by the National Mekong Committees.

A minor modification was done for the two sub-areas of the Mekong delta (10V and 10C). Here, a part of the Vam Co basin was added, because of its connection with the Mekong delta during peak floods.

Further details on the methodology followed for climate-crop modelling and the FBS can be found in the following sections.

Region and catchment groupings	Sub-area code	Area (km^2)
A: Northern Highlands		
Northern Lao PDR	1L	80,544
Chiang Rai, northern Thailand	2T	17,321
B: Central Plateau & Highlands		
Nong Khai / Songkhram	3L (Lao PDR)	3,299
	3T (Thailand)	47,260
Central Lao PDR	4L	87,093
Mun / Chi River Basin	5T	119,163
C: Southeast Highlands		
Southern Lao PDR	6L (Lao PDR)	15,861
	6C (Cambodia)	3,210
Se San / Sre Pok / Se Kong river basins	7L (Lao PDR)	22,585
	7C (Cambodia)	26,377
	7V (Viet Nam)	29,385
D: Southern Region		
Kratie	8C	22,680
Tonle Sap basin	9C	86,045
Mekong delta	10C (Cambodia)	23,346
	10V (Viet Nam)	35,158

Figure 12. Sub-area descriptions and surface areas. (Source: BDP Atlas, 2011)

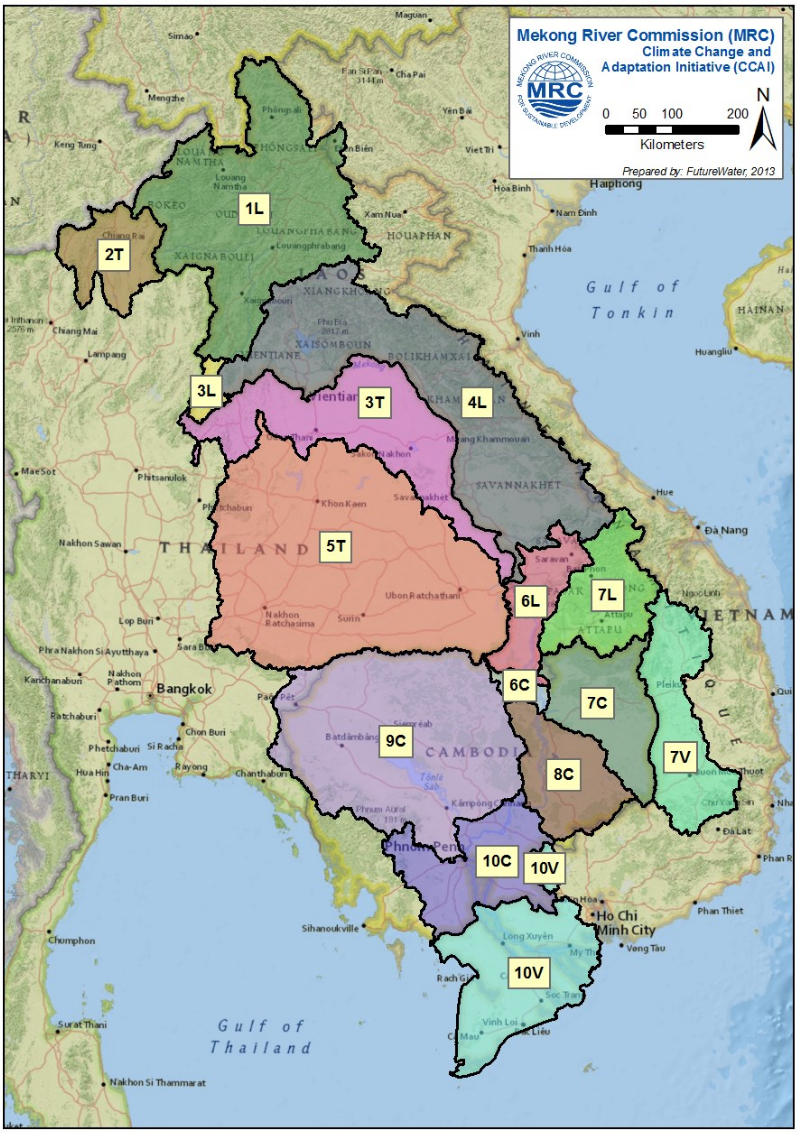


Figure 13. Map indicating the 15 sub areas on which the food analysis is based.

3.2 Climate change projections

Climate projections originate from Global Circulation Models (GCMs) and in some specific cases from Regional Climate Models (RCMs). Many institutes have their own GCMs but the ones approved by the IPCC can be considered to be the most relevant models. A total of 21 GCMs were included in the 4th Assessment Report (AR4) of the IPCC. Data were stored in the so-called CMIP-3 (Coupled Model Intercomparison Project). In autumn 2013, the IPCC presented its 5th Assessment Report (AR5). At the same time, CMIP-5 climate projections were made available.

In the AR4 there were four distinct so-called Special Reports on Emission Scenarios (SRES). These four were developed by combing economic growth figures and political willingness to reduce GHG emissions. These four scenarios, often referred to as storylines, were called A1, A2, B1 and B2. Over the years, various combinations were developed of which A1b is used most commonly. In the AR5, the SRES approach has been abolished and replaced by the resulting global increase in energy levels in W/m^2 by 2100. The four scenarios, referred to as RCPs (Representative Concentration Pathways), are RCP8.5, RCP6, RCP4.5 and RCP2.6. These four RCPs correspond to concentrations of CO_2 equivalents of 1370, 850, 650, and 490 ppm by the end of this century.

Downscaled climate projections for the CMIP5 data are not yet available, since those CMIP5 data were only recently published. Therefore data as presented by IPCC in maps and graphs in the AR5 have been used to derive the projected climate changes for the LMB. Typical examples of these IPCC results can be observed in Figure 14 and Figure 15. IPCC published changes in temperature in absolute values (oC) and for precipitation in percentages for two selected period in the year. Difference between those two different periods was small and therefore one correction factor for the entire year was used. Spatial distribution indicated that on average the northern part of the LMB is projected to have a higher increase in temperature and at the same time more precipitation is expected. Combing all this information the final temperature and precipitation projections can be found in Table 7 and Table 8.

Table 7. Changes in temperature relative to current (in oC) for the four RCPs and the Southern and Northern LMB. Source: IPCC, 2013

	Temp (South)				Temp (North)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.8	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.8
2026-2035	0.3	0.6	0.8	1.4	0.8	1.1	1.3	1.9
2046-2055	0.5	1.0	1.3	2.3	1.0	1.5	1.8	2.8
2090-2099	0.9	1.8	2.3	4.1	1.4	2.3	2.8	4.6

Table 8. Changes in precipitation relative to current (in % for the four RCPs and the Southern and Northern LMB. Source: IPCC, 2013

	Precipitation (South)				Precipitation (North)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.8	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.8
2026-2035	-2.2	-1.2	-1.5	0.8	2.8	3.8	3.5	5.8
2046-2055	-1.9	-0.3	-0.8	3.1	3.1	4.7	4.2	8.1
2090-2099	-1.5	1.5	0.5	7.5	3.5	6.5	5.5	12.5

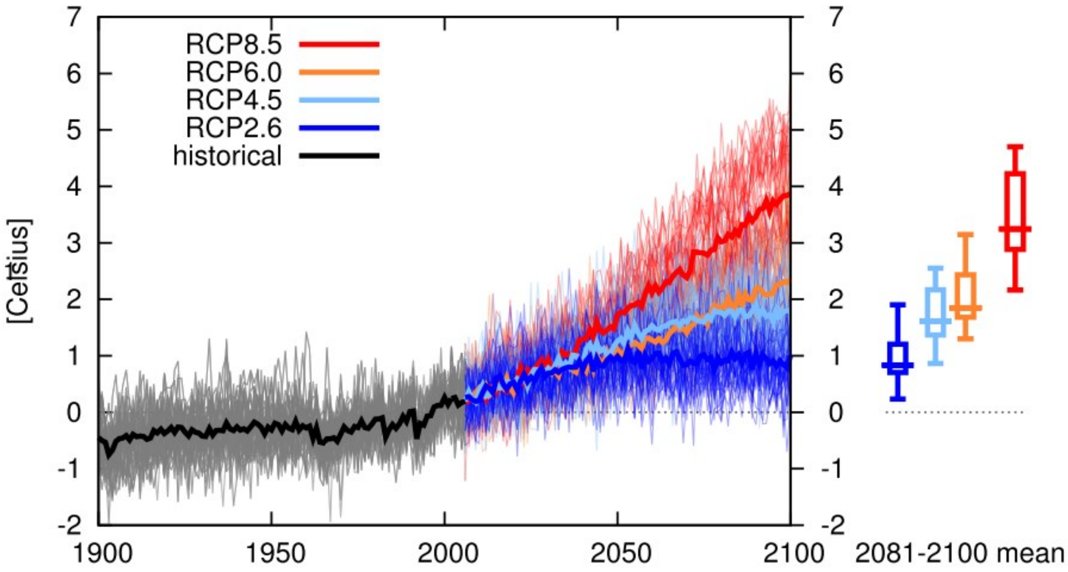


Figure 14. Temperature change Southeast Asia December-February. Source: IPCC, 2013

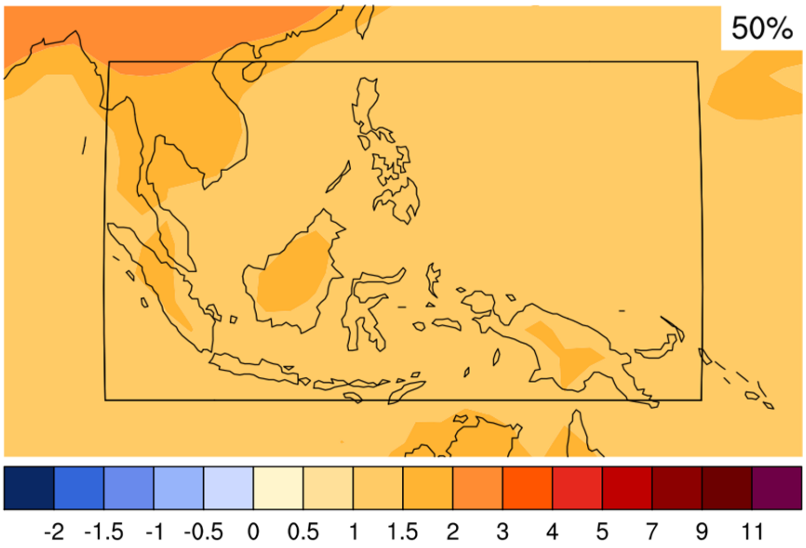


Figure 15. Map of temperature changes in 2081–2100 with respect to 1986–2005 in the RCP4.5 scenario. For each point, the 50th percentile of the distribution of the CMIP5 ensemble are shown, this includes both natural variability and inter-model spread. Source: IPCC, 2013

3.3 Crop modelling under climate change

3.3.1 Overview

The previous chapter summarized the wide range of studies that have been undertaken on the impact of climate change on agricultural production in the Lower Mekong Basin. Although those studies are useful in their specific context, their outcomes are limited to the specific conditions (agronomic, soils, slopes, elevation, etc) and are difficult to interpret on the scale of the whole basin. In general, the drawbacks of these existing studies for a regional status overview are: (i) different approaches, methodologies, data, (ii) based on outdated climate change scenarios (CMIP3), (iii) mostly focused on impact only and hardly any analysis of adaptation options.

This section describes the methodology for a first-order assessment of the impact of climate change on agricultural production based on a generic approach, using common and straightforward tools and procedures. The outcomes should provide insight in the regional differences and challenges related with climate change and crop production in the LMB.

The State of the Basin report [*MRC*, 2010b] states that the following 4 crops are dominant in the LMB, and of special relevance for future developments:

1. **Rice**: large-scale production in Thailand and Vietnam, both for import and export, and the main crop for subsistence in Cambodia and Lao PDR. In this study AqauCrop has been setup to distinguish rainfed from irrigated rice.
2. **Maize**: principal field crop in the 4 countries, expanding in Lao PDR.
3. **Sugarcane**: rapidly expanding for domestic use in Vietnam and Lao PDR.
4. **Cassava**: especially key crop in Thailand, but also in Cambodia and Lao PDR.

These crops are analyzed for the 15 sub-areas identified in the Planning Atlas of the Basin Development Plan Programme [*MRC*, 2011], with minor modifications as commented previously. The following time frames are used based upon the definitions as used in the BDP scenarios work:

- Baseline Situation (=1981-2010)
- Foreseeable Future Situation (=2026-2035)
- Long-term Future Situation (=2046-2055)
- Horizon Situation (=2090-2099)

The specified years are slightly different from the BDP scenarios work to optimize use of data and information. Also, the end of the century situation (defined here as Horizon) was not included in the BDP scenarios but is included here given the long-term impact of climate change.

The objective of this analysis is to provide an explorative look on the impact of climate change on crop production. The assessment provides insight in the possible consequences on the agricultural production under different climate scenarios for each sub-area in the Lower Mekong Basin and the potential of different adaptation measures.

For this analysis, simulations have been carried out over a large number of dimensions (975), as is summarized in Table 9. The results of these simulations are evaluated over the 3 future periods and compared with the baseline situation. Each of those period is represented by 30 years, so total AquaCrop model runs is 29,250. Advanced scripting and database management has been setup to handle this.

The crop model AquaCrop (FAO) is set up and used for each of the modelling dimensions shown in Table 9. A first order calibration is carried out with regional and temporal data on yields, as further detailed below.

Table 9. Dimensions for crop modelling assessment

Type	A Crop types	B Sub-Areas	C Climate scenarios
Classes	1. Rice: wet season 2. Rice: dry season 3. Maize 4. Sugarcane 5. Cassava	**Cambodia**: 10C - Mekong delta 6C - Southeast Highlands 7C - Se San / Sre Pok / Se Kong 8C - Kratie 9C - Tonle Sap basin **Lao PDR**: 1L - Northern Lao PDR 3L - Nong Khai / Songkhram 4L - Central Lao PDR 6L - Southern Lao PDR 7L - Se San / Sre Pok / Se Kong **Thailand** 2T - Chiang Rai 3T - Nong Khai / Songkhram 5T - Mun / Chi River Basin **Vietnam**: 10V - Mekong delta 7V - Se San / Sre Pok / Se Kong	0. Baseline Situation (=1981-2010) 1. Foreseeable Future Situation (=2026-2035) 2. Long-term Future Situation (=2046-2055) 3. Horizon Situation (=2090-2099) And each future horizon with the 4 RCPs in CMIP5: RCP8.5, RCP6, RCP4.5 and RCP2.6
Number	**Crops: 5**	**Sub-Area: 15**	**Climate:13 (1 baseline + 3x4 (future x RCP)**
		Total dimensions (A*B*C) = **975**	

3.3.2 Crop model

Model selection

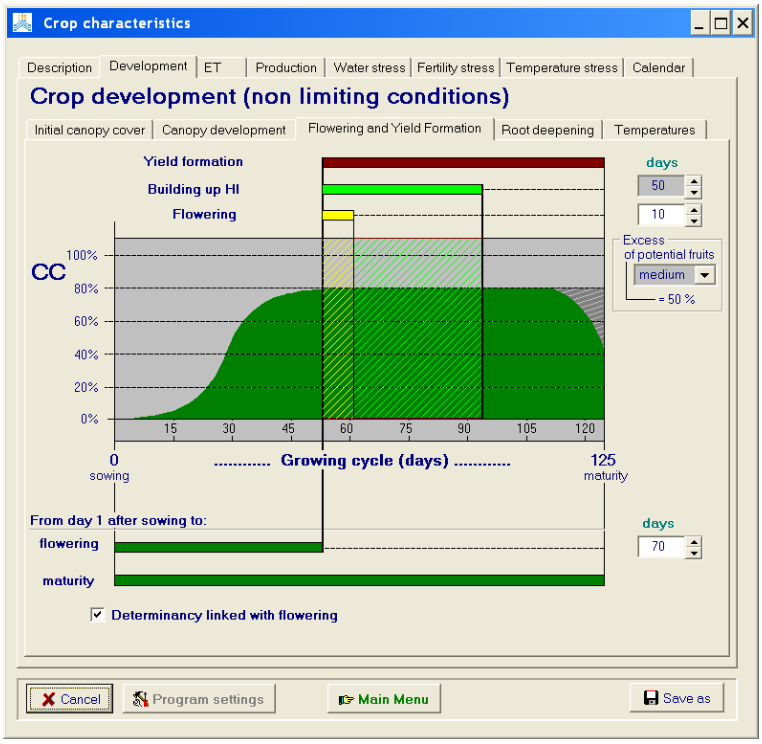
To evaluate the regional effects of climate change on crop production, statistical data-based approaches can be used [*Heft-Neal et al.*, 2013] or deterministic crop models can be used [*Hoanh et al.*, 2003; *Mainuddin et al.*, 2010]. To assess the impact of potential adaptation strategies models, in principle, deterministic models are more suitable as they can be considered more reliable under changing conditions. The use of these models can lead to: (i) a better understanding of water-food-climate change interactions, and (ii) better insight in options to improve agricultural production now and under future climates.

Some of the frequently applied agricultural models are [*Rivington and Koo*, 2010]:

- CropWat
- AquaCrop
- CropSyst
- SWAP/WOFOST
- CERES
- DSSAT
- EPIC

Each of these models is able to simulate crop growth for a range of crops. The main differences between these models are the representation of physical processes and the main focus of the model. Some of the models mentioned are strong in analysing the impact of fertilizer use, the ability to simulate different crop varieties, farmer practices, etc. For this analysis, it is required to use a modeling approach with a strong emphasis on crop-water-climate interactions. The three models that are specifically focused on this relationship between water availability, crop growth and climate change are CropWat, AquaCrop and SWAP/WOFOST. Moreover, these three models are in the public domain, have been applied world-wide frequently, and have a user-friendly interface (Figure 16).

In summary, the main advantages of AquaCrop over other tools are: limited data requirements, a user-friendly interface, strong focus on climate change, water focused, developed and supported by FAO, expanding growing group of users world-wide, and flexibility in level of detail.



Yield formation: days 50

Flowering: days 10

Excess of potential fruits: medium = 50 %

flowering: days 70

☑ Determinancy linked with flowering

Figure 16. Typical examples of input screen of AquaCrop on crop development.

Model concepts

AquaCrop is the FAO crop-model to simulate yield response to water. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios. AquaCrop is a completely revised version of the successful CropWat model. The main difference between CropWat and AquaCrop is that the latter includes more advanced crop growth routines.

AquaCrop includes the following sub-model components: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and CO2 concentration; and the management, with its major agronomic practice such as irrigation and fertilization. AquaCrop flowchart is shown in Figure 17.

The particular features that distinguishes AquaCrop from other crop models is its focus on water, the use of ground canopy cover instead of leaf area index, and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration. This enables the model with the extrapolation capacity to diverse locations and seasons, including future climate scenarios. Moreover, although the model is simple, it gives particular attention to the fundamental processes involved in crop productivity and in the responses to water, from a physiological and agronomic background perspective.

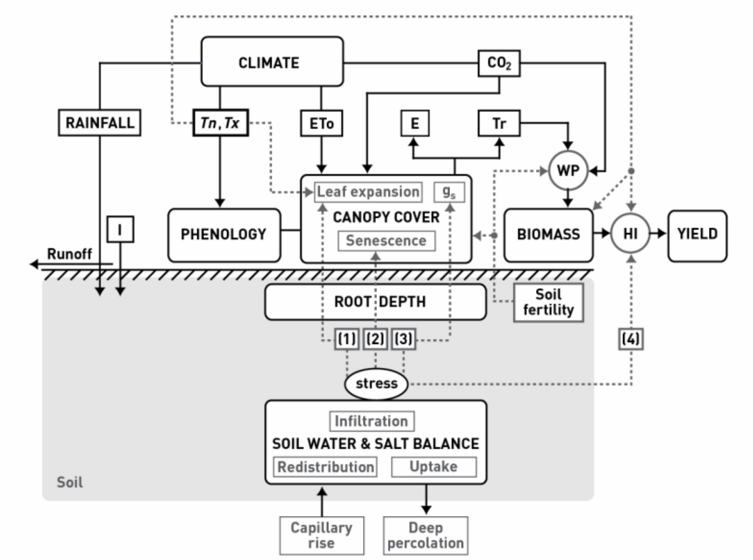


Figure 17. Main processes included in AquaCrop.

Theoretical assumptions

The complexity of crop responses to water deficits led to the use of empirical production functions as the most practical option to assess crop yield response to water. Among the empirical function approaches, FAO Irrigation & Drainage Paper nr 33 (Doorenbos and Kassam, 1979) represented an important source to determine the yield response to water of field, vegetable and tree crops, through the following equation:

$$\left(\frac{Y_x - Y_a}{Y_x}\right) = k_y \left(\frac{ET_x - ET_a}{ET_x}\right) \qquad \text{Eq. 1}$$

where Y_x and Ya are the maximum and actual yield, ET_x and ETa are the maximum and actual evapotranspiration, and k_y is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach by separating (i) the ET into soil evaporation (E) and crop transpiration (Tr) and (ii) the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confounding effect of the non-productive consumptive use of water (E). This is important especially during incomplete ground cover. The separation of Y into B and HI allows the distinction of the basic functional relations between environment and B from those between environment and HI. These relations are in fact fundamentally different and their use avoids the confounding effects of water stress on B and on HI. The changes described led to the following equation at the core of the AquaCrop growth engine:

$$B = WP \cdot \Sigma Tr \qquad \text{Eq. 2}$$

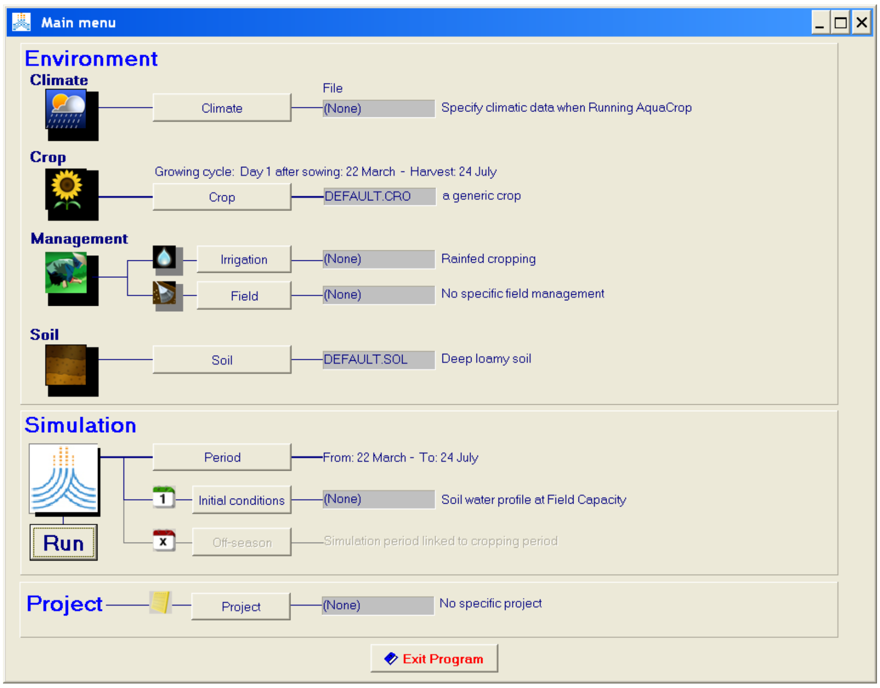
where Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m_2 and per mm of cumulated water transpired over the time period in which the biomass is produced). This step from Eq. 1.1 to Eq. 1.2 has a fundamental implication for the robustness of the model due to the conservative behavior of WP (Steduto et al., 2007). It is worth noticing, though, that both equations are different expressions of a water-driven growth-engine in terms of crop modeling design (Steduto, 2003). The other main change from Eq. 1 to AquaCrop is in the time scale used for each one. In the case of Eq. 1.1, the relationship is used seasonally or for long periods (of the order of months), while in the case of Eq. 2 the relationship is used for daily time steps, a period that is closer to the time scale of crop responses to water deficits.

The main components included in AquaCrop to calculate crop growth are Figure 18:

- Atmosphere
- Crop
- Soil
- Field management

- Irrigation management

More details on each of these components can be found in the AquaCrop documentation (Raes et al., 2009)



Climate — File: (None) — Specify climatic data when Running AquaCrop

Growing cycle: Day 1 after sowing: 22 March - Harvest: 24 July

Crop — DEFAULT.CRO — a generic crop

Irrigation — (None) — Rainfed cropping

Field — (None) — No specific field management

Soil — DEFAULT.SOL — Deep loamy soil

Period — From: 22 March - To: 24 July

Initial conditions — (None) — Soil water profile at Field Capacity

Off-season — Simulation period linked to cropping period

Project — (None) — No specific project

Figure 18. Overview of AquaCrop showing the most relevant components.

3.3.3 Meteorological data

For the meteorological input of the crop model, the database was used that was generated for the study “Development of baseline climate data set and trend analysis in the Mekong Basin” [MRC-CCAI, 2013]. This database includes the quality-checked data of all the weather stations of the global GSOD database and all the weather station data available to the MRC-CCAI.

For each of the sub-areas, a representative weather station for temperature and for precipitation was selected, based on its closeness to agricultural areas and central position in the sub-area (see Table 10). Preference was given to stations with both quality-checked temperature as well as precipitation data. If not available, a close station was chosen for the lacking variable.

For some sub-areas (Table 10), no weather station within the boundaries of the sub-area was available. For these sub-areas, a virtual weather station was generated based on existing data of the closest stations. First, long-term average temperature and/or precipitation fields were spatially interpolated. Then, the interpolated value on the location of the virtual weather station was used to adjust the daily temperature and/or precipitation data of the closest weather station.

Table 10. Weather stations used for temperature and precipitation from quality-checked GSOD and MRC database

Sub-area	Temperature ID	Name	Precipitation ID	Name
10C	489910 (GSOD)	Phnom Penh *	110432 (MRC)	Kong Pisey / Chroy Thmar
6C	484070 (GSOD)	Ubon Ratchathani*	140501 (MRC)	Muong Khong*
7C	488660 (GSOD)	Pleiku City*	140705 (MRC)	Attapeu*
8C	489910 (GSOD)	Phnom Penh *	120603 (MRC)	Kratie
9C	484620 (GSOD)	Aranyaprathet	484620 (GSOD)	Aranyaprathet
1L	489300 (GSOD)	Luang-Prabang	190202 (MRC)	Luang Prabang
3L	483530 (GSOD)	Loei*	170110 (MRC)	Ban Pak Huai
4L	483520 (GSOD)	Nong Khai*	180307 (MRC)	Meuang Kao
6L	484070 (GSOD)	Ubon Ratchathani*	150504 (MRC)	Pakse
7L	488660 (GSOD)	Pleiku City*	170502 (MRC)	Mahaxai
2T	483030 (GSOD)	Chiang Rai	483030 (GSOD)	Chiang Rai
3T	483560 (GSOD)	Sakon Nakhon	483560 (GSOD)	Sakon Nakhon
5T	484160 (GSOD)	Tha Tum	484160 (GSOD)	Tha Tum
10V	489140 (GSOD)	Ca Mau	90503 (MRC)	Can Tho / Ca Mau
7V	488750 (GSOD)	Banmethuot	120801 (MRC)	Buon Me Thuot

* used for virtual station

The resulting daily timeseries contained on average 73% valid data. The remaining data gaps were filled using long-term mean daily values representative for each month in the year. Figure 19 shows the range in annual rainfall for each of the sub-areas, and Figure 20 shows the average of the daily mean, minimum and maximum temperature.

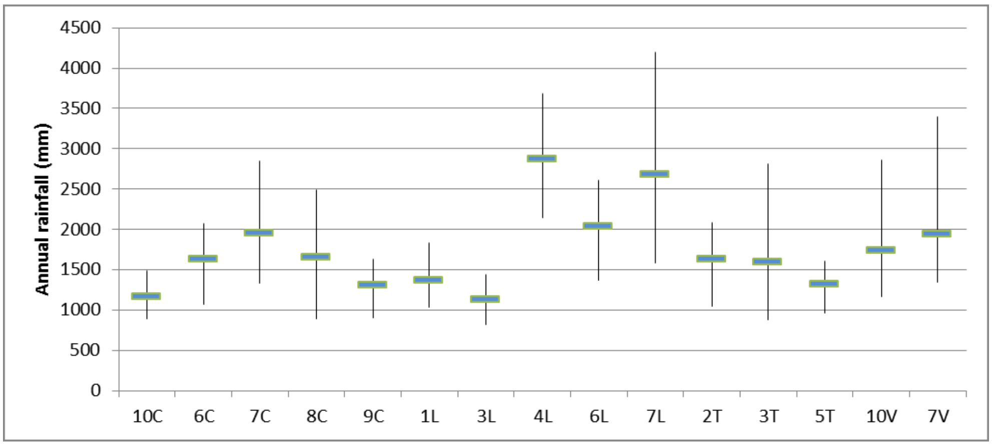


Figure 19. Annual rainfall, showing mean and the range between minimum and maximum based on data between 1981-2010 (mm)

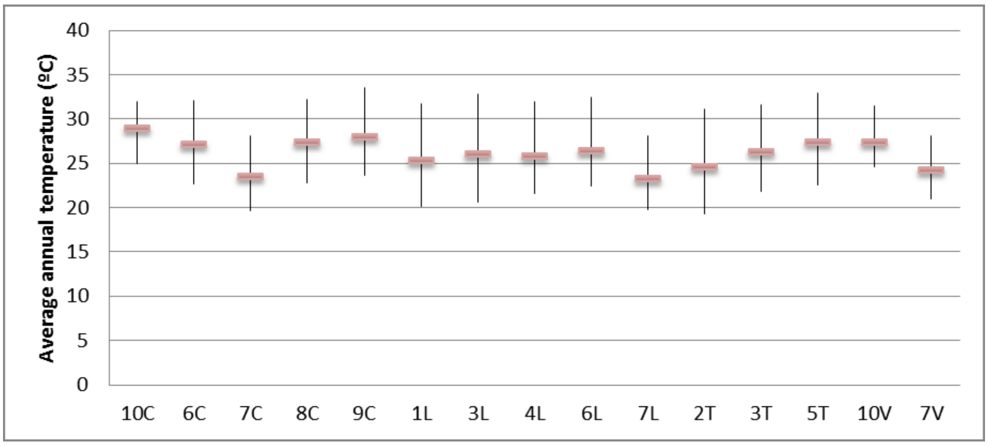


Figure 20. Average of the daily mean, minimum and maximum temperature, based on data between 1981-2010 (mm)

Based on the temperature data, and global radiation calculated for each sub-area, the reference evapotranspiration was calculated (input for AquaCrop) using the method described by Hargreaves [*Hargreaves and Samani*, 1985]. Figure 21 shows the annual reference evapotranspiration for each location, ranging over the entire LMB between approximately 1300 and 1850 mm.

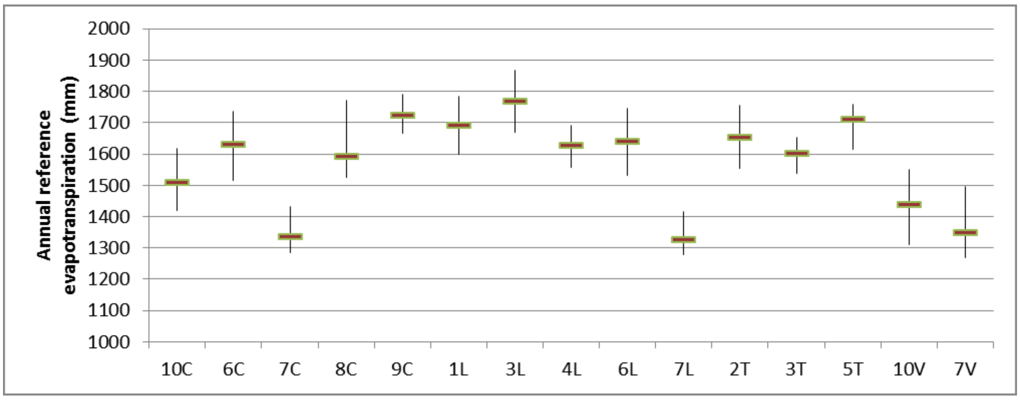


Figure 21. Annual reference evapotranspiration based on data between 1981-2010 (mm)

3.3.4 Crop characteristics

Rice

The paddy-rice production system is dominant in the LMB [*Heft-Neal et al.*, 2013]. Most of it is principally rain-fed, in which the yields are highly variable and dependent on rainfall amounts. At the same time, the area under irrigation has expanded gradually in all four LMB countries. Most of the installed irrigation infrastructure is found in northeast Thailand and the Viet Nam delta. Irrigated rice systems, benefit from higher yields in the wet season as well as a second production cycle during the dry season.

Water needs

Rain-grown rice usually requires an annual rainfall in excess of 1500 mm. If below, non-optimal yields will be achieved as water stress may occur. Rice in the LMB is cultivated both in the wet as in the dry season. During the dry season irrigation is necessary. It was assumed that during this period irrigation ranges between 300 and 400 mm.

Yields

Typical yields in the Lower Mekong Basin range between 2.5 and 5.5 ton/ha (Figure 22). Obviously some farmers my obtain lower yields while other manage to get higher yields, depending on crop variety, local conditions, fertilizer inputs and farmers' management.

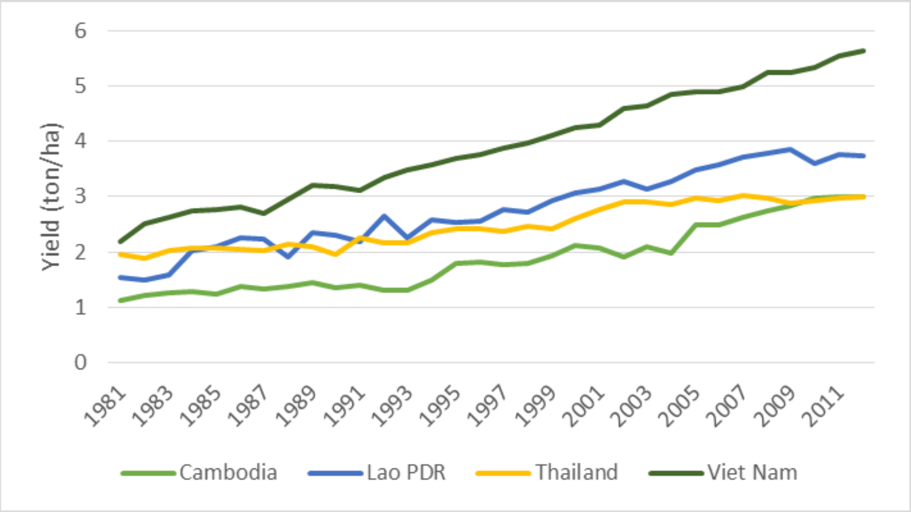


Figure 22. Trend in rice yield for the 4 countries in the LMB region over the period 1981-2010 (source: FAOSTAT)

Soil and fertility

Paddy rice production needs a heavy, relatively impervious soil. The pH is generally not important, as rice has the capacity to neutralize the soil on which it is growing. For this assessment, a heavy clay soil was assumed with two horizons (0.5 m silty clay on top, and 1.5 m heavy clay below)

In paddy rice, land preparation for planting usually involves some incorporation of organic matter, either from a previous grass/ legume pasture, green manure crop or from plants cut and transported to the field. A basic phosphorus and potash dressing may be required but nitrogen fertilization is a main determinant of yield. Half the nitrogen may be applied at transplanting with the remainder at ear initiation, and the application may be 150-250 kg/ha. In the LMB, it was assumed that fertility status of the soils was non-optimal (50%), due to the generally poor conditions.

More details crop model parameters can be found in Annex I – Crop parameters

Maize

Crop development

Maize is grown during the period of the year when mean daily temperatures are above 15°C and frost-free. The adaptability of varieties in different climates varies widely. In the LMB the maize crop can be found in all sub-areas.

Water Needs

Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate. In the LMB, maize is generally not irrigated.

Yields

Under irrigation and good fertility, a good commercial grain yield is 6 to 9 ton/ha (10 to 13 percent moisture). In this study a dry matter content of 87% was assumed. In the LMB, much lower yields are obtained, due to water and fertility stress and non-optimal practices. Typical yields in the LMB range between 1.5 and 3.5 ton/ha.

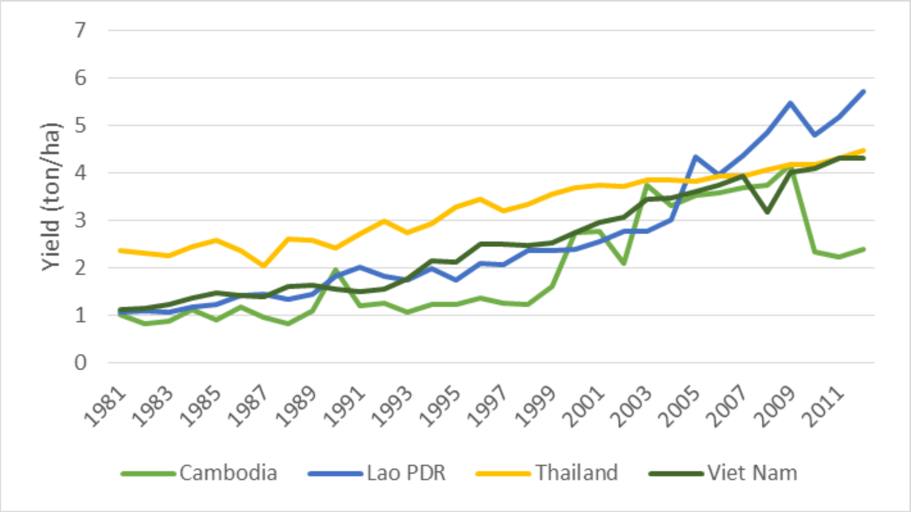


Figure 23. Trend in maize yield for the 4 countries in the LMB region over the period 1981-2010 (source: FAOSTAT)

Soil and fertility

The fertility demands for grain maize are relatively high and amount, for high-producing varieties, up to about 200 kg/ha N, 50 to 80 kg/ha P and 60 to 100 kg/ha K. In general the crop can be grown continuously as long as soil fertility is maintained. In the LMB, fertilizer use for this crop is limited. The sensitivity to stress of the crop is moderate. A deep uniform sandy loam soil was assumed to be associated with this crop, with a moderate fertility level (40%).

More details crop model parameters can be found in Annex I – Crop parameters

Sugarcane

Crop development

Sugar cane flourishes under a long, warm growing season with a high incidence of radiation and adequate moisture, followed by a dry, sunny and fairly cool but frost-free ripening and harvesting period. Optimum temperature for sprouting (germination) of stem cuttings is 32 to 38°C. Optimum growth is achieved with mean daily temperatures between 22 and 30°C. Minimum temperature for active growth is approximately 20°C.

Water Needs

Water requirements of sugarcane are 1500 to 2500 mm evenly distributed over the growing season. Irrigation is necessary during the dry season. Irrigation in the LMB was assumed to range between 300-500mm, under furrow irrigation.

Yields

A long growing season is essential for high yields. Plant (first) crop is normally followed by 2 to 4 ratoon crops, and in certain cases up to a maximum of 8 crops are taken, each taking about 1 year to mature.

Sugar yield depends on cane tonnage, sugar content of the cane and on the cane quality. It is important that the cane is harvested at the most suitable moment when the economic optimum of recoverable sugar per area is reached. Harvesting is generally done in the dry period and when the stalks contain the maximum amount of sucrose

Cane tonnage at harvest can vary between 50 and 150 ton/ha or more, which depends particularly on the length of the total growing period and whether it is a plant or a ratoon crop. Cane yields produced under rainfed conditions can vary greatly. Good yields in the humid tropics of a totally rainfed crop can be in the range of 70 to 100 ton/ha cane, and in the dry tropics and subtropics with irrigation, 110 to 150 ton/ha cane. For this study, a dry matter content of 30 percent was assumed. Sugar content at harvest is usually between 10 and 12 percent of the cane fresh weight, but under experimental conditions 18 percent or more has been observed. In the LMB region, typical yields are between 20 and 50 ton/ha.

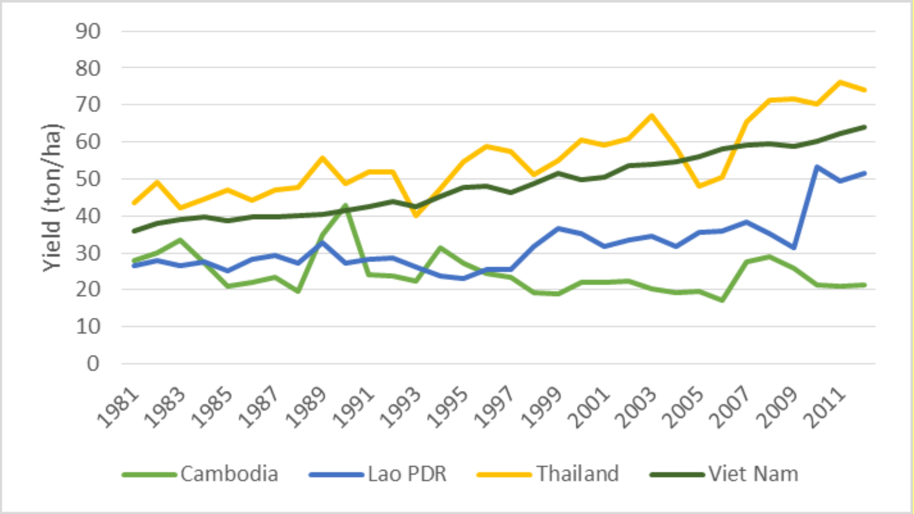


Figure 24. Trend in sugar cane yield for the 4 countries in the LMB region over the period 1981-2010 (source: FAOSTAT)

Soil and fertility

Sugarcane does not require a special type of soil. Best soils are those that are more than 1 m deep but deep rooting to a depth of up to 5 m is possible. For this analysis, a deep uniform sandy loam soil was assumed to be associated with this crop.

Sugarcane has high nitrogen and potassium needs and relatively low phosphate requirements, or 100 to 200 kg/ha N, 20 to 90 kg/ha P and 125 to 160 kg/ha K for a yield of 100 ton/ha cane, but application rates are sometimes higher. For this analysis, a moderate fertility level (40%) was assumed.

More details crop model parameters can be found in Annex I – Crop parameters

Cassava

In the LMB, cassava has traditionally been considered as a snack food or for making starch used in desserts. The crop was usually planted in small areas near the house to dig up some fresh roots for making traditional desserts. Presently, more and more cassava roots are utilized for production of starch, both for export and domestic use. In Thailand has cassava made the transition from a staple food to products and raw materials for the processing industry.

Water needs

Once established, cassava can grow in areas that receive just 400 mm of average annual rainfall. But much higher yields can be obtained with higher levels of water supply. Although cassava can withstand periods of drought, it is very sensitive to soil water deficit during the first three months after planting. Water stress at any time in that early period reduces significantly the growth of roots and shoots, and impairs subsequent development of the storage roots.

In areas with two rainy seasons per year, cassava can be planted in the early or middle part of either rainy season and harvested after 10 to 14 months, preferably during the dry season. Cassava also responds well to irrigation, but is not common.

Yield

Being a low-value crop that is also well adapted to areas of poor soils and low or unpredictable rainfall, cassava is pushed more and more into the least favorable areas**.** To convert to dry matter, a a general conversion factor, in terms of kg of dry matter per kg fresh weight, of 0.25 was used. Even with the use of improved varieties and cultural practices yields are therefore not optimal. Typical yields in the LMB range between 5 and 15 ton/ha.

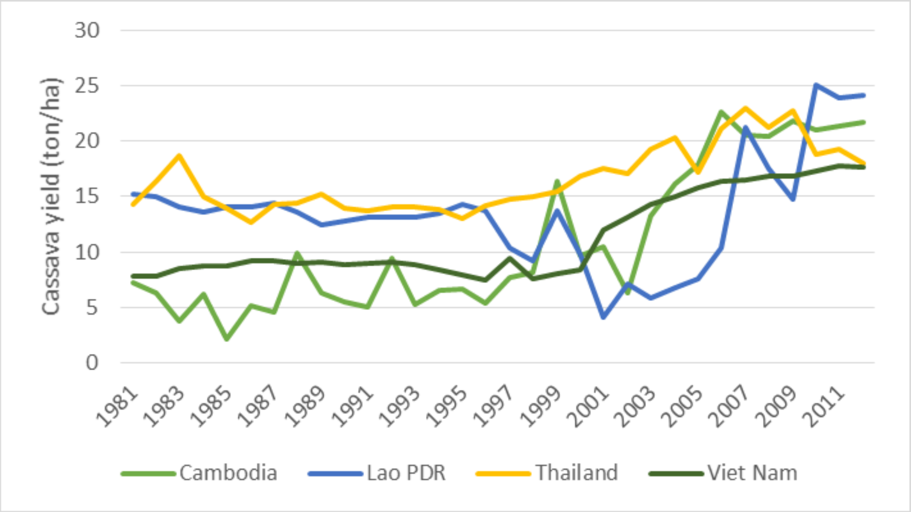


Figure 25. Trend in cassava yield for the 4 countries in the LMB region over the period 1981-2010 (source: FAOSTAT)

Soil and fertility

Cassava is grown on sandy or loamy soils and on slightly or moderately undulating land; these soils tend to be of low fertility and are very susceptible to erosion. Despite growing demand and its production potential, cassava is generally grown in areas that have little or no access to improved varieties, fertilizer and other production inputs, by small scale farmers often cut off from marketing channels and agro-processing industries. However, in some areas, especially in Thailand, inputs are more significant and yields are higher.

More details crop model parameters can be found in Annex I – Crop parameters

3.3.5 Crop yields per sub-area

Data on crop yields were obtained from the following sources:

- Sub-area reports published by MRC around 2003 and 2011.
- Data provided by MRC-CCAI on area harvested and yields of 2003.
- FAOSTAT data on country-level, for trends and variability

Not for all combinations of the four crops and the 15 sub-areas, data were available. These data gaps were filled by calculating the relative productivity of each sub-area compared to the overall productivity based on MRC data, and by multiplying this relative value with the average yield for the particular crop, based on FAO data.

The final yields that were considered representative for each sub-area are listed in Table 11. As can be seen, quite some variability exists among the sub-areas, as also shown in the maps of Figure 26.

Table 11. Yields and variability (standard deviation) for the 4 crops and for each sub-area.

	Sub-area	**10C**	**6C**	**7C**	**8C**	**9C**	**1L**	**3L**	**4L**	**6L**	**7L**	**2T**	**3T**	**5T**	**10V**	**7V**
Cassava	Average	13.6	11.5	15.2	21.4	17.7	13.1	10.3	10.3	9.0	9.8	19.6	19.6	18.7		12.9
	Stdev	4.9	4.1	5.5	7.7	6.4	6.9	5.4	5.5	4.8	5.2	2.4	2.4	2.2		2.4
Maize	Average	3.3	2.3	3.4	3.2	4.5	4.4	3.9	3.6	2.9	3.5	3.9	3.9	3.7		3.0
	Stdev	0.6	0.4	0.6	0.6	0.8	1.3	1.2	1.1	0.9	1.0	0.2	0.2	0.2		0.4
Rice	Average	2.5	2.1	2.4	2.3	2.3	4.3	3.4	3.4	2.9	3.2	2.9	3.0	2.7	5.3	4.3
	Stdev	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.4	0.3
Sugarcane	Average	21.7	17.5	22.6	24.7	25.9	44.4	30.6	34.0	31.5	31.0	61.3	61.3	58.4		49.3
	Stdev	3.7	2.9	3.8	4.2	4.4	2.9	2.0	2.2	2.1	2.0	7.9	7.9	7.6		3.2

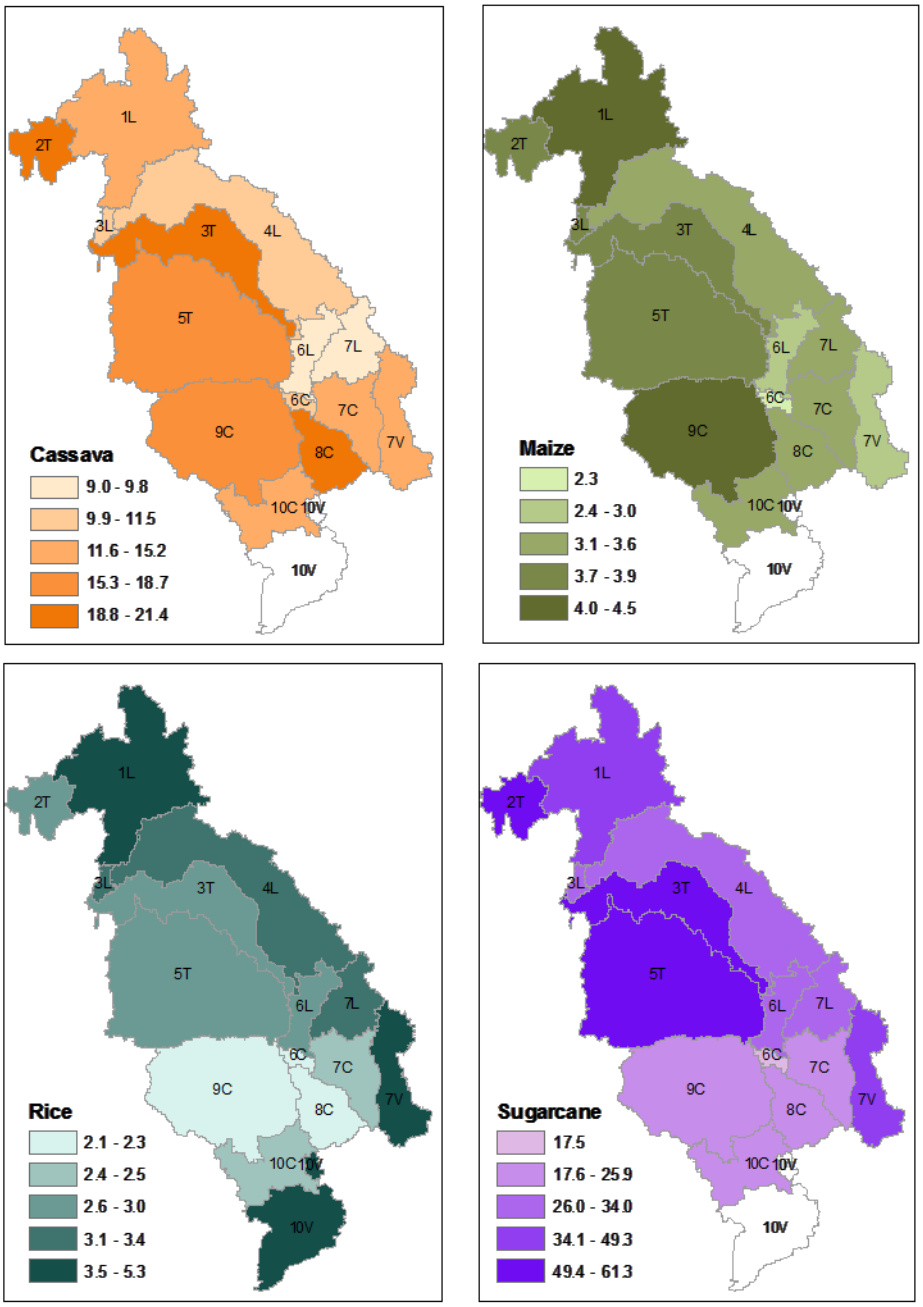


Figure 26. Average yields in ton per hectare for the 4 crops and for each sub-area. Source: MRC, 2003; MRC, 2011; FAOstat, 2013.

3.4 Food Balance Sheets

3.4.1 Introduction

The previous sections presented crop yields of the four major crops in the LMB. Focus was on yields, expressed in kilogram per hectare. However, food availability to the people in the LMB depends on many more factors such as the area of each crop, changes in population, but also on other food components such as fish, meet. Moreover, import and export are also very relevant when analysing the amount of food per capita that is available.

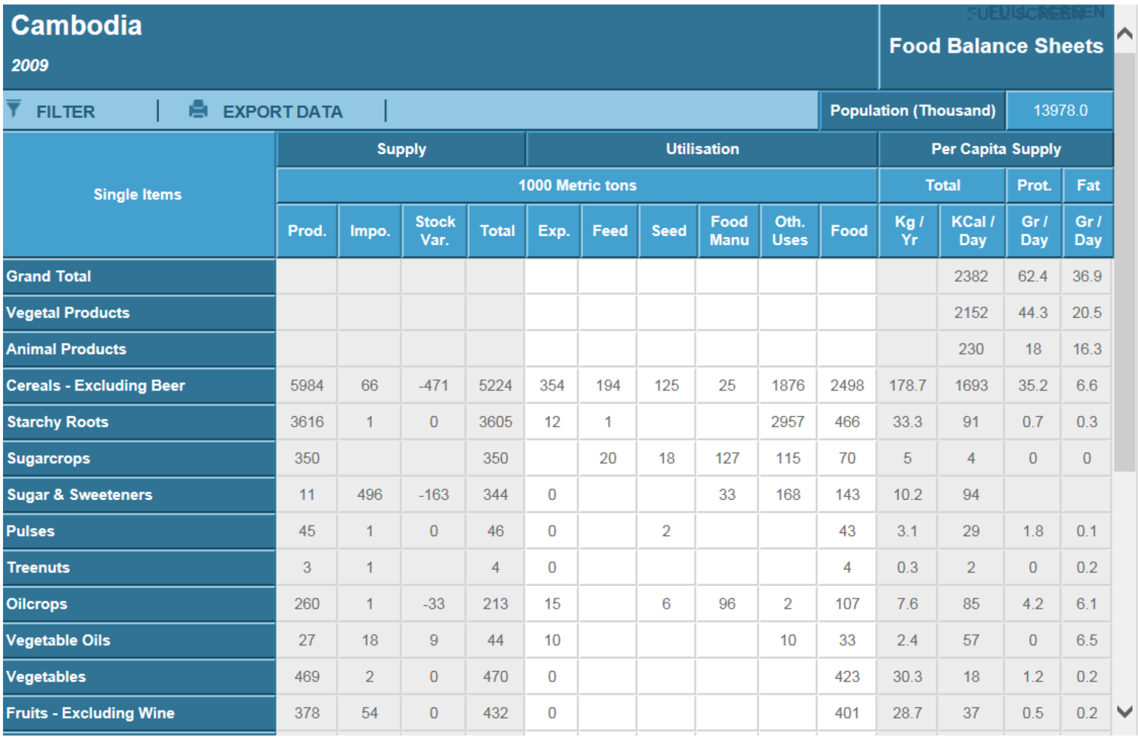
Food Balance Sheets are the appropriate tools to analyse past, current, and future food demand and supply. Various definitions of a Food Balance Sheet exist. The FAO short definition is (http://faostat.fao.org/site/354/default.aspx):
"A food balance sheet presents a comprehensive picture of the pattern of a country's food supply during a specified reference period."

In general, a Food Balance Sheet includes: (i) quantities, (ii) calories, (iii) proteins, and (iv) fats and has the following domains:

- Production
- Trade
- Feed and Seed
- Waste
- Other utilisation
- Food availability

Besides these generic descriptions no standardized FBS (Food Balance Sheet) methodology exists. Over the last decades various formats have been proposed and used. In general all these FBSs are based on three main categories: (i) domestic supply, (ii) domestic utilization, and (iii) per capita supply. Currently the FAO FBS approach can be considered as the de-factor standard and will be the starting point for the analysis here. A typical example of such an FBS is presented in Figure 27.

The overall objective of a FBS is to assess whether sufficient food is available for the population in a country and/or region often expressed as the amount of energy, proteins and fat. The amount of energy, proteins and fat required by a human being depends on many factors such as gender, age, activity level, amongst others. A typical example of a definition of recommended energy intake is "2,700 and 2,100 kcal (11,000 and 8,800 kJ) for men and women (respectively) between 31 and 50, at a physical activity level equivalent to walking about 3 to 5 kilometers per day at 4 to 5 kilometers per hour in addition to the light physical activity associated with typical day-to-day life".



Cambodia

2009

Food Balance Sheets

Population (Thousand) 13978.0

Single Items	Supply				Utilisation						Per Capita Supply			
	1000 Metric tons										Total		Prot.	Fat
	Prod.	Impo.	Stock Var.	Total	Exp.	Feed	Seed	Food Manu	Oth. Uses	Food	Kg / Yr	KCal / Day	Gr / Day	Gr / Day
Grand Total												2382	62.4	36.9
Vegetal Products												2152	44.3	20.5
Animal Products												230	18	16.3
Cereals - Excluding Beer	5984	66	-471	5224	354	194	125	25	1876	2498	178.7	1693	35.2	6.6
Starchy Roots	3616	1	0	3605	12	1			2957	466	33.3	91	0.7	0.3
Sugarcrops	350			350		20	18	127	115	70	5	4	0	0
Sugar & Sweeteners	11	496	-163	344	0			33	168	143	10.2	94		
Pulses	45	1	0	46	0		2			43	3.1	29	1.8	0.1
Treenuts	3	1		4	0					4	0.3	2	0	0.2
Oilcrops	260	1	-33	213	15		6	96	2	107	7.6	85	4.2	6.1
Vegetable Oils	27	18	9	44	10				10	33	2.4	57	0	6.5
Vegetables	469	2	0	470	0					423	30.3	18	1.2	0.2
Fruits - Excluding Wine	378	54	0	432	0					401	28.7	37	0.5	0.2

Figure 27. Example of a Food Balance Sheet based on FAO-stat.

The current analysis takes the so-called Recommended Daily Intake (RDI) as base. The RDI is defined as the daily intake level of food that is considered to be sufficient to meet the requirements of 97–98% of healthy individuals[1]. The USDA uses the following numbers, which is followed by most other organizations:

- Energy
    - 2400 kCal/capitay/day
- Total protein
    - 50 g/capita/day
- Total fat
    - 65 g/capita/day

3.4.2 Building MRC specific food balance sheets

As introduced in the previous sections FBS (Food Balance Sheets) present *"a comprehensive picture of the pattern of a country's food supply during a specified reference period."* For this study FBS will be refined and tailored towards the need of the MRC-CCAI in three ways. First of all, the FBS will be set up to reflect sub-area analysis using the 15 BDP sub-areas (Figure 13). Second, the FBS setup will be extended by coupling this to the AquaCrop output. Finally, the FBS have been extended so they can be used for future

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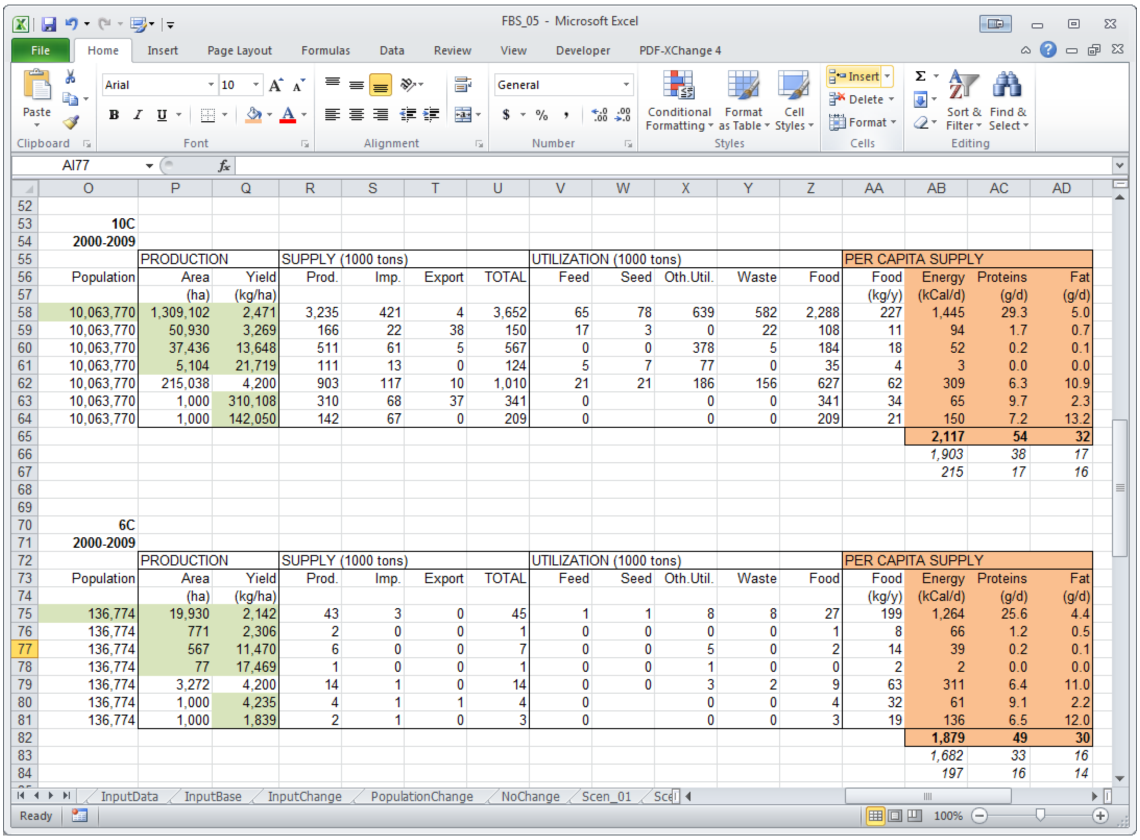
[1] (http://en.wikipedia.org/wiki/Reference_Daily_Intake; http://en.wikipedia.org/wiki/Food_energy#Recommended_daily_intake

projections and to evaluate scenarios. The latter will include more or less autonomous (unavoidable) projected changes such as climate and population growth as well as policy and management influenced changes (agricultural area, agricultural production, import, export).

The most important steps to create FBS for the 15 BDP areas can be summarized as:

- (i) Obtain base data for each sub-area
- (ii) Calibrate, validate, control the FBS
- (iii) Use the FBS for the future without interventions
- (iv) Evaluate the impact of interventions



10C
2000-2009

	PRODUCTION		SUPPLY (1000 tons)				UTILIZATION (1000 tons)					PER CAPITA SUPPLY			
Population	Area (ha)	Yield (kg/ha)	Prod.	Imp.	Export	TOTAL	Feed	Seed	Oth.Util.	Waste	Food	Food (kg/y)	Energy (kCal/d)	Proteins (g/d)	Fat (g/d)
10,063,770	1,309,102	2,471	3,235	421	4	3,652	65	78	639	582	2,288	227	1,445	29.3	5.0
10,063,770	50,930	3,269	166	22	38	150	17	3	0	22	108	11	94	1.7	0.7
10,063,770	37,436	13,648	511	61	5	567	0	0	378	5	184	18	52	0.2	0.1
10,063,770	5,104	21,719	111	13	0	124	5	7	77	0	35	4	3	0.0	0.0
10,063,770	215,038	4,200	903	117	10	1,010	21	21	186	156	627	62	309	6.3	10.9
10,063,770	1,000	310,108	310	68	37	341	0		0	0	341	34	65	9.7	2.3
10,063,770	1,000	142,050	142	67	0	209	0		0	0	209	21	150	7.2	13.2
													2,117	**54**	**32**
													1,903	*38*	*17*
													215	*17*	*16*

6C
2000-2009

	PRODUCTION		SUPPLY (1000 tons)				UTILIZATION (1000 tons)					PER CAPITA SUPPLY			
Population	Area (ha)	Yield (kg/ha)	Prod.	Imp.	Export	TOTAL	Feed	Seed	Oth.Util.	Waste	Food	Food (kg/y)	Energy (kCal/d)	Proteins (g/d)	Fat (g/d)
136,774	19,930	2,142	43	3	0	45	1	1	8	8	27	199	1,264	25.6	4.4
136,774	771	2,306	2	0	0	1	0	0	0	0	1	8	66	1.2	0.5
136,774	567	11,470	6	0	0	7	0	0	5	0	2	14	39	0.2	0.1
136,774	77	17,469	1	0	0	1	0	0	1	0	0	2	2	0.0	0.0
136,774	3,272	4,200	14	1	0	14	0	0	3	2	9	63	311	6.4	11.0
136,774	1,000	4,235	4	1	1	4	0		0	0	4	32	61	9.1	2.2
136,774	1,000	1,839	2	1	0	3	0		0	0	3	19	136	6.5	12.0
													1,879	**49**	**30**
													1,682	*33*	*16*
													197	*16*	*14*

Figure 28. Example of the developed Food Balance Sheets

Obtain base data for the each sub-area

Based on various data sources and information sub-areas specific FBS has been constructed. The most relevant data used are:

- Basin Development Plan Programme, Sub-Area Analysis and Development (2003)
- Basin Development Plan Programme, Phase 2, Sub-Area Analysis and Development (2011)
- BDP Socio-Economic data base 2010
- BDP Atlas
- Country statistics as compiled by FAOstat

For the current situation (base line) average data over the period 2000-2009 were used. Details about the construction of the FBS can be found in Appendix II

Calibrate, validate, control the FBS

Food Balance Sheets require a substantial amount of data which is not always readily availbale. Especially on smaller scales than countries, like here where sub-basins were used, some data can only be obtained by integrating data with expert knowledge. For the 15 FBS developed here, a comparison has been made with the country statistics as collected by the four member countries and compiled by FAOstat. Figure 29 shows the comparison between the energy supply as derived by country statistics and the numbers as derived based on the developed FBS. Note that for the countries Cambodia and Lao PDR five FBS were constructed and the sum of those five are shown. Since almost the entire countries are located within the LMB the comparison between country statistics and the FBS can be made. For Thailand and Vietnam only a part of these countries fall within the LMB and the sume of the FBS and the country statstics can differ.

The Figure clearly shows that for Cambodia and Lao PDR the numbers are almost the same, so the FBS can be trusted. For Thailand and Vietnam differences can be caused by the fact that big cities (with higher energy supplies) are included in the country statistics but are not located in sub-areas.

Overall, it can be concluded that the FBS can be trusted, although care should be taken as validation at the sub-area scale is very difficult because of lack of data. However, it has been proven that relative accuracy (= comparing different scenarios) is always much higher than absolute accuracy (=comparing models with reality).

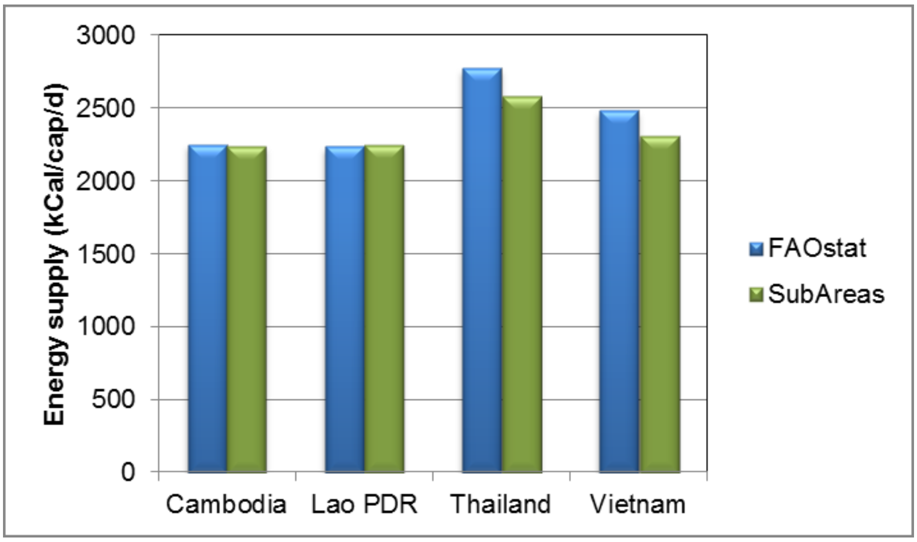


Figure 29. Comparison between country statistics (FAOstat) and sub-areas food balance sheets.

Use the FBS for the future without interventions

The third step to be taken is to use the developed FBS to assess the impact of climate change if not adaptation strategies will be taken. Changes in climate have been discussed in a previous section and are used to derive changes in projected yields as calculated by AquaCrop.

Changes in population are based on country projections and compiled by FAOstat. For Cambodia and Lao PDR population growth will continue, while for Thailand and Vietnam the peak in population is expected to be around 2030 (Thailand) and 2050 (Vietnam). Average population for the four selected time frames is shown in Table 12. Values for 2090-2099 are not provided by FAOstat and are therefore obtained by extrapolation based on the linear trend in the period 2041-2050. In order to asses population growth for each of the sub-areas the percentage changes in population compared to 2000-2009 has been derived.

Evaluate the impact of interventions

Since autonomous changes (climate change, population) might lead to undesirable impact on food supply, interventions can be considered. In order to evaluate the most effective intervention types the FBS can be used to analyze the impact of various interventions. The following interventions have been analyzed:

- Changes in agricultural area
- Changes in crop yields by enhanced farming techniques (knowledge, seeds, fertilizer)
- Changes in animal production
- Mix of above.

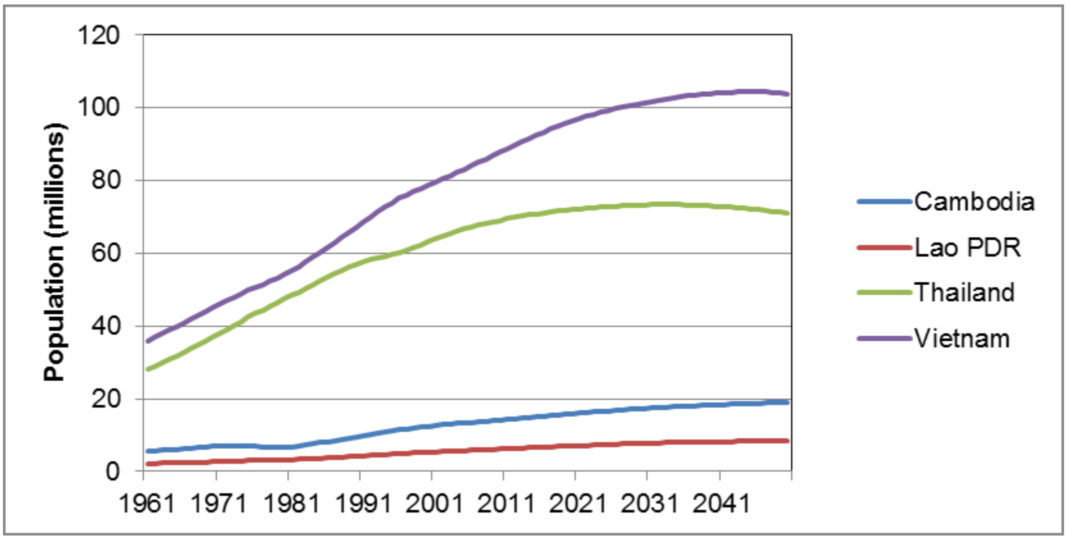


Figure 30. Population and projected changes for the four countries. Source: FAOstat.

Table 12. Projected population for the four time frames (in millions), in brackets changes compared to 2000-2009. Source: FAOstat

	Cambodia	Lao PDR	Thailand	Vietnam
2000-2009	13.3	5.7	66.2	82.8
2026-2035	17.4 (+31%)	7.8 (+36%)	73.3 (+11%)	101.6 (+23%)
2046-2050	18.9 (+42%)	8.4 (+46%)	71.5 (+8%)	104.2 (+26%)
2090-2099	21.5 (+62%)	9.2 (+61%)	62.3 (-6%)	103.1 (+25%)

4 Results

4.1 Current situation

4.1.1 Crop yields

This section summarizes the baseline situation as was simulated using the methodology previously described. The outcomes are compared with the yields reported and listed in Table 13. The coefficient of determination is indicated as well, comparing how well the simulated values fit the reported values. All values are close to one, suggesting the model is able to represent well the conditions in each sub-area.

Table 13. Reported versus simulated (AquaCrop) yields for each sub-area and crop. Averages for the period 1981-2010.

	Cassava		**Maize**		**Rice**		**Sugarcane**	
Sub-area	**Reported**	**Simulated**	**Reported**	**Simulated**	**Reported**	**Simulated**	**Reported**	**Simulated**
10C	13.6	13.6	3.3	3.4	2.5	2.6	21.7	24.0
6C	11.5	11.3	2.3	2.4	2.1	2.3	17.5	20.8
7C	15.2	15.3	3.4	3.5	2.4	2.5	22.6	24.7
8C	21.4	21.5	3.2	3.3	2.3	2.4	24.7	27.9
9C	17.7	17.6	4.5	4.5	2.3	2.5	25.9	27.7
1L	13.1	13.1	4.4	4.2	4.3	3.9	44.4	42.9
3L	10.3	10.3	3.9	3.9	3.4	3.2	30.6	32.2
4L	10.3	10.0	3.6	3.7	3.4	3.5	34.0	35.4
6L	9.0	8.7	2.9	3.1	2.9	3.1	31.5	32.1
7L	9.8	9.4	3.5	3.6	3.2	3.1	31.0	32.8
2T	19.6	19.6	3.9	4.0	2.9	3.0	61.3	55.4
3T	19.6	19.8	3.9	4.0	3.0	3.1	61.3	52.3
5T	18.7	18.5	3.7	3.8	2.7	2.9	58.4	50.1
10V					5.3	4.1		
7V	12.9	12.9	3.0	3.2	4.3	3.8	49.3	48.4
R^2	**0.99**		**0.99**		**0.93**		**0.98**	

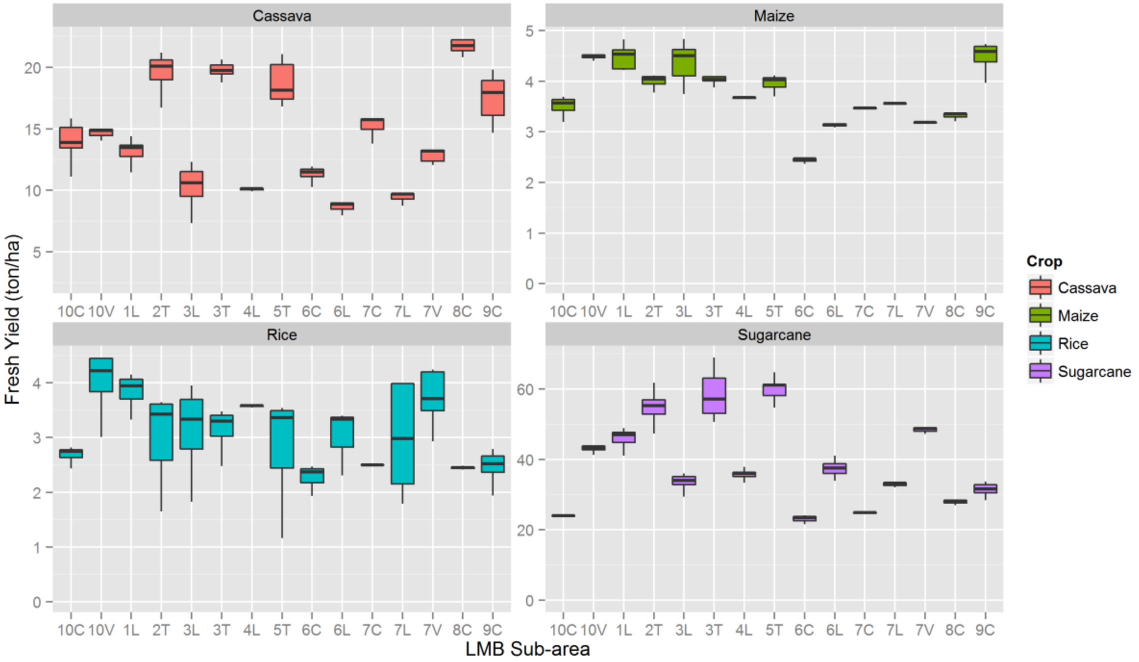


Figure 31. Boxplots[2] of variability of crop yields (ton/ha) in each sub-area based on simulations using AquaCrop of baseline period (1981-2010).

Figure 31 shows the variability of the simulated crop yields over the baseline period. As can be seen the variability is highly different for each sub-area, principally related with the climatic conditions. In several sub-areas the variability simulated is minimal as generally no water-limiting conditions occur due to the high rainfall amounts. Temperature stress during the baseline period is limited for all sub-areas. In summary, variability as displayed in the Figure reflects that for each of the 30 years yields are not exactly the same and varies because of weather conditions.

4.1.2 Food balances

Using the Food Balance Sheets (FBS) for the 15 sub-areas as described in the previous sections, the amount of energy supply, protein supply, and fat supply per capita can be calculated. Figure 32 presents those results in a comprehensive way. Considering the Recommended Daily Intake (RDI) for energy (2400 kCal/cap/d) as defined by the USDA it is clear that this number is not met for all sub-areas. The RDI for protein (50 g/cap/d) is met for most sub-areas. The RDI for fat (65 g/cap/d) is only met for the three sub-areas in Thailand.

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[2] A boxplots displays variation within data. The bottom and top of the box indicate the first and third quartiles, and the band inside the box is the second quartile (the median). The lines indicate the minimum and maximum. Outliers are presented as a small +.

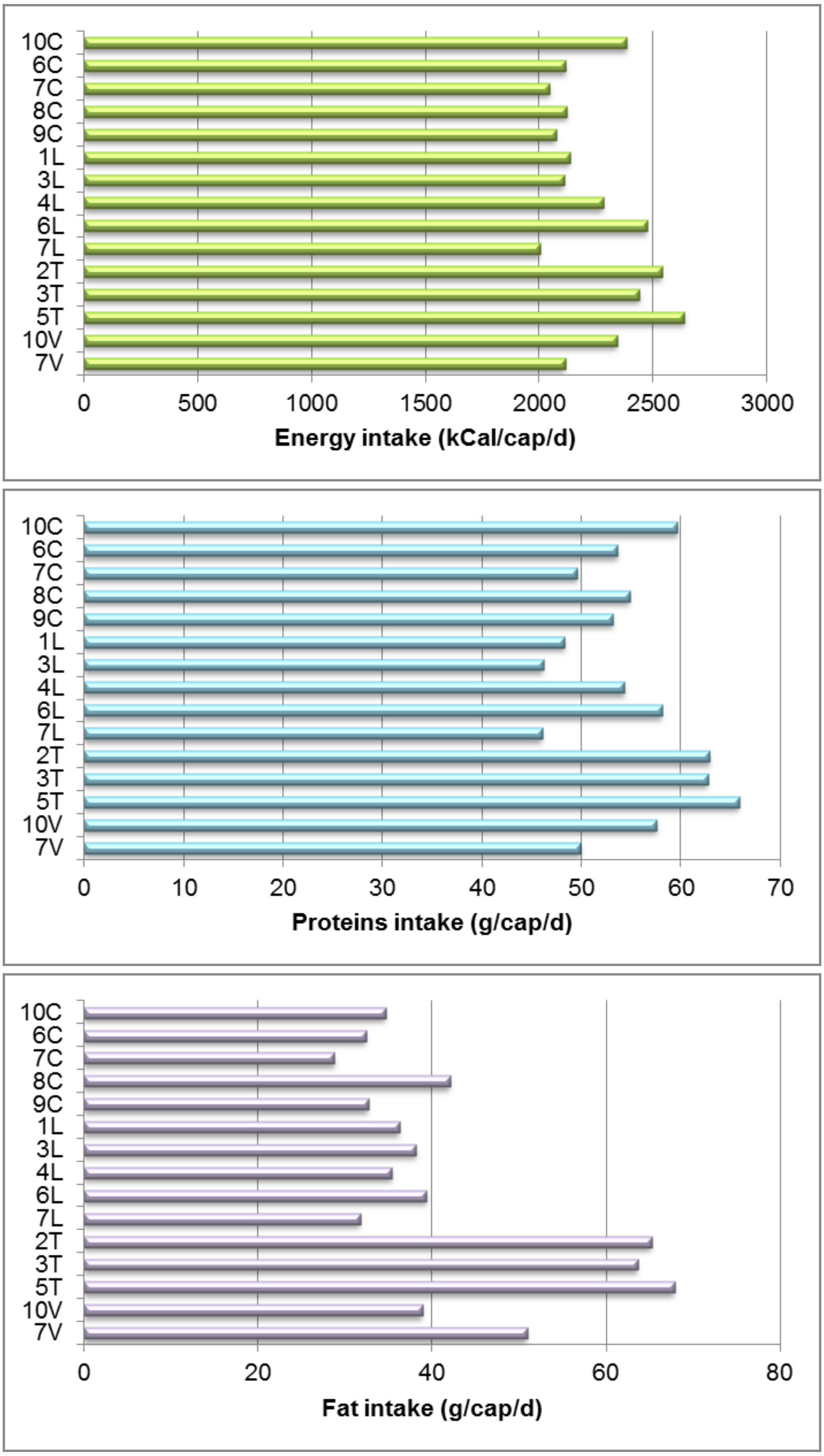

Figure 32. Daily energy, proteins and fat intake for the 15 sub-areas (2000-2009).

4.2 Climate change impacts on crop yields

For the 3 future horizons and the 4 RCPs (total 12 combinations) simulations have been carried out using AquaCrop for each of the 4 crops and sub-areas. Table 14 and Table 15 show the changes to temperature and rainfall that have been applied to the 30 year baseline period, for each scenario and sub-area. As can be seen, generally rainfall increases in the LMB. Only for a few scenarios precipitation decreases, especially in the southern part of the LMB. Temperature increases in all scenarios and for each sub-area.

Table 14. Relative changes in temperature for each climate change scenario (°C). Source: CMIP5.

Scenario / Sub-area	10C	6C	7C	8C	9C	1L	3L	4L	6L	7L	2T	3T	5T	10V	7V
H2026-2035_RCP2.6	0.3	0.3	0.3	0.3	0.3	0.8	0.8	0.6	0.3	0.3	0.8	0.6	0.6	0.3	0.3
H2046-2055_RCP2.6	0.5	0.5	0.5	0.5	0.5	1.0	1.0	0.8	0.5	0.5	1.0	0.8	0.8	0.5	0.5
H2090-2099_RCP2.6	0.9	0.9	0.9	0.9	0.9	1.4	1.4	1.2	0.9	0.9	1.4	1.2	1.2	0.9	0.9
H2026-2035_RCP4.5	0.6	0.6	0.6	0.6	0.6	1.1	1.1	0.9	0.6	0.6	1.1	0.9	0.9	0.6	0.6
H2046-2055_RCP4.5	1.0	1.0	1.0	1.0	1.0	1.5	1.5	1.3	1.0	1.0	1.5	1.3	1.3	1.0	1.0
H2090-2099_RCP4.5	1.8	1.8	1.8	1.8	1.8	2.3	2.3	2.1	1.8	1.8	2.3	2.1	2.1	1.8	1.8
H2026-2035_RCP6.0	0.8	0.8	0.8	0.8	0.8	1.3	1.3	1.1	0.8	0.8	1.3	1.1	1.1	0.8	0.8
H2046-2055_RCP6.0	1.3	1.3	1.3	1.3	1.3	1.8	1.8	1.6	1.3	1.3	1.8	1.6	1.6	1.3	1.3
H2090-2099_RCP6.0	2.3	2.3	2.3	2.3	2.3	2.8	2.8	2.6	2.3	2.3	2.8	2.6	2.6	2.3	2.3
H2026-2035_RCP8.8	1.4	1.4	1.4	1.4	1.4	1.9	1.9	1.7	1.4	1.4	1.9	1.7	1.7	1.4	1.4
H2046-2055_RCP8.8	2.3	2.3	2.3	2.3	2.3	2.8	2.8	2.6	2.3	2.3	2.8	2.6	2.6	2.3	2.3
H2090-2099_RCP8.8	4.1	4.1	4.1	4.1	4.1	4.6	4.6	4.4	4.1	4.1	4.6	4.4	4.4	4.1	4.1

Table 15. Relative changes in precipitation for each climate change scenario (%). Source CMIP5.

Scenario / Sub-area	10C	6C	7C	8C	9C	1L	3L	4L	6L	7L	2T	3T	5T	10V	7V
H2026-2035_RCP2.6	-2.2	-2.2	-2.2	-2.2	-2.2	2.8	2.8	0.3	-2.2	-2.2	2.8	0.3	0.3	-2.2	-2.2
H2046-2055_RCP2.6	-1.9	-1.9	-1.9	-1.9	-1.9	3.1	3.1	0.6	-1.9	-1.9	3.1	0.6	0.6	-1.9	-1.9
H2090-2099_RCP2.6	-1.5	-1.5	-1.5	-1.5	-1.5	3.5	3.5	1	-1.5	-1.5	3.5	1	1	-1.5	-1.5
H2026-2035_RCP4.5	-1.2	-1.2	-1.2	-1.2	-1.2	3.8	3.8	1.3	-1.2	-1.2	3.8	1.3	1.3	-1.2	-1.2
H2046-2055_RCP4.5	-0.3	-0.3	-0.3	-0.3	-0.3	4.7	4.7	2.2	-0.3	-0.3	4.7	2.2	2.2	-0.3	-0.3
H2090-2099_RCP4.5	1.5	1.5	1.5	1.5	1.5	6.5	6.5	4	1.5	1.5	6.5	4	4	1.5	1.5
H2026-2035_RCP6.0	-1.5	-1.5	-1.5	-1.5	-1.5	3.5	3.5	1	-1.5	-1.5	3.5	1	1	-1.5	-1.5
H2046-2055_RCP6.0	-0.8	-0.8	-0.8	-0.8	-0.8	4.2	4.2	1.7	-0.8	-0.8	4.2	1.7	1.7	-0.8	-0.8
H2090-2099_RCP6.0	0.5	0.5	0.5	0.5	0.5	5.5	5.5	3	0.5	0.5	5.5	3	3	0.5	0.5
H2026-2035_RCP8.8	0.8	0.8	0.8	0.8	0.8	5.8	5.8	3.3	0.8	0.8	5.8	3.3	3.3	0.8	0.8
H2046-2055_RCP8.8	3.1	3.1	3.1	3.1	3.1	8.1	8.1	5.6	3.1	3.1	8.1	5.6	5.6	3.1	3.1
H2090-2099_RCP8.8	7.5	7.5	7.5	7.5	7.5	12.5	12.5	10	7.5	7.5	12.5	10	10	7.5	7.5

4.2.1 Rice

Rice was simulated using Aquacrop for dry and wet season separately. For further analysis these two were combined into one average yield. Since weather and irrigation practices are different for the dry and wet season, also the impact of climate change is different.

For rice, simulations showed a decrease in yield for all of the scenarios and sub-areas, mainly due to the increase in temperature and crop water requirements (see Table 17). In some areas, this effect is counteracted by the increase in rainfall or the overall abundant rainfall amounts. Also Figure 33 shows a slight decreasing trend in crop yield depending on the RCP. Variability in yields increases as shown by the boxplots.

Overall, one can conclude that rice yields will reduce by a few percentages for the near future (2026-2035) for most sub-areas. For some sub-areas yields will reduce more, especially under the RCP8.8

Table 16. Average changes in projected rice yield over the entire LMB area for the wet and dry season combined for each climate change scenario.

	H2026-2035				**H2046-2055**				**H2090-2099**			
	RCP2.6	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**
Rice wet season	0%	0%	-1%	-1%	0%	-1%	-1%	-1%	-1%	-1%	-1%	-5%
Rice dry season	-2%	-4%	-5%	-9%	-4%	-7%	-8%	-18%	-6%	-12%	-17%	-34%

Table 17. Average changes in projected rice yield (wet and dry season combined) for each climate change scenario and sub-area.

	H2026-2035				**H2046-2055**				**H2090-2099**			
Sub-area	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**
10C	-1%	-1%	-2%	-3%	-1%	-2%	-2%	-4%	-2%	-3%	-4%	-10%
6C	0%	-1%	-1%	-2%	-1%	-2%	-2%	-5%	-2%	-3%	-4%	-13%
7C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
8C	0%	0%	-1%	-1%	0%	-1%	-1%	-1%	0%	-1%	-1%	-8%
9C	-1%	-1%	-2%	-5%	-1%	-3%	-4%	-12%	-3%	-9%	-12%	-34%
1L	-1%	-1%	-2%	-3%	-1%	-2%	-3%	-7%	-2%	-4%	-6%	-28%
3L	-4%	-7%	-9%	-12%	-6%	-11%	-11%	-20%	-9%	-14%	-19%	-32%
4L	-1%	-2%	-2%	-4%	-2%	-3%	-4%	-9%	-2%	-5%	-7%	-17%
6L	-1%	-2%	-3%	-5%	-2%	-3%	-5%	-13%	-3%	-7%	-12%	-26%
7L	0%	0%	0%	0%	0%	0%	0%	-1%	0%	-1%	-1%	-2%
2T	-3%	-5%	-6%	-7%	-4%	-6%	-6%	-13%	-4%	-9%	-12%	-25%
3T	-2%	-3%	-4%	-6%	-3%	-5%	-6%	-15%	-5%	-10%	-14%	-23%
5T	-3%	-7%	-9%	-19%	-6%	-13%	-15%	-27%	-11%	-21%	-27%	-36%
10V	0%	-1%	-1%	-2%	-1%	-1%	-2%	-4%	-1%	-3%	-4%	-14%
7V	0%	-1%	-1%	-2%	-1%	-1%	-1%	-3%	-1%	-2%	-3%	-5%

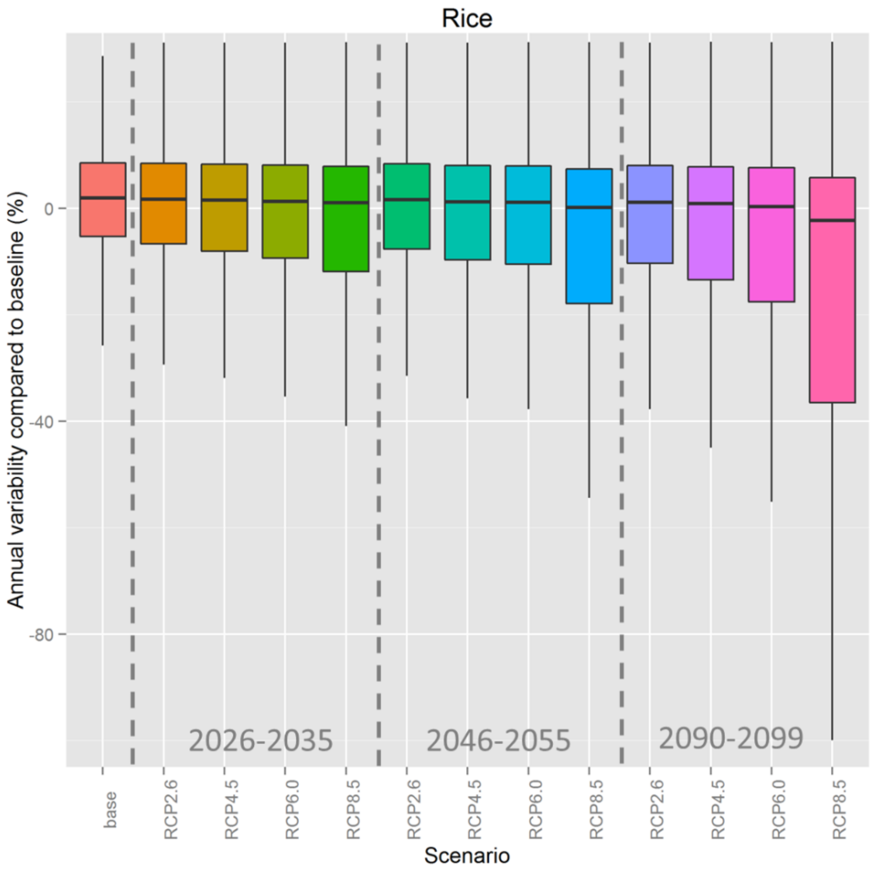

Figure 33. Boxplots of changes in rice yields over the entire LMB, for each climate scenario.

4.2.2 Maize

For maize, simulations showed a slight decrease in yield for some of the scenarios and sub-areas, mainly due to the increase in temperature and crop water requirements (see Table 17). For some areas and scenarios even an increase in yields is predicted due to the increase in rainfall. Variability in yields increases as shown by the boxplots in Figure 34.

Table 18. Maize yield changes for each climate change scenario and sub-area.

Sub-area	H2026-2035				H2046-2055				H2090-2099			
	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
10C	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	2%	-1%	-3%	-12%
6C	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	-4%
7C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
8C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-9%
9C	-1%	-1%	-3%	-1%	-1%	-1%	-2%	-5%	-1%	-2%	-2%	-23%
1L	1%	-1%	-8%	-13%	-3%	-3%	-8%	-12%	1%	-7%	-21%	-83%
3L	1%	1%	1%	-4%	-2%	4%	3%	-9%	3%	2%	-7%	-27%
4L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-13%
6L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-5%
7L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2T	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-7%
3T	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	-1%	-10%
5T	-2%	-2%	-2%	-2%	-3%	-3%	-3%	-5%	-3%	0%	-3%	-25%
10V	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-6%
7V	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

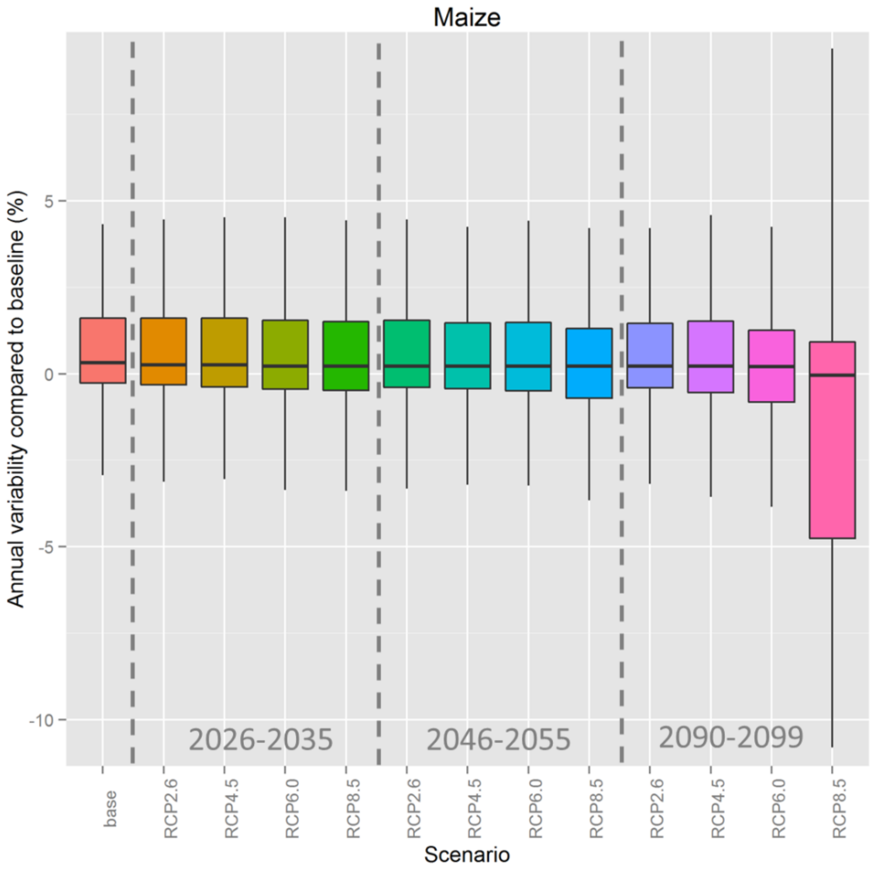

Figure 34. Boxplots of changes in maize yields over the entire LMB, for each climate scenario.

4.2.3 Sugarcane

For sugarcane, simulations showed no general trend yield: for some of the scenarios and sub-areas yield increases due to the increase in rainfall, in others yield decrease due to the additional crop water requirements (see Table 17). Variability in yields increases as shown by the boxplots.

Table 19. Sugarcane yield changes for each climate change scenario and sub-area

	H2026-2035				H2046-2055				H2090-2099			
Sub-area	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**
10C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-3%
6C	-8%	-8%	-11%	-9%	-11%	-5%	-12%	-6%	-12%	-6%	-10%	1%
7C	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
8C	0%	0%	0%	-1%	0%	0%	-1%	-1%	0%	-1%	-4%	-2%
9C	-5%	-1%	-1%	3%	-1%	3%	3%	-3%	4%	3%	-3%	11%
1L	-4%	-5%	-6%	6%	-2%	2%	6%	5%	-2%	6%	1%	0%
3L	0%	-4%	-1%	-1%	-1%	-5%	-5%	-2%	-1%	-5%	-2%	-11%
4L	0%	-1%	-1%	-2%	-1%	-1%	-2%	-10%	-1%	-1%	-6%	-11%
6L	3%	3%	3%	2%	-1%	-2%	2%	5%	-5%	2%	1%	14%
7L	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	-1%	-5%
2T	0%	0%	0%	-1%	0%	0%	0%	-1%	-1%	0%	-10%	-6%
3T	3%	3%	6%	5%	3%	11%	5%	9%	11%	9%	-1%	3%
5T	4%	3%	-3%	-4%	3%	-3%	-4%	-5%	-2%	2%	-1%	-2%
10V	0%	0%	0%	-1%	0%	-1%	-1%	-1%	0%	-1%	-4%	-8%
7V	0%	0%	0%	0%	0%	0%	0%	-4%	0%	-1%	-4%	-8%

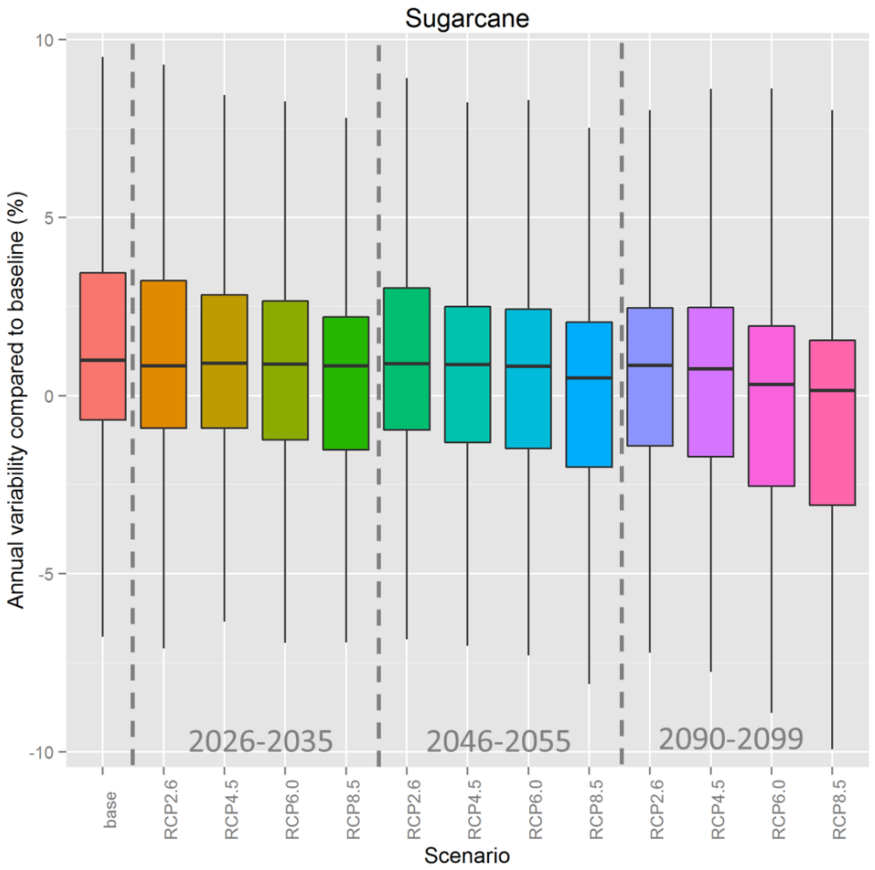

Figure 35. Boxplots of changes in sugarcane yields over the entire LMB, for each climate scenario.

4.2.4 Cassava

For cassava, simulations showed only very minor impacts, rainfall and temperature do hardly impact the yield predictions (see Table 17). Variability in yields increases as shown by the boxplots.

Table 20. Cassava yield changes for each climate change scenario and sub-area

Sub-area	H2026-2035				H2046-2055				H2090-2099			
	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
10C	-2%	-3%	-2%	-2%	-2%	-3%	-2%	-1%	-2%	-1%	-3%	-3%
6C	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	0%	-1%	-1%	-1%
7C	0%	0%	0%	0%	-1%	0%	0%	1%	0%	1%	0%	-1%
8C	-1%	-1%	-1%	-1%	-1%	0%	-1%	-2%	-2%	0%	-3%	-1%
9C	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-2%	-3%
1L	0%	0%	-1%	0%	-1%	0%	-1%	-1%	-1%	1%	-2%	-3%
3L	1%	1%	0%	0%	-1%	0%	1%	-2%	-3%	2%	-3%	2%
4L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6L	-1%	-1%	-1%	0%	0%	0%	0%	-1%	-1%	0%	-2%	-1%
7L	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%
2T	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-2%	-2%
3T	0%	0%	-1%	0%	0%	-1%	-1%	-1%	0%	0%	-1%	-1%
5T	-1%	-1%	-1%	-1%	-1%	-1%	-1%	0%	-2%	0%	-3%	0%
10V	-1%	0%	-1%	0%	-1%	0%	0%	-1%	0%	1%	-1%	0%
7V	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%

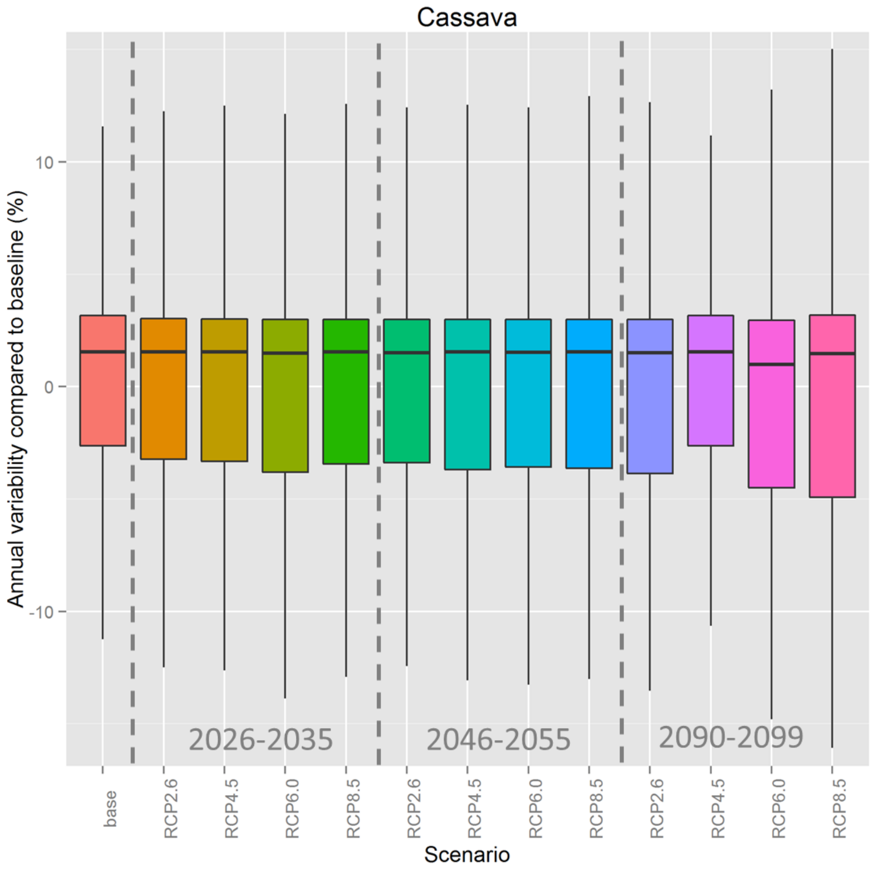

Figure 36. Boxplots of changes in cassava yields over the entire LMB, for each climate scenario.

4.3 Future Food Demand and Supply

Projected changes in crop yields as a result of climate change as explored in the previous section, is just one component of the entire food supply and demand challenge. The Food Balance Sheets (FBS) as explained in the previous chapter have been used to extent the changes in projected yield in the full food demand and supply projections.

Two different analyses using FBS have been undertaken: business as usual and intervention options. The business as usual considers that only changes in climate and population will occur and that no other intervention actions will be taken to overcome potential negative trends. The intervention options assume that decision makers, managers and farmers take actions as a response to projected changes.

4.3.1 Business as usual

First the FBS will be used to analyze the business as usual case. This case represents the situation in the future, if no changes in policies and interventions are taken. The following scenarios have been analyzed for the three time periods: (i) Foreseeable Future (2026-2035), Long-term Future (2046-2055), and Horizon (2090-2099):

- Scen_01: only population growth
- Scen_02: population growth and climate change

The first results presented here is to assess what will happen if nothing changes with the only exception of population growth (Scen_01). This is a very unlikely scenario since climate change is most likely going to have an impact on agricultural production. However, it is interesting to explore this option since changes in population is one of the least uncertain projections. Figure 37 shows for the period around 2050 changes in energy, protein and fat intake. It is very clear that for all sub-areas the food intake will decrease and for most sub-areas below critical threshold levels (energy: 2400 kCal/cap/d, protein: 50 g/cap/d, fat: 65 g/cap/d). Interesting is that the food situation for 2T, 3T and 5T hardly changes, since population growth is expected to be low for these sub-areas.

Considering projections for other future time periods interesting trends can be observed (Table 21). In general food supply will decrease below recommended levels. Especially protein intake, which used to be on average around recommended levels currently, will decline substantially with again the exception for 2T, 3T and 5T.

In reality, climate change will affect crop yields as explained in the previous Chapters. Especially, higher temperatures and changes in precipitation will have a negative impact on crop production. Since the projected climate is uncertain, the whole range of Representative Concentration Pathways (RCPs) has been considered in the analysis. The expected changes in crop yield were assessed using the AquaCrop model as discussed in the previous section. For the two extreme RCPs (2.6 = least impact and 8.8 = most impact) the impact of combined population growth and climate change is shown in Table 22 and Table 23. It is clear that the combined effect of climate change as well as population growth has a major impact on food security in the LMB.

The overall conclusion is that food supply is clearly threatened by future changes and that appropriate actions have to be taken.

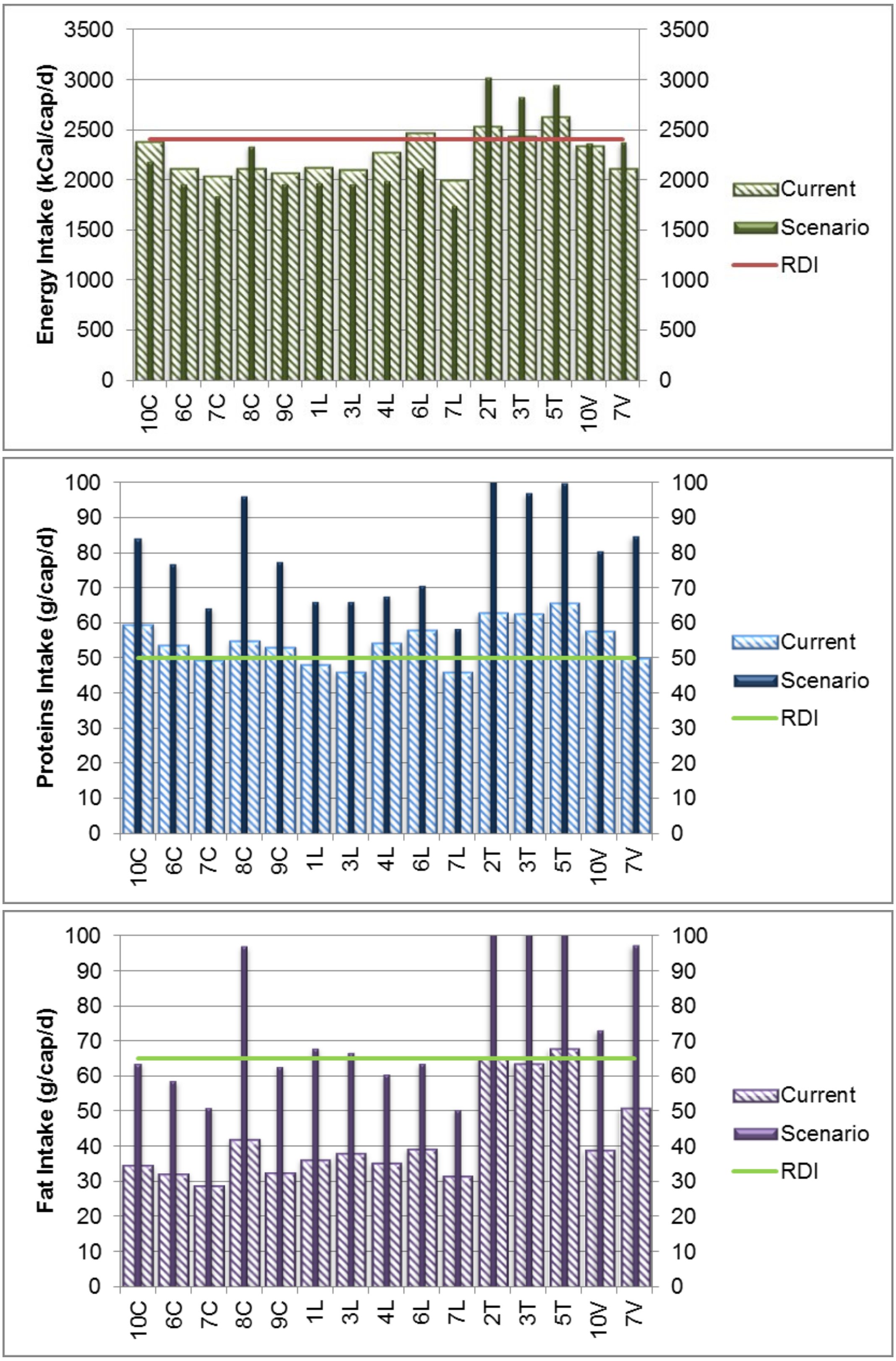

Figure 37. Daily energy, proteins and fat intake for the 15 sub-areas. Current is current situation, Scenario is the situation around 2050 taking population growth into account (Scen_01).

Table 21. Changes in food supply for Scen_01: population growth.

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▼ 1865	▼ 1737	▼ 1551	▲ 60	▬ 49	▬ 47	▼ 43	▼ 35	▼ 30	▼ 29	▼ 27
6C	▼ 2113	▼ 1656	▼ 1542	▼ 1378	▲ 54	▼ 45	▼ 42	▼ 39	▼ 32	▼ 28	▼ 27	▼ 25
7C	▼ 2043	▼ 1594	▼ 1482	▼ 1320	▲ 50	▼ 40	▼ 38	▼ 35	▼ 29	▼ 25	▼ 24	▼ 22
8C	▼ 2118	▼ 1694	▼ 1588	▼ 1435	▲ 55	▬ 47	▬ 45	▼ 42	▼ 42	▼ 38	▼ 37	▼ 36
9C	▼ 2071	▼ 1628	▼ 1518	▼ 1358	▲ 53	▼ 44	▼ 42	▼ 39	▼ 33	▼ 29	▼ 28	▼ 26
1L	▼ 2132	▼ 1623	▼ 1523	▼ 1404	▬ 48	▼ 39	▼ 37	▼ 35	▼ 36	▼ 31	▼ 30	▼ 29
3L	▼ 2106	▼ 1602	▼ 1503	▼ 1385	▬ 46	▼ 37	▼ 36	▼ 34	▼ 38	▼ 32	▼ 31	▼ 30
4L	▬ 2277	▼ 1723	▼ 1614	▼ 1484	▲ 54	▼ 43	▼ 41	▼ 38	▼ 35	▼ 30	▼ 29	▼ 27
6L	▲ 2470	▼ 1865	▼ 1746	▼ 1604	▲ 58	▬ 46	▼ 44	▼ 41	▼ 39	▼ 33	▼ 31	▼ 30
7L	▼ 2001	▼ 1510	▼ 1414	▼ 1299	▬ 46	▼ 37	▼ 35	▼ 33	▼ 32	▼ 26	▼ 25	▼ 24
2T	▲ 2536	▬ 2322	▬ 2371	▲ 2673	▲ 63	▲ 59	▲ 60	▲ 65	▲ 65	▬ 61	▬ 62	▲ 68
3T	▲ 2437	▬ 2228	▬ 2276	▲ 2571	▲ 63	▲ 58	▲ 59	▲ 65	▬ 64	▬ 60	▬ 60	▲ 66
5T	▲ 2635	▲ 2408	▲ 2460	▲ 2781	▲ 66	▲ 61	▲ 62	▲ 69	▲ 68	▬ 63	▬ 64	▲ 71
10V	▬ 2340	▼ 1947	▼ 1903	▼ 1920	▲ 58	▲ 50	▬ 49	▬ 49	▼ 39	▼ 35	▼ 34	▼ 35
7V	▼ 2111	▼ 1773	▼ 1736	▼ 1751	▲ 50	▼ 44	▼ 43	▼ 44	▼ 51	▼ 46	▼ 45	▼ 45

Base = current situation (2000-2009); FF = Foreseeable Future (2026-2035); LF = Long-term Future (2046-2055); H = Horizon (2090-2099). Green = above recommended intake level; yellow = maximal 10% below recommended intake level, yellow = 10% or more below recommended intake level.

Table 22. Changes in food supply for Scen_02: population growth and changes in crop yields by climate change for the low climate change impact (RCP2.6).

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▼ 1856	▼ 1721	▼ 1527	▲ 60	▬ 49	▬ 47	▼ 43	▼ 35	▼ 30	▼ 29	▼ 27
6C	▼ 2113	▼ 1651	▼ 1532	▼ 1363	▲ 54	▼ 44	▼ 42	▼ 39	▼ 32	▼ 28	▼ 27	▼ 25
7C	▼ 2043	▼ 1594	▼ 1482	▼ 1320	▲ 50	▼ 40	▼ 38	▼ 35	▼ 29	▼ 25	▼ 24	▼ 22
8C	▼ 2118	▼ 1692	▼ 1584	▼ 1429	▲ 55	▬ 47	▬ 45	▼ 42	▼ 42	▼ 38	▼ 37	▼ 36
9C	▼ 2071	▼ 1620	▼ 1503	▼ 1331	▲ 53	▼ 44	▼ 42	▼ 38	▼ 33	▼ 29	▼ 28	▼ 26
1L	▼ 2132	▼ 1620	▼ 1503	▼ 1395	▬ 48	▼ 39	▼ 37	▼ 35	▼ 36	▼ 31	▼ 30	▼ 29
3L	▼ 2106	▼ 1603	▼ 1475	▼ 1384	▬ 46	▼ 37	▼ 35	▼ 34	▼ 38	▼ 32	▼ 31	▼ 30
4L	▬ 2277	▼ 1707	▼ 1593	▼ 1461	▲ 54	▼ 43	▼ 41	▼ 38	▼ 35	▼ 30	▼ 29	▼ 27
6L	▲ 2470	▼ 1853	▼ 1728	▼ 1574	▲ 58	▬ 46	▼ 43	▼ 40	▼ 39	▼ 33	▼ 31	▼ 30
7L	▼ 2001	▼ 1510	▼ 1412	▼ 1296	▬ 46	▼ 37	▼ 35	▼ 33	▼ 32	▼ 26	▼ 25	▼ 24
2T	▲ 2536	▬ 2295	▬ 2331	▲ 2631	▲ 63	▲ 58	▲ 59	▲ 65	▲ 65	▬ 61	▬ 62	▲ 68
3T	▲ 2437	▬ 2205	▬ 2243	▲ 2509	▲ 63	▲ 58	▲ 59	▲ 64	▬ 64	▬ 59	▬ 60	▲ 66
5T	▲ 2635	▬ 2372	▬ 2394	▲ 2643	▲ 66	▲ 60	▲ 61	▲ 66	▲ 68	▬ 63	▬ 64	▲ 70
10V	▬ 2340	▼ 1940	▼ 1893	▼ 1903	▲ 58	▬ 49	▬ 48	▬ 49	▼ 39	▼ 35	▼ 34	▼ 35
7V	▼ 2111	▼ 1772	▼ 1733	▼ 1746	▲ 50	▼ 44	▼ 43	▼ 44	▼ 51	▼ 46	▼ 45	▼ 45

Base = current situation (2000-2009); FF = Foreseeable Future (2026-2035); LF = Long-term Future (2046-2055); H = Horizon (2090-2099). Green = above recommended intake level; yellow = maximal 10% below recommended intake level, yellow = 10% or more below recommended intake level.

Table 23. Changes in food supply for Scen_02: population growth and changes in crop yields by climate change for the high climate change impact (RCP8.8).

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▼ 1832	▼ 1686	▼ 1444	▲ 60	▬ 49	▬ 46	▼ 41	▼ 35	▼ 30	▼ 29	▼ 27
6C	▼ 2113	▼ 1631	▼ 1495	▼ 1260	▲ 54	▼ 44	▼ 41	▼ 37	▼ 32	▼ 28	▼ 27	▼ 25
7C	▼ 2043	▼ 1594	▼ 1481	▼ 1317	▲ 50	▼ 40	▼ 38	▼ 35	▼ 29	▼ 25	▼ 24	▼ 22
8C	▼ 2118	▼ 1686	▼ 1575	▼ 1371	▲ 55	▬ 47	▬ 45	▼ 41	▼ 42	▼ 38	▼ 37	▼ 36
9C	▼ 2071	▼ 1575	▼ 1398	▼ 1052	▲ 53	▼ 43	▼ 40	▼ 33	▼ 33	▼ 28	▼ 27	▼ 25
1L	▼ 2132	▼ 1562	▼ 1438	▼ 988	▬ 48	▼ 38	▼ 35	▼ 27	▼ 36	▼ 31	▼ 30	▼ 26
3L	▼ 2106	▼ 1549	▼ 1403	▼ 1151	▬ 46	▼ 36	▼ 34	▼ 29	▼ 38	▼ 32	▼ 30	▼ 28
4L	▬ 2277	▼ 1674	▼ 1517	▼ 1310	▲ 54	▼ 42	▼ 39	▼ 35	▼ 35	▼ 30	▼ 28	▼ 27
6L	▲ 2470	▼ 1800	▼ 1594	▼ 1331	▲ 58	▬ 45	▼ 41	▼ 35	▼ 39	▼ 33	▼ 31	▼ 29
7L	▼ 2001	▼ 1507	▼ 1408	▼ 1286	▬ 46	▼ 37	▼ 35	▼ 32	▼ 32	▼ 26	▼ 25	▼ 24
2T	▲ 2536	▬ 2262	▬ 2250	▲ 2402	▲ 63	▲ 58	▲ 57	▲ 60	▲ 65	▬ 61	▬ 62	▲ 67
3T	▲ 2437	▼ 2158	▼ 2113	▬ 2284	▲ 63	▲ 57	▲ 56	▲ 60	▬ 64	▬ 59	▬ 60	▲ 65
5T	▲ 2635	▬ 2212	▬ 2173	▬ 2328	▲ 66	▲ 57	▲ 56	▲ 60	▲ 68	▬ 63	▬ 63	▲ 69
10V	▬ 2340	▼ 1922	▼ 1848	▼ 1726	▲ 58	▬ 49	▬ 48	▬ 45	▼ 39	▼ 35	▼ 34	▼ 34
7V	▼ 2111	▼ 1767	▼ 1722	▼ 1721	▲ 50	▼ 44	▼ 43	▼ 43	▼ 51	▼ 46	▼ 45	▼ 45

Base = current situation (2000-2009); FF = Foreseeable Future (2026-2035); LF = Long-term Future (2046-2055); H = Horizon (2090-2099). Green = above recommended intake level; yellow = maximal 10% below recommended intake level, yellow = 10% or more below recommended intake level.

4.3.2 Interventions

As shown above, the combined effect on climate change and population growth is expected to have a severe impact on food conditions in the LMB. Therefore, interventions are needed. In order to assess the impact of potential interventions, the Food Balance Sheets have been used to analyze the effectiveness of various interventions. The following interventions (scenarios) have been explored:

- Scen_03: extension of agricultural lands
    - Looking at the trends over the last 10 years it can be expected that a further expansion of agricultural lands is likely to continue. As shown in Table 3 the area of rice has increased especially for Cambodia and to a lesser extent for Lao PDR. It is however unlikely that the same trend will continue given limitation in land resources. Therefore this intervention scenario is based on the following increase in agricultural area. For the sub-areas in Cambodia 3% increase per year, for Lao PDR by 2% per year, and for Thailand and Vietnam 1% per year. After 2050 no further expansion is considered.
- Scen_04: increase in agricultural production.
    - Crop yields have increased for all sub-areas and for all crops over the last 10 years. This intervention scenario assumes that crop yields will increase for all sub-areas and for all crops by 1% per year. After 2050 the yields are considered to remain constant.
- Scen_05: increase in agricultural production.
    - This Scenario is the same as the previous one, but here it is assumed that crop yields will increase by 2% per year.
- Scen_06: increase in animal production

    - Animal production is relatively low for most sub-areas (with the exception of the sub-areas in Thailand). In order to produce sufficient fat, an increase in animal production is assessed. This intervention assumes an increase in animal production of 2% per year.
- Scen_07: increase in animal production
    - This Scenario is the same as the previous one, but here it is assumed that increase in animal production will be 5% per year.
- Scen_08: mix of interventions.
    - Based on the previous interventions it is clear that a mix of intervantions has to be taken to ensure food security in the LMB. The following mix is considered:
        - Increase in cropped area for the sub-areas in Cambodia 1%, Lao PDR by 1%, and for Thailand and Vietnam 0% per year.
        - Increase in yield by 2% for all sub-areas
        - Animal production will increase by 5% for the sub-areas in Cambodia and Lao PDR; and by 1% for Thailand and Vietnam
        - After 2050 no further increase in cropped area, crop yield and animal production.

The first intervention (Scen_03) in which the area of agricultural land will expand, has a positive impact on the entire food supply as shown in Table 24. For most sub-areas energy supply will be at the recommended level for the LF (Long-term Future = around 2050). For the FS (Foreseeable Future = around 2030) energy supply will increase to reasonable levels. Interesting is that the considered ranges in climate scenario has only a major impact for the so-called Horizon (H = end of century) future. The expected fat intake will remain low in the future and appropriate actions are needed.

The two interventions where an increase in agricultural yields (Scen_04 and Scen_05) is explored are presented in Table 25 and Table 26. Since the differences in the various climate projections (RCPs) are limited, only RCP 4.5 is presented here. It is clear that an increase in agricultural yields by 1% is not sufficient to compensate for the negative impacts of population growth and climate change. For Scen_05, where an increase in yield of 2% per year is considered, caloric supply and protein supply are more or less sufficient to meet future food demands (Table 26). However for some sub-areas food supply remain on the low site.

Interventions Scen_06 and Scen_07 are looking at the option to increase fat production in the sub-areas. This can be achieved by increasing imports of animal products or by raising the internal production. Figure 38 shows the results for the two options: increasing by 2% and by 5% per year. It is clear that for most sub-areas an increase of about 5% is needed to fulfil fat demand intake by the population. For the sub-areas in Thailand and to a lesser extent to the ones in Vietnam an increase of 2% is sufficient. For sub-areas 7C and 7L fat intake will remain on the low site, even with an increase of 5%.

The last intervention explored here assumes of mixture of intervention actions that will be taken. Increase of agricultural area by spatial planning and farmers financing support; increase in yield by improved farming techniques; and improved animal production (or increase in animal import products). By using this mix of interventions sufficient food will be available to support all sub-areas. Table 27 indicates that for all future scenarios energy intake and protein intake will be sufficient. Fat supply will remain on the low site for the coming years, but if increase in animal production will continue to 2050 also this shortage can be overcome.

Table 24. Changes in food intake for Scen_03: increased agricultural area. For RCP 2.6 (top) and RCP 8.8 (bottom).

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▲ 3087	▲ 3756	▲ 3298	▲ 60	▲ 74	▲ 87	▲ 78	▼ 35	▼ 41	▼ 47	▼ 43
6C	▼ 2113	▲ 2741	▲ 3335	▲ 2936	▲ 54	▲ 66	▲ 78	▲ 70	▼ 32	▼ 38	▼ 44	▼ 40
7C	▼ 2043	▲ 2669	▲ 3266	▲ 2886	▲ 50	▲ 62	▲ 74	▲ 66	▼ 29	▼ 34	▼ 40	▼ 36
8C	▼ 2118	▲ 2706	▲ 3266	▲ 2901	▲ 55	▲ 65	▲ 76	▲ 69	▼ 42	▼ 47	▼ 52	▼ 49
9C	▼ 2071	▲ 2677	▲ 3245	▲ 2842	▲ 53	▲ 65	▲ 76	▲ 68	▼ 33	▼ 38	▼ 44	▼ 40
1L	▼ 2132	▬ 2325	▲ 2668	▲ 2462	▬ 48	▲ 52	▲ 58	▲ 54	▼ 36	▼ 38	▼ 42	▼ 40
3L	▼ 2106	▬ 2304	▲ 2622	▲ 2449	▬ 46	▲ 50	▲ 55	▲ 52	▼ 38	▼ 41	▼ 45	▼ 42
4L	▬ 2277	▲ 2470	▲ 2864	▲ 2613	▲ 54	▲ 58	▲ 66	▲ 61	▼ 35	▼ 37	▼ 42	▼ 39
6L	▲ 2470	▲ 2687	▲ 3118	▲ 2824	▲ 58	▲ 62	▲ 71	▲ 65	▼ 39	▼ 42	▼ 47	▼ 44
7L	▼ 2001	▬ 2190	▲ 2550	▬ 2329	▬ 46	▲ 50	▲ 56	▲ 52	▼ 32	▼ 34	▼ 38	▼ 35
2T	▲ 2536	▲ 2789	▲ 3236	▲ 3671	▲ 63	▲ 68	▲ 76	▲ 84	▲ 65	▲ 70	▲ 79	▲ 87
3T	▲ 2437	▲ 2689	▲ 3130	▲ 3516	▲ 63	▲ 68	▲ 77	▲ 86	▬ 64	▲ 69	▲ 78	▲ 86
5T	▲ 2635	▲ 2894	▲ 3345	▲ 3705	▲ 66	▲ 71	▲ 80	▲ 88	▲ 68	▲ 74	▲ 83	▲ 92
10V	▬ 2340	▬ 2371	▲ 2646	▲ 2661	▲ 58	▲ 58	▲ 64	▲ 64	▼ 39	▼ 39	▼ 42	▼ 42
7V	▼ 2111	▼ 2143	▬ 2382	▲ 2401	▲ 50	▲ 50	▲ 55	▲ 55	▼ 51	▼ 51	▼ 55	▼ 55

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▲ 3045	▲ 3672	▲ 3103	▲ 60	▲ 73	▲ 85	▲ 74	▼ 35	▼ 41	▼ 47	▼ 42
6C	▼ 2113	▲ 2707	▲ 3247	▲ 2695	▲ 54	▲ 65	▲ 76	▲ 65	▼ 32	▼ 38	▼ 44	▼ 40
7C	▼ 2043	▲ 2669	▲ 3263	▲ 2879	▲ 50	▲ 62	▲ 74	▲ 66	▼ 29	▼ 34	▼ 40	▼ 36
8C	▼ 2118	▲ 2696	▲ 3245	▲ 2766	▲ 55	▲ 65	▲ 75	▲ 66	▼ 42	▼ 47	▼ 52	▼ 48
9C	▼ 2071	▲ 2597	▲ 2998	▬ 2186	▲ 53	▲ 64	▲ 72	▲ 55	▼ 33	▼ 38	▼ 43	▼ 38
1L	▼ 2132	▬ 2239	▲ 2544	▼ 1690	▬ 48	▲ 50	▲ 56	▼ 40	▼ 36	▼ 38	▼ 41	▼ 35
3L	▼ 2106	▬ 2223	▲ 2485	▼ 2007	▬ 46	▬ 48	▲ 52	▼ 44	▼ 38	▼ 40	▼ 44	▼ 39
4L	▬ 2277	▲ 2421	▲ 2718	▬ 2325	▲ 54	▲ 57	▲ 63	▲ 55	▼ 35	▼ 37	▼ 41	▼ 38
6L	▲ 2470	▲ 2608	▲ 2864	▬ 2364	▲ 58	▲ 61	▲ 66	▲ 56	▼ 39	▼ 42	▼ 46	▼ 42
7L	▼ 2001	▬ 2186	▲ 2541	▬ 2309	▬ 46	▲ 50	▲ 56	▲ 52	▼ 32	▼ 34	▼ 38	▼ 35
2T	▲ 2536	▲ 2747	▲ 3119	▲ 3340	▲ 63	▲ 67	▲ 74	▲ 78	▲ 65	▲ 70	▲ 78	▲ 85
3T	▲ 2437	▲ 2630	▲ 2942	▲ 3190	▲ 63	▲ 67	▲ 74	▲ 79	▬ 64	▲ 69	▲ 77	▲ 85
5T	▲ 2635	▲ 2694	▲ 3024	▲ 3249	▲ 66	▲ 67	▲ 74	▲ 78	▲ 68	▲ 73	▲ 82	▲ 90
10V	▬ 2340	▬ 2348	▲ 2581	▲ 2404	▲ 58	▲ 58	▲ 62	▲ 59	▼ 39	▼ 39	▼ 42	▼ 41
7V	▼ 2111	▼ 2136	▬ 2366	▬ 2365	▲ 50	▲ 50	▲ 54	▲ 54	▼ 51	▼ 51	▼ 55	▼ 55

Base = current situation (2000-2009); FF = Foreseeable Future (2026-2035); LF = Long-term Future (2046-2055); H = Horizon (2090-2099). Green = above recommended intake level; yellow = maximal 10% below recommended intake level, yellow = 10% or more below recommended intake level.

Table 25. Changes in food intake for Scen_04 (RCP 4.5): increased agricultural yields by 1%.

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▬ 2187	▬ 2269	▼ 2007	▲ 60	▲ 56	▲ 57	▲ 52	▼ 35	▼ 31	▼ 31	▼ 29
6C	▼ 2113	▼ 1941	▼ 2012	▼ 1776	▲ 54	▲ 50	▲ 52	▬ 47	▼ 32	▼ 29	▼ 29	▼ 27
7C	▼ 2043	▼ 1893	▼ 1978	▼ 1756	▲ 50	▬ 46	▬ 48	▼ 44	▼ 29	▼ 26	▼ 26	▼ 24
8C	▼ 2118	▼ 1974	▼ 2057	▼ 1843	▲ 55	▲ 52	▲ 53	▲ 50	▼ 42	▼ 39	▼ 39	▼ 38
9C	▼ 2071	▼ 1904	▼ 1957	▼ 1669	▲ 53	▲ 50	▲ 51	▬ 45	▼ 33	▼ 30	▼ 29	▼ 27
1L	▼ 2132	▼ 1896	▼ 1981	▼ 1792	▬ 48	▼ 44	▬ 45	▼ 42	▼ 36	▼ 32	▼ 32	▼ 31
3L	▼ 2106	▼ 1871	▼ 1990	▼ 1802	▬ 46	▼ 42	▼ 44	▼ 41	▼ 38	▼ 34	▼ 34	▼ 32
4L	▬ 2277	▼ 2000	▼ 2083	▼ 1878	▲ 54	▬ 49	▲ 50	▬ 46	▼ 35	▼ 31	▼ 30	▼ 29
6L	▲ 2470	▼ 2159	▬ 2241	▼ 1986	▲ 58	▲ 52	▲ 53	▬ 48	▼ 39	▼ 34	▼ 33	▼ 31
7L	▼ 2001	▼ 1775	▼ 1855	▼ 1698	▬ 46	▼ 42	▼ 43	▼ 40	▼ 32	▼ 27	▼ 27	▼ 26
2T	▲ 2536	▲ 2544	▲ 2795	▲ 3108	▲ 63	▲ 63	▲ 67	▲ 73	▲ 65	▬ 62	▬ 64	▲ 69
3T	▲ 2437	▲ 2435	▲ 2652	▲ 2910	▲ 63	▲ 63	▲ 68	▲ 73	▬ 64	▬ 60	▬ 62	▲ 67
5T	▲ 2635	▲ 2583	▲ 2752	▲ 2965	▲ 66	▲ 65	▲ 68	▲ 72	▲ 68	▬ 64	▲ 66	▲ 71
10V	▬ 2340	▬ 2274	▲ 2474	▲ 2473	▲ 58	▲ 56	▲ 60	▲ 60	▼ 39	▼ 36	▼ 36	▼ 37
7V	▼ 2111	▼ 2014	▼ 2155	▬ 2171	▲ 50	▬ 48	▲ 50	▲ 50	▼ 51	▼ 47	▼ 47	▼ 47

Table 26. Changes in food intake for Scen_05 (RCP 4.5): increased agricultural yields by 2%. For RCP 4.5.

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▲ 2527	▲ 2830	▲ 2496	▲ 60	▲ 62	▲ 68	▲ 62	▼ 35	▼ 33	▼ 33	▼ 31
6C	▼ 2113	▬ 2235	▲ 2499	▬ 2198	▲ 54	▲ 56	▲ 61	▲ 55	▼ 32	▼ 30	▼ 30	▼ 28
7C	▼ 2043	▬ 2192	▲ 2474	▬ 2191	▲ 50	▲ 52	▲ 58	▲ 52	▼ 29	▼ 27	▼ 27	▼ 25
8C	▼ 2118	▬ 2259	▲ 2530	▬ 2258	▲ 55	▲ 57	▲ 62	▲ 57	▼ 42	▼ 41	▼ 41	▼ 39
9C	▼ 2071	▬ 2195	▲ 2430	▼ 2061	▲ 53	▲ 56	▲ 60	▲ 53	▼ 33	▼ 31	▼ 31	▼ 29
1L	▼ 2132	▬ 2185	▲ 2460	▬ 2219	▬ 48	▬ 49	▲ 54	▬ 49	▼ 36	▼ 34	▼ 34	▼ 33
3L	▼ 2106	▼ 2152	▲ 2470	▬ 2230	▬ 46	▬ 47	▲ 52	▬ 48	▼ 38	▼ 36	▼ 37	▼ 35
4L	▬ 2277	▬ 2300	▲ 2582	▬ 2322	▲ 54	▲ 55	▲ 60	▲ 55	▼ 35	▼ 32	▼ 32	▼ 30
6L	▲ 2470	▲ 2477	▲ 2767	▲ 2444	▲ 58	▲ 58	▲ 64	▲ 57	▼ 39	▼ 35	▼ 35	▼ 33
7L	▼ 2001	▼ 2040	▬ 2298	▼ 2101	▬ 46	▬ 47	▲ 51	▬ 48	▼ 32	▼ 29	▼ 29	▼ 27
2T	▲ 2536	▲ 2807	▲ 3274	▲ 3641	▲ 63	▲ 67	▲ 75	▲ 82	▲ 65	▬ 63	▲ 65	▲ 71
3T	▲ 2437	▲ 2673	▲ 3081	▲ 3373	▲ 63	▲ 68	▲ 77	▲ 83	▬ 64	▬ 61	▬ 63	▲ 69
5T	▲ 2635	▲ 2833	▲ 3185	▲ 3414	▲ 66	▲ 70	▲ 77	▲ 82	▲ 68	▲ 65	▲ 67	▲ 73
10V	▬ 2340	▲ 2612	▲ 3064	▲ 3062	▲ 58	▲ 63	▲ 72	▲ 72	▼ 39	▼ 37	▼ 38	▼ 39
7V	▼ 2111	▬ 2257	▲ 2581	▲ 2600	▲ 50	▲ 52	▲ 57	▲ 57	▼ 51	▼ 48	▼ 49	▼ 49

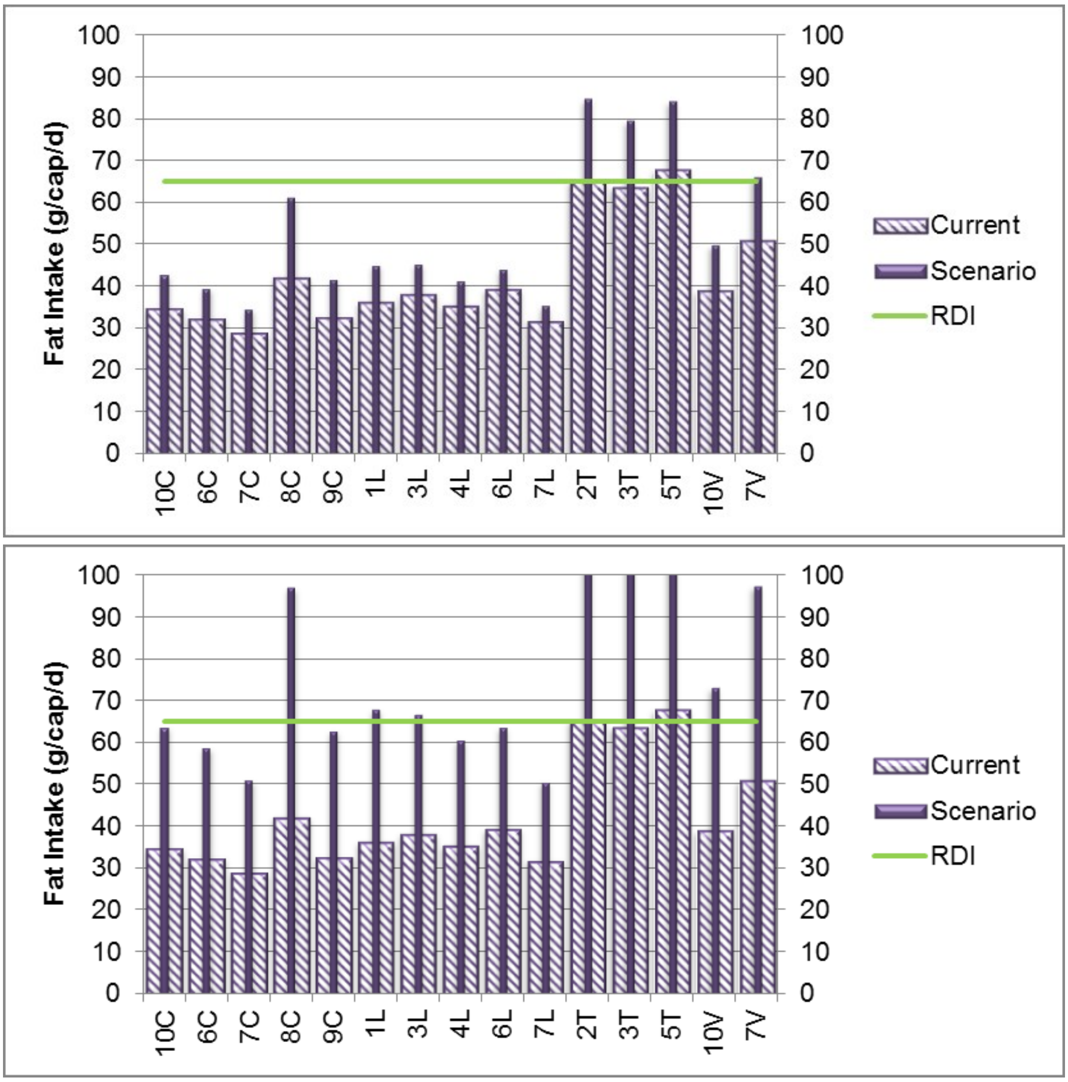

Figure 38. Daily fat intake for the 15 sub-areas for Scen_06 and Scen_07: increased animal production. Top: increase in production by 2% per year (Secn_06); bottom: increase by 5% per year (Scen_07). All results for the Long term Future (LF = 2050) and for RCP4.5

Table 27. Changes in food intake for Scen_08 (RCP 4.5): a mixture of interventions (area expansion, yield increase, and animal production).

	Energy Intake (kCal/cap/d)				Protein Intake (g/cap/d)				Fat Intake (g/cap/d)			
	Base	FF	LF	H	Base	FF	LF	H	Base	FF	LF	H
10C	▬ 2383	▲ 3374	▲ 4490	▲ 4006	▲ 60	▲ 95	▲ 129	▲ 120	▼ 35	▼ 56	▲ 76	▲ 73
6C	▼ 2113	▲ 2991	▲ 3977	▲ 3541	▲ 54	▲ 86	▲ 117	▲ 108	▼ 32	▼ 52	▲ 70	▲ 67
7C	▼ 2043	▲ 2901	▲ 3877	▲ 3466	▲ 50	▲ 77	▲ 105	▲ 97	▼ 29	▼ 46	▬ 61	▬ 59
8C	▼ 2118	▲ 3163	▲ 4278	▲ 3883	▲ 55	▲ 94	▲ 131	▲ 123	▼ 42	▲ 77	▲ 107	▲ 105
9C	▼ 2071	▲ 2956	▲ 3905	▲ 3370	▲ 53	▲ 85	▲ 116	▲ 105	▼ 33	▼ 54	▲ 73	▲ 70
1L	▼ 2132	▲ 2940	▲ 3944	▲ 3595	▬ 48	▲ 74	▲ 102	▲ 95	▼ 36	▬ 59	▲ 80	▲ 78
3L	▼ 2106	▲ 2891	▲ 3942	▲ 3595	▬ 46	▲ 72	▲ 99	▲ 93	▼ 38	▬ 61	▲ 83	▲ 79
4L	▬ 2277	▲ 3056	▲ 4070	▲ 3694	▲ 54	▲ 81	▲ 109	▲ 102	▼ 35	▼ 54	▲ 72	▲ 70
6L	▲ 2470	▲ 3280	▲ 4344	▲ 3875	▲ 58	▲ 85	▲ 115	▲ 105	▼ 39	▬ 58	▲ 77	▲ 74
7L	▼ 2001	▲ 2699	▲ 3600	▲ 3314	▬ 46	▲ 69	▲ 94	▲ 88	▼ 32	▼ 47	▬ 62	▬ 60
2T	▲ 2536	▲ 2887	▲ 3418	▲ 3784	▲ 63	▲ 72	▲ 85	▲ 92	▲ 65	▲ 69	▲ 77	▲ 83
3T	▲ 2437	▲ 2741	▲ 3203	▲ 3495	▲ 63	▲ 72	▲ 85	▲ 91	▬ 64	▲ 67	▲ 73	▲ 79
5T	▲ 2635	▲ 2903	▲ 3311	▲ 3541	▲ 66	▲ 74	▲ 85	▲ 90	▲ 68	▲ 71	▲ 77	▲ 83
10V	▬ 2340	▲ 2666	▲ 3162	▲ 3160	▲ 58	▲ 67	▲ 79	▲ 79	▼ 39	▼ 42	▼ 46	▼ 46
7V	▼ 2111	▲ 2619	▲ 3233	▲ 3252	▲ 50	▲ 75	▲ 98	▲ 98	▼ 51	▲ 77	▲ 102	▲ 102

5 Conclusions

The analyses presented in this study are based on two well-established tools: AquaCrop and Food Balance Sheets. These tools were applied using the best available data currently, to explore the impact and potential adaptation options to climate change in the 15 sub-areas across the four member countries of the LMB.

From the results presented it can be concluded that future food security will reduce if appropriate actions will not be taken. Depending on the expected climate scenario food security will reduce in all sub areas. The most vulnerable sub areas are in Cambodia (7C and 9C) and in Lao PDR (7L and 3L). From the three food components evaluated (energy, protein, fat) is the daily available fat intake the most problematic considering the recommended daily intake levels. The analysis reveals also that not only climate change is the driver of this reduced food security but that population change is equally important.

The tools as presented in this study are also used to explore potential adaptation options (interventions). From the selected set of interventions is the one that includes a mix of actions the most effective one.

Based on the assessments as presented in this study the following actions are recommended:

- The analyses are based on well-established and tested tools. However, the weakest link remains the availability and accuracy of data. Results presented here should therefore be considered as indicative. Data collection and appropriate storage should remain a high priority.
- Results of the current analysis can be used interactively with stakeholders. Especially the Food Balance Sheets are excellent to discuss with stakeholders potential interventions and analyze the effectiveness of proposed actions.
- The tools can be applied very well on smaller scales. Pilot case studies with appropriate data collection might be setup. Especially local-specific interventions can then be explored and analyzed on effectiveness.
- Finally, actions can be taken already based on the analysis. Some typical examples are: (i) enhance crop yields by better support and training of farmers, (ii) consider expansion of the agricultural area taking into account environmental issues, and (iii) increase fat supply by promoting livestock husbandry.

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Annex I. Crop parameters

Rice

The pre-calibrated AquaCrop crop file for paddy rice has been used with small changes to represent average local conditions in LMB. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting density: 250,000 plants per hectare.
- Well covered (maximum between 80%-100%)
- Dry matter content harvested product: 87%
- Irrigation method: furrow
- Irrigation during wet season only supplementary (between 150 and 250 mm), during dry season between 400 and 500 mm
- Harvest index = 43%
- Planting and harvesting is location, and dry and wet season specific and

Maize

The pre-calibrated AquaCrop crop file for maize has been used with small changes to represent average local conditions in LMB. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting density: 20,000 plants per hectare.
- Fairly well covered (maximum between 50%-70%)
- Dry matter content harvested product: 87%
- No irrigation
- Harvest index = 48%
- Planting and harvesting is location specific

Sugarcane

The pre-calibrated AquaCrop crop file for maize has been used with small changes to represent average local conditions in LMB. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting density: 35,000 plants per hectare.
- Fairly well covered (maximum between 60%-80%)
- Dry matter content harvested product: 30%
- Furrow irrigation, 250-400 mm

- Harvest index = 73%
- Cycle of ratoon crop starts at the start of the wet season, harvested at the end of the dry period.
- Total crop cycle: one year (365 days).
- Planting and harvesting in April of each year.

Cassava

The pre-calibrated AquaCrop crop file for maize has been used with small changes to represent average local conditions in LMB. The most important assumptions and crop information used to parameterize the crop files in AquaCrop are:

- Planting density: 10.000 plants per hectare.
- Fairly well covered (maximum between 50%-70%)
- Dry matter content harvested product: 25%
- No irrigation
- Harvest index = 63%
- Planting in second half of April, harvesting second half of October

Appendix II: Food Balance Sheets

Input parameters used to develop Food Balance Sheets

Parameter	Unit	Source
Area, rice	ha	MRC shapefile, landcover
Area, maize	ha	MRC shapefile, landcover
Area cassava	ha	MRC shapefile, landcover
Area sugar cane	ha	MRC shapefile, landcover
Area other crops	ha	FAOstat as percentage
Yield, rice	kg/ha	AquaCrop
Yield, maize	kg/ha	AquaCrop
Yield cassava	kg/ha	AquaCrop
Yield sugar cane	kg/ha	AquaCrop
Yield other crops	kg/ha	FAOstat as percentage
Population		BDP 2010
Total sub area	ha	BDP 2010
Import for each crop	ton/y	FAOstat as percentage
Export for each crop	ton/y	FAOstat as percentage
Feed for each crop	ton/y	FAOstat as percentage
Seed for each crop	ton/y	FAOstat as percentage
Other utility for each crop	ton/y	FAOstat as percentage
Processing for each crop	ton/y	FAOstat as percentage
Waste for each crop	ton/y	FAOstat as percentage
Energy per crop	kCal/kg	Country statistics
Proteins per crop	g/100g	Country statistics
Fat per crop	g/100g	Country statistics
Fish production	ton/y	BDP Socio-Economic data base 2010
Meat production	ton/y	BDP Socio-Economic data base 2010

Data sheets in Food Balance Sheets

The Food Balance Sheet as developed in excel has the following sheets:

- [CountryData] = base country data for the period 2000-2009 obtained from FAOstat
- [InputBase] = the base line input data for each of the 15 sub-areas on which the calculation of (i) food supply, (ii) food utilization and (iii) per capita supply, is based
- [InputData] = same as above, but adjusted for the selected scenario.
- [InputChange] = changes from baseline. This sheet is used to calculate [InputData]

- [PopulationChange] = changes in population based on FAOstat
- [NoChange] = used as Scen_00: no changes
- [Scen_xx] = sheets with defined changes in yields, areal and fish and meat production
- [Cambodia] = the food balance sheets for the sub-areas in Cambodia
- [Lao] = the food balance sheets for the sub-areas in Lao PDR
- [Thailand] = the food balance sheets for the sub-areas in Thailand
- [Vietnam] = the food balance sheets for the sub-areas in Vietnam
- [Results] = results for the current scenario. Also used to define the scenario.
- [AllResults] = copy/pastes from the [Results] for the different scenarios analysed.

Scenario analysis in Food Balance Sheets

The Food Balance Sheets are setup to enable fast scenario analysis. In short the following steps should be taken.

- Create a new scenario:
    - Copy the sheet [Scen_01] to a new number
    - Change parameters in this new sheet. Typical examples are
        - Changes in agricultural area
        - Changes in crop yield
        - Changes in fish catch
        - Changes in animal production
    - All changes should be provided in % per year and can be sub-area specific

- Add this new scenario in the sheet [Results] in column AC

- Analyse the scenario by selecting three predefined options:
    - Select the Scenario
        - Use drop list in cell W6.
    - Select the Period
        - This is predefined and can be: 2000-2009, or 2026-2035, or 2046-2055, or 2090-2099
    - Select the climate scenario RCP (Reference Concentration Pathway)
        - Can be: 0.0, 2.6, 4.5, 6.0, 8.8

ScenarioSheet	**Scen_07**
Period	**2046-2055**
RCP	**4.5**

- Results can be seen in cells D3:H19. Figures are automatically updated.

- To plot results in sheet [AllResults] one can copy cells D3:H19 into the appropriate cells in [AllResults].