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Abstract

Energy, water and food are the "resource pillars on which global security, prosperity and equity stand" (Hague, 2010). There is increasing recognition, supported by multiple studies, that both meeting demand for these resources from a growing, increasingly urban and affluent population will strain planetary environmental limits, and that the impacts are interrelated; meeting the predicted 70% increase in food demand by 2050 requires major intensification of agriculture and extensive land conversion, negatively impacting land-based ecosystem services and water resources. Despite prioritisation of this issue at the highest level, and although much groundwork has been done, there are, to date, surprisingly few tools for evaluating and communicating the food security environment trade-off.

This paper presents a case-study on West Africa, one of the world's poorest and least developed regions, using quantified scenarios that each represent different development paths, to understand and communicate the pressures on food security. The analysis shows that through 2050, food security in this massive region is increasingly precarious: the combination of population growth, development needs and global resource pressures requires either massive land conversion, exhausting most cultivatable land, or a potentially unaffordable, input driven agricultural transformation, potentially stretching water resources; both with questionable soil quality sustainability. The implications for policy makers and businesses are in line with other commentators and include the need for massive investment in ecologically-based agriculture to sustainably transform yields and clear governance to control international land "grabbing" and ecosystem destruction.

With strong existing work available to define the key input variables, this case study shows how the use of quantified scenarios, with relatively simple tools, to visualise and communicate the results can provide clear insight into the pressures on future food security that, with some enhancements, should be of value to a wide range of stakeholders.

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List of Acronyms

CDSB	Carbon Disclosure Standards Board
ECI	Environmental Change Institute
ESSV	Eco system service value
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global agro-ecological zones
GDP	Gross domestic product
GIS	Global Information System
HDI	Human Development Index
IRWS	Internal renewable water supply
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
ISU	International Sustainability Unit
LUT	Land utilisation types
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
SSA	Sub-Saharan Africa
SOLAW	The state of the world's land and water resources for food and agriculture
TEEB	The Economics Of Ecosystems And Biodiversity
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development
WSI	Water Stress indicator

1. Introduction

In his recent book “Full Planet, Empty Plates” Brown (2012) argues that time is running out as “The world may be much closer to an unmanageable food shortage – replete with soaring food prices, spreading food unrest, and ultimately political instability – than most people realize.” The arguments are simple: substantially more demand for food will need to be met at a time when the world’s resources are being increasingly over-exploited and reaching capacity. Rising population and incomes are expected to call for 70% more food production globally and 100% more in developing countries by 2050 (FAO SOLAW, 2011) requiring both dramatic intensification to drive 71% yield increases and extensive land conversion (Bruinsma 2009). The UN’s high level panel (Dobermann and Nelson, 2013) argues that achieving this must be decoupled from unsustainable utilization of water, energy, fertilisers, chemicals, and land”.

However, these global resource and environmental challenges to global food security are already being felt by the world’s poor; dramatic food price escalation of 2008, driven by increased competition for land from biofuels and animal feed and increasing oil based fertilizer prices (Dobbs et al, 2011), pushed a further 110 million more people into hunger (Nellemann et al, 2009). Protectionist responses by developed country governments and companies, which included bans on grain exports and an acceleration of overseas “land grabbing”, exacerbated the situation, making food imports for poor countries less affordable and reliable.

Nowhere is this issue more pressing than Sub-Saharan Africa, home to almost one third of the world’s hungry (260 million people, FAO, 2012) while spending some \$40 billion on food imports, and with its population is set to double to 2050. The African Union, which has declared 2014 the “Year of Agriculture and food security”, is seeking food self-sufficiency, by transforming African agriculture as part of an agriculturally-led development pathway for the continent (New African, 2014). The scale of transformation is massive, but despite still having some 60% of the remaining unused global arable land available, agricultural development is already taking its toll on Africa’s environment with some 75 million hectares of forest lost since 1990 (similar in scale to losses in South America), 65% of current agricultural land “degraded” and widespread soil erosion lowering productivity, while lack of sanitation is polluting river and wetlands (UNEP, GEO-4 fact sheet 8, 2007).

These multiple, increasing and competing pressures will dramatically increase the tension between food security and the environment, as agricultural development puts pressure on land and ecosystem services, potentially driving unintended negative feedbacks as summarized by the author in figure 1:

- Development needs and population growth increase domestic demand for calories, to alleviate hunger, and support a larger, wealthier and more urbanised population

- Global resource shortages make imports less affordable and reliable, increasing pressure for domestic agricultural expansion, further increasing pressure on land
- Increased output requires “natural state” land conversion, and intensification (higher yields) through higher inputs of water and fertilisers, both reducing the value of ecosystem services provided by the land as well as impacting water quality, availability, river flows and wetlands.
- Meanwhile ‘land grabs’ for export crops and biofuels increase competition for the best land (Friis et al, 2010), as Africa’s abundant cheap land, often perceived as “empty spaces”, seem attractive to overseas investors.
- Finally, climate change impacts in the region are expected to reduce yields significantly from 2080 (Cline 2007)
- The result is a strong risk of negative feedbacks from overgrazing, soil erosion and water shortage, compounding existing environmental degradation to further reduce productivity.

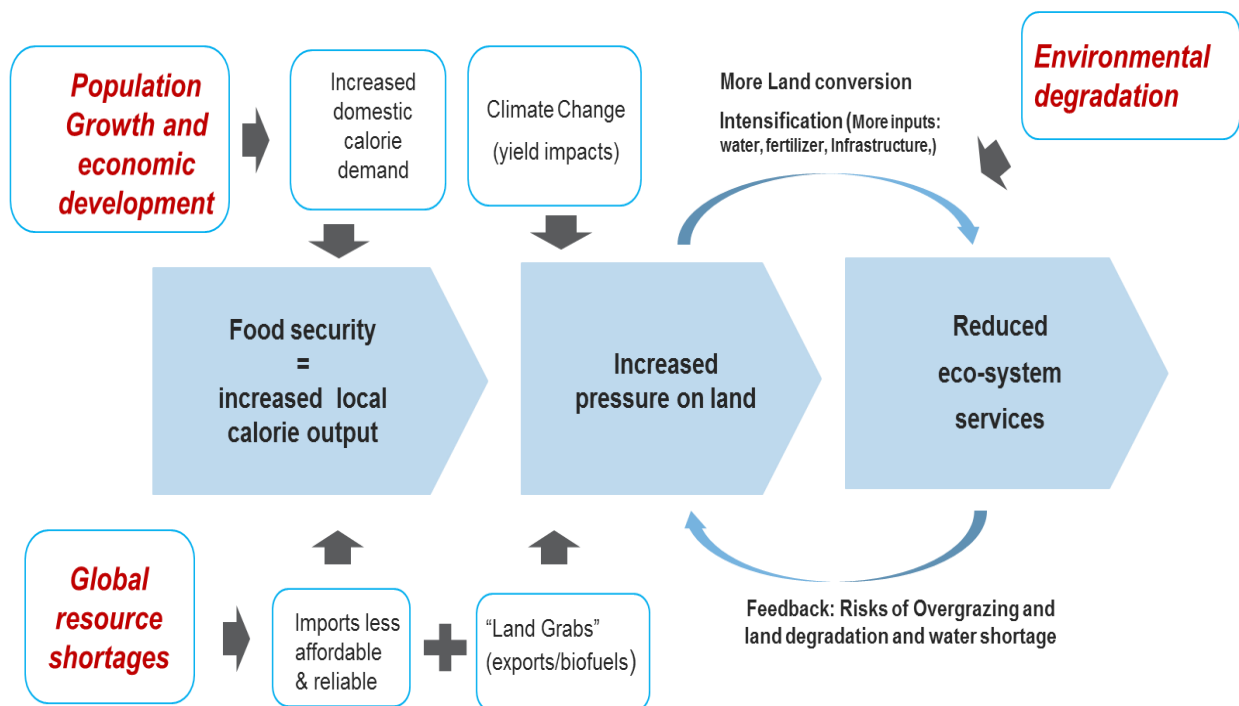


Figure 1: Multiple, Competing pressures on food security for the world’s poor

The importance of managing the development vs. environment trade-off is explicitly recognised by the United Nations Environmental Programme’s (UNEP) in its report “Putting Ecosystem Management in the Vision of African” (UNEP 2011, p2) arguing that there is an urgent need to understand the relationships and trade-offs between economic growth and the sustainability of ecosystems in Africa and that tools that

capture ecosystem services values are vital in designing effective policies for sustainable growth (UNEP, 2011).

However, despite having such a clear imperative outlined and agreed at the highest level, to date there are few tools to help navigate the trade-offs. Detailed relevant global databases have been built over the past 20 years, including land utilisation types (LUT), crop catalogues and thermal/LUT needs, land characteristics with soil and terrain constraints (GIS), as well as demographic profiles and forecast and climate impact models (Fischer et al, 2002)). Nonetheless there is little work focusing on how to support decision making” (Bazilian et al. 2011). The ISU (2011) argues that although existing tools exist and more are being developed “what is needed is an integrated approach that allows policymakers to look at food systems as a whole and to weigh up different options” and tools that “help policymakers and food producers assess the performance of agriculture against multiple goals: economic productivity, environmental impacts, social costs and benefits, and resilience”.

2. Objectives

It is clear from this assessment of the literature that understanding, quantifying and communicating the potential environmental impacts of different approaches to achieving food security is vital if the scramble for global resources is not going to degenerate into a free for all, to the detriment both of the world’s poor and the environment. Nowhere is this truer than in Africa where the confluence of global resource pressures, population growth and development need will drive unprecedented food security pressures which could result in major stress on environmental resources.

This paper addresses these issues through a case Study of West Africa, quantifying and visualising the impact of different potential scenarios. Its objectives are to:

1. Quantify required changes in land use to achieve food security through to 2050 under different agricultural development pathways scenarios– using West Africa as a case study
2. Visualise land use changes in an easy and comprehensible way using Sankey diagrams
3. Assess the feasibility and resilience of each scenario to understand likely pressures on future food security, by quantifying impacts on ecosystem services and other resources.

3. West Africa Case Study

West Africa is vast, covering some 600 million ha (40% bigger than the EU27), comprising 15 countries (Figures 2) and supporting 300 million people (60% of the EU27).



Figure 2: West Africa: Region definition

It is one of the world's poorest and least developed regions, both economically and socially, with two thirds of the countries ranked in the bottom twenty of the UN's Human Development Index. Poverty is wide spread with poor performance on most of the millennium development goals. Its agriculturally based economy is dependent on small holder farmers, but productivity is low with almost no irrigation and very low levels of fertiliser (Aquastat and FAO databases). The region survives on below average calorie consumption while still importing 15% of its food (Riddell et al 2006), while unreliable rainfall and recurring droughts sparks food crises in the region (Gubbells, 2011). The result is that repeated food crises and chronic malnutrition are seen as endemic to the area, and the FOA classified 14 out of 15 West African countries as having "high vulnerability to food insecurity" through to 2050, based on the countries' wealth, population growth, per capita productive land and water availability, and climate change impact on crop potential (Fisher et al, 2007).

It is therefore a significant and clearly identified region which exemplifies many of the challenges to food security faced by the world's poor today – making it an ideal case study for this paper

4. Building the Scenarios

In this section the major building blocks and inputs for the scenarios are discussed in three parts: firstly, defining the basis of the 2030 and 2050 calorie targets; secondly, reviewing theoretical domestic calorie output potential, by land type and farming regime; and thirdly, defining the two scenario storylines and summarising the key assumptions for each.

4.1 Defining Calorie Targets for Food Security

Calorie targets were set for 2030 and 2050 based on population forecasts and average daily per capita calorie consumption consistent with “reasonable” food security as summarised below (Fig 3):

- The current population of 304 million is predicted to grow at 2.5% p.a., one of the highest growth rates in the world, reaching 740 million by 2050 (UN forecasts from AQUASTAT databases).
- Individual food security threshold requires some 2100 kcal/cap/day, but massive inequalities in access to food mean country averages need to be significantly above this level, (Gubells, 2011) so that West Africa's current level of 2600 kilocalories per person per day (kcal/cap/day) is recognised as contributing to the significant undernourishment and hunger (Gubells, 2011). The level broadly consistent with food security is around 3050 kcal/cap/day, which is the level typically consumed by “better off developing countries” (Bruinsma, 2009). This paper assumes this is achieved by 2050, which is also consistent with the 0.4% annual growth rate projection by Riddell and Westlake (2006)

Thus, the combination of population growth and calorie consumption increase will drive an almost three fold increase in total calorie demand by 2050, (Figure 3), adding some 8% to today's global food consumption

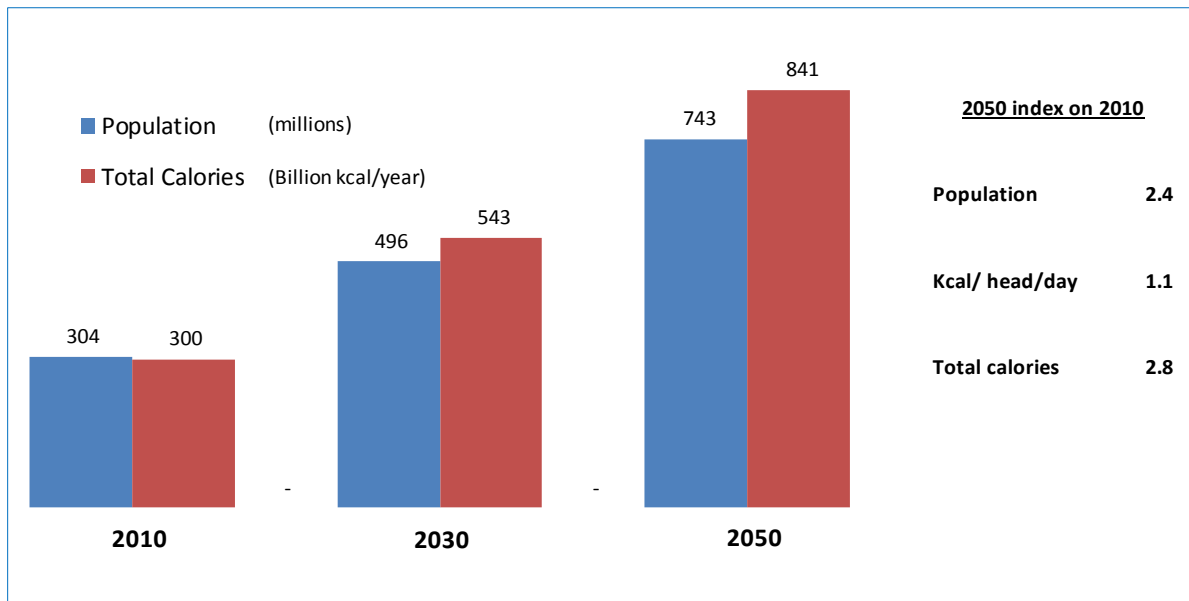


Figure 3: West Africa Population and Calorie Demand to 2050

4.2 Current and Potential Yields Under Different Farming Regimes

Understanding the region's "natural state" land type and soil quality is critical to determining the potential yields from that land and so the region's theoretical calorie output. It is particularly relevant for West Africa, where 40% of its huge area is effectively unproductive sparsely vegetated or barren land and, of the balance, divided 75% grass and woodland and 25% forest, only one quarter has good soil quality. The result is that only 15% of the region can be classed as high yield land, potentially suitable for intensive cultivation, severely limiting the region's theoretical calorie output.

In this paper we have used simplified land quality definitions consistent with the Global Agro-ecological Assessment (GAEZ), and used by Fischer et al (FAO TR02), to divide the forest and the grass and woodland areas into two "land suitability" types that reflect broadly a factor of two difference in yield potential: "prime and good (P&G)" (also known as suitable and very suitable (S and VS)) delivering 80% of maximum constraint-free yield and "marginal and very marginal (M&VM)", poorer quality land delivering only 40%.

Knowing that on average there is a factor of two between the different land classifications and combining it with the current calorie output and land types used, enables the current yield by land type to be calculated. Applying these yields to the remaining available land by type, enables the region's theoretical maximum calorie output at today's yields to be calculated (details of the calculation are in the text box). The results (figure 4) indicate that, using all productive land, the region's theoretical maximum calorie output at today's yields is some 850 billion kilocalories per year –

only just meeting projected calorie demand for 2050 of 840 billion kilocalories per year.

*The “natural state” is defined as the type of land (or biome) that would exist if the land had not been used (or disturbed, or converted) for other purposes, mostly agriculture or infrastructure, and has been estimated, based on the predominant land types in that country, and is consistent with known deforestation trends for the region

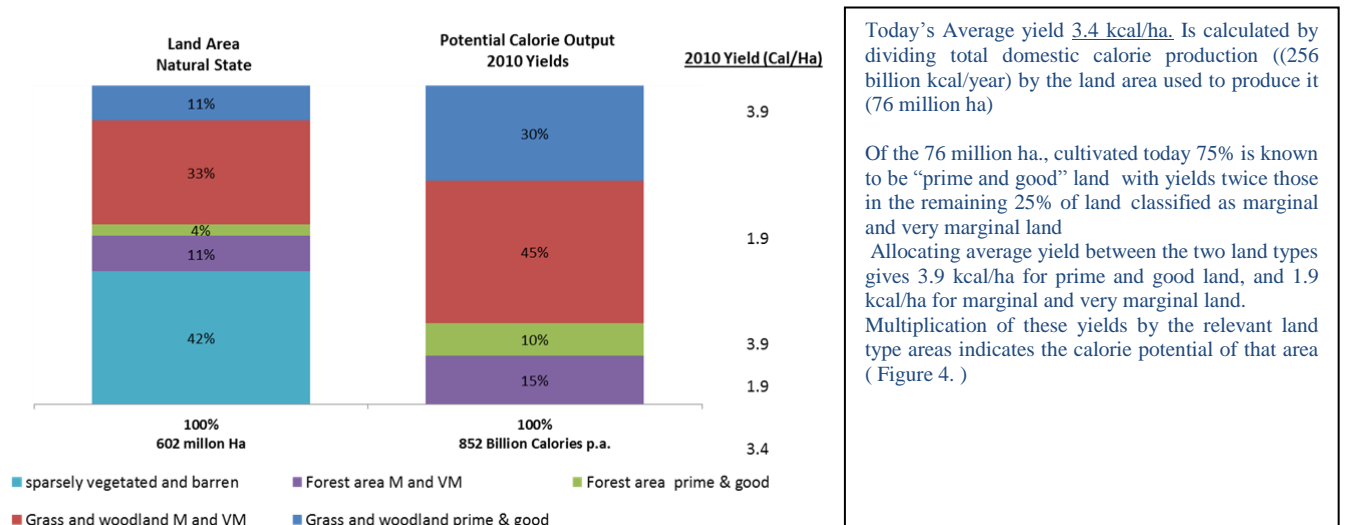


Figure 4: Natural state land areas and today's calorie output and yields

Fortunately, as Bruinsma (2009) argues, there is considerable potential to raise crop yields in developing countries, predicting that increased yields will drive “over 80% of growth in crop production”. Fischer et al (2007) go further and define actual versus potential yields for the region under two different farming regimes:

- Firstly, assuming a “low inputs” regime, with continuation of mostly rain-fed crops with few additional fertilisers, limited irrigation and traditional farming methods; it suggests that in Western Africa, actual yields are some 70% of potential yields (based on cereals), but higher at 94% based on all crops (Fischer et al, FAO TR02, p50), implying scope to close the yield gap and increasing calorie potential by 25% to 1110 billion kcal. p.a. by 2050
- The second, “mixed input” regime, represents a move to intensive farming using fertilisers and irrigation where required and optimising land management techniques and crop selection. Fisher et al (FAO TR02) calculate that a mixed inputs farming regime has the potential to drive a fourfold increase in yields vs. today where soil depth, soil nutrients and physical terrain allow the land to be intensively farmed. This “suitable” land is

broadly consistent with land classified as ‘prime and good’ (Fischer et al, FAO TR02) which accounts for around 30% of the remaining uncultivated land. Nonetheless the move to intensive farming is potentially transformative, more than doubling the region’s potential calorie output to over 2000 billion calories per annum (or implying a far smaller area to meet specific calorie targets)

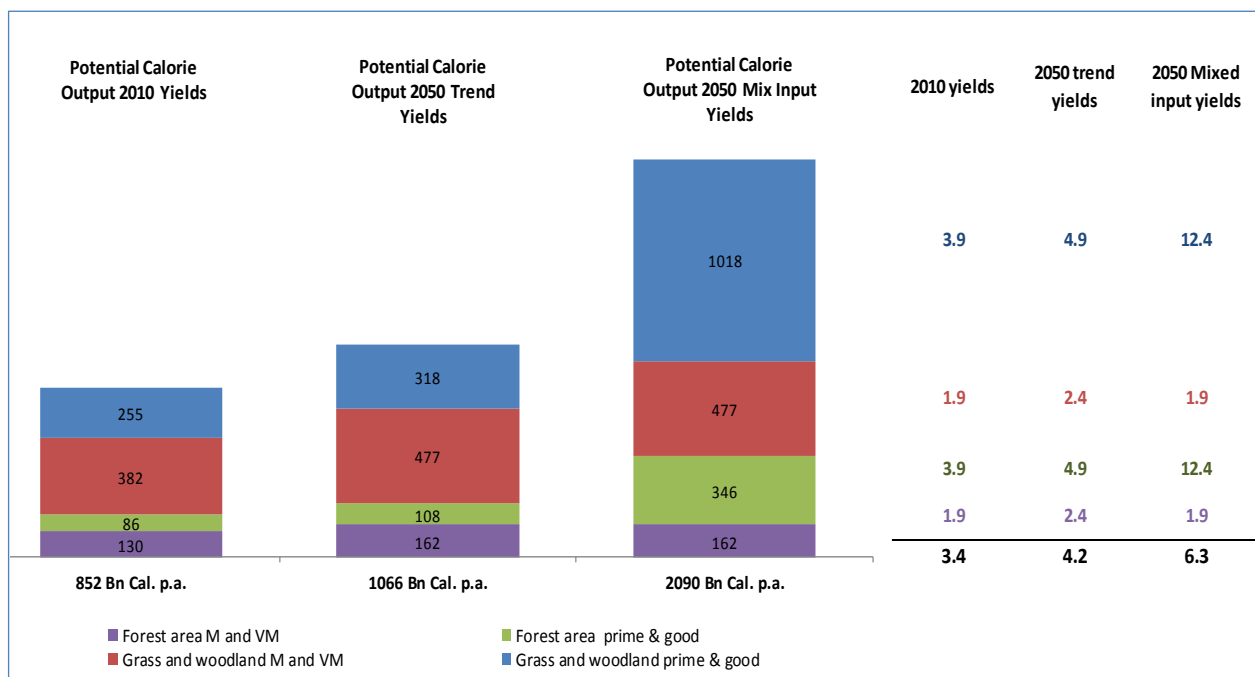


Figure 5: The move to intensive farming regimes could be transformative...

4.3 Defining and Building Appropriate Scenarios

We therefore need to develop plausible scenarios that reflect the very different potential development paths to meet the defined 2050 calorie demand that is consistent with food security for the region. Each of the scenarios represents a credible, internally consistent but opposing story line:

- Scenario 1 - Business as usual:** This low development scenario assumes the region continues to rely principally on rain-fed cultivation, with a continuation of current rain-fed yield trends and very limited inputs of fertiliser or increased irrigation. Consistent with this underdevelopment, “land grabs” are assumed to be constrained so that increases in land used for exports is limited.

- **Scenario 2 - High investment/mixed input:** The high development scenarios assumes that the substantial investment in agriculture, both for export and domestic markets, leads to a transformation of yields, based on mixed input farming (as defined in section 3.3) with its associated increases in irrigation, fertiliser usage and land management expertise. However, it also assumes that the urbanisation and increased affluence increases the consumption of meat with animals supported by locally grown animal feed.

Both scenarios assume that rapid urbanisation takes place; reducing land available for cultivation and, in response to global resource shortages and food price escalation, the region becomes more self-sufficient, with imports held at 2010 levels.

In addition to the quantification of current and potential yields, described in sections 3.1-3.4, a wide range of publicly available sources is used to define the current situation. Looking forward, inputs to the two future scenarios builds off this base, using historical trends and forecasts from the major agencies (FAO, UNEP etc.), as well as some of the author's own assessment of likely changes. The key assumptions are summarised in figure 6 and discussed in more detail in appendix II

Scenario Input Area	Scenario 1: Low development (Business as usual)	Scenario 2: High development (Major investment in agriculture)
Major agricultural method	Continued use of Rain fed (very limited fertilizer or irrigation)	Mixed inputs (irrigation, fertilizers, optimal crop management where soils allow)
Yield growth (CAGR %)	Continuation of Historical yield improvement trends 2010-30 0.7% p.a. 2030-50 0.5% p.a. (approx. 25% increase closes gaps vs. potential yield - Fischer et al, 2007)	For "prime and good land" (approx. 25% of cultivatable land) yields are assumed to increase by a factor of 4 vs. today. For all other land, yield growth assumed to be the same as Scenario 1
Imports of calories (% of total consumption)	Remains fixed at 15% of 2010 calorie consumption	Remains fixed at 15% of 2010 calorie consumption
Land area for Exports/non-food (million ha)	Known planned projects completed, but restrictions on land grabs implemented (2010 10; 2030 15; 2050 15 – all on "prime and good" land)	Extensive external investment (but managed, and with skills transfer) (2010 10; 2030 30; 2050 50 – all on "prime and good" land)

Dietary change vs. 2010	No significant change	40% increase in meat per capita consumption; land for feed increases to 10% of land: 25% efficiency of calorie production:7.5% yield impact
Urban land use (driven by population growth) (million ha)	Urban population grows 4 fold by 2050 (UN forecasts). Urban expansion at current density. (2010 10; 2030 15; 2050 15 – mostly on cultivatable land, near existing settlements)	As scenario 1
Water withdrawals (cubic kilometers p.a.)	Domestic consumption driven by urban population growth @ 150l/day. Agriculture irrigation driven by historic trend of 0.4% CAGR with 35% increase in water productivity (2010 28; 2030 61; 2050 88) – Irrigated area grows from 1 million ha in 2010 to 2 and 3 million ha in 2030 and 2050 respectively)	As scenario 1, but with extensive irrigation development (2010 28; 2030 177; 2050 349 – Irrigated area grows from 1 million ha in 2010 to 9 and 18 million ha in 2030 and 2050 respectively)

Figure 6: Key assumptions by scenario

Three other factors that potentially impact yield – wastage, land degradation and climate change – are assumed to have limited or unclear impacts within this timeframe. They have not been included in the scenarios, but are discussed further in Appendix III.

5. Results

The critical output from each scenario is its impact on land use. Sankey diagrams, which are a specific type of flow diagram, where the width of the lines is shown proportionally to the flow quantity, have been used to visualize land use evolution because they show both the evolution of different categories of land and identify the

dominant contributions to an overall flow (Sankey diagrams.com, (2013)), providing clear, sometimes stark, visualisation of change in land use.

Three diagrams are presented, firstly showing evolution from the region's natural land states to today and then separately its evolution to 2030 and 2050 for each of the two scenarios defined above. The final section draws a comparison between the two scenarios based on a set of four output metrics.

5.1 Current Situation

Starting on the left of the diagram, the land is divided into its major "natural state" (pre-cultivation) biomes of forest (15%), grass and woodland (43%), sparsely vegetated and barren (41%), and inland water (1%). Moving to the right, settlement and infrastructure and cultivated land use areas for 2010 are added. These biomes are then further subdivided: forest and grass and woodland are subdivided into two, based on the land's suitability for cultivation and cultivated land is divided between that for export crops (of any kind) and that for domestic calories; imported food is shown as avoided land, at equivalent yields. Finally, on the right of the diagram the land flows are re-grouped to show land available for Ecosystem services and other "used" land (for cultivation or infrastructure)

Today, only 16% (93 million Ha) of the land has been converted from its "natural state", split between cultivated land for exports (10%), infrastructure (7%) and domestic food production (83%), which is supplemented by imports equivalent to 13Ha (14%), at local yields, which has been termed "avoided land". It leaves a huge area of some 260 million Ha or 74% of all potentially cultivatable land still apparently unused, although only around 20% of this is "prime and good" land with high yield potential, and 63% of the region's forests still intact. This clearly provides a strong starting point for development and it is not surprising that investors see opportunity in the region's "wide open spaces" (figure 7).

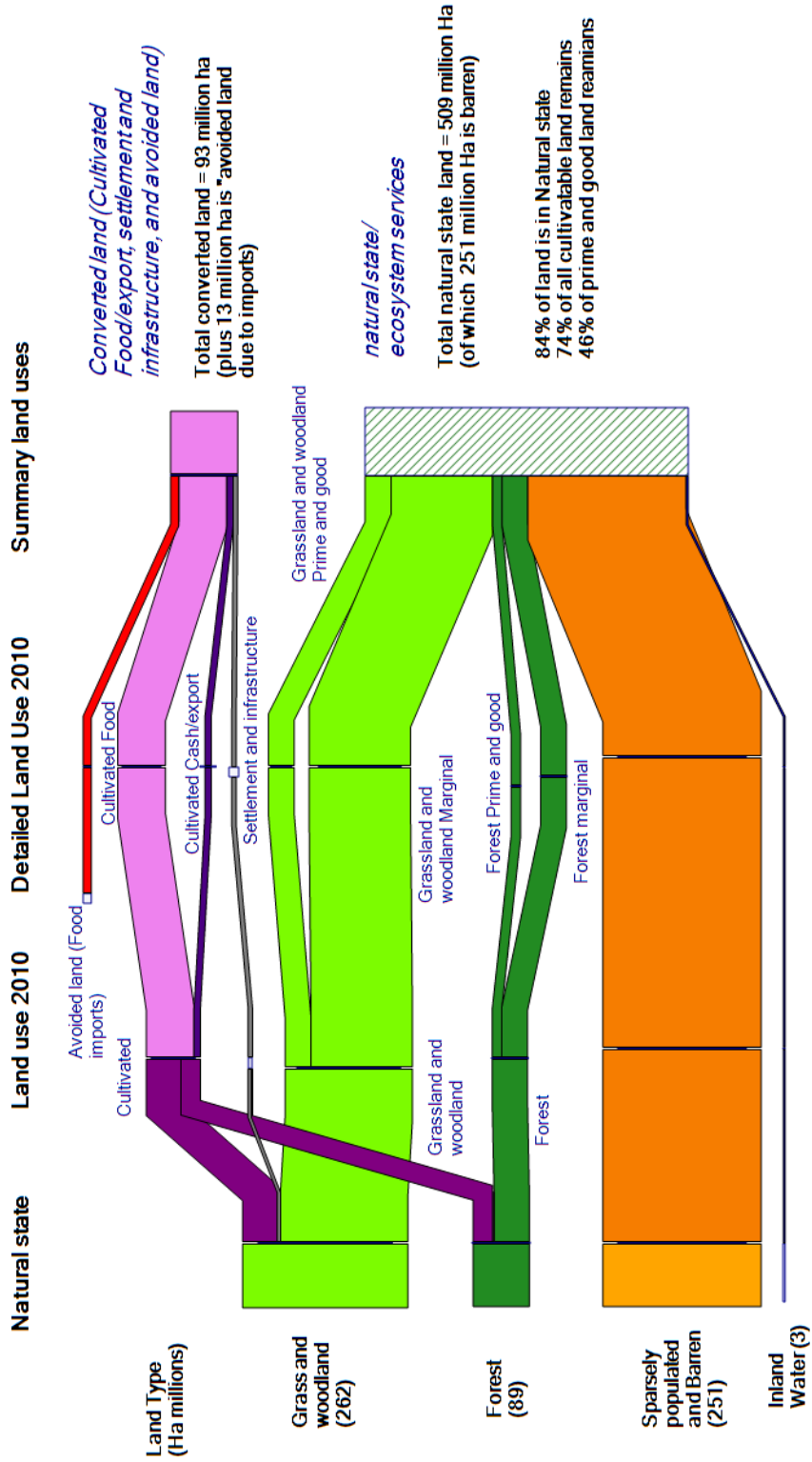


Figure 7: Land use Evolution from Natural state to today

5.2 Scenario 1: Low Development – “Business as usual”

In the Business as usual scenario, based on continued rain-fed production, we see a massive change in land use from today to meet the expected calorie demands in 2030 and 2050 (figure 8):

- In the next 40 years, a further 176 million hectares of natural state land will have been converted from its natural state, of which 85% (150 million ha) will be for domestic calories, with the balance split 10% for settlement and infrastructure and 5% for export crops.
- Land converted from its natural state will therefore increase from 16% in 2010 to 45% in 2050, leaving 55% of land available for ecosystem services; however, 75% of this land is low value sparsely vegetated and barren, 20% is grass and woodland and only 5% is forest (only 19% of the region’s forests remain)
- Critically, usage of cultivatable land increase from 26% in 2010 to 46% in 2030 and over 75% by 2050. As “prime and good” land is prioritised, it is largely converted by 2030 (10% remaining), and completely used by 2050 so that much of the newly converted land for cultivation from 2030 onwards is low yield “marginal and very marginal” land, accelerating the pace of land conversion.

5.3 Scenario 2: high development - “High investment/mixed input”

In contrast the high investment/mixed input scenario shows that heavy investment in agriculture, increasing yields by up to four times though increased use of irrigation and fertilisers on “prime and good” land, could be transformative (figure 9):

- By 2050, a further 80 million hectares of natural state land will have been converted from its natural state, of which about half (50 million ha) is assumed for exports, with the balance split evenly between domestic agriculture, and settlement and infrastructure.
- The percentage of land converted from its natural state will therefore increase by 13 points to 29% leaving some 70% of total land is available for ecosystem services, of which 35% (150 million ha) and 15% is forest (one third of the regions forests remain)

- 51% of all cultivable land remains unused with the majority of growth coming from dramatically increasing yields on existing and new “prime and good” land; unsurprisingly though, given its potentially very high productivity, almost 90% of the region’s “prime and good” land has been targeted for conversion, by 2050.
- The scenario assumes that the yield transformation from advanced farming techniques would be available by 2030, and illustrates the potential benefits with only an incremental 10% of all cultivatable land and forests being converted from the natural state.

However, although clearly less disruptive in terms of land conversion, the resource needs are substantial, as discussed in the next section.

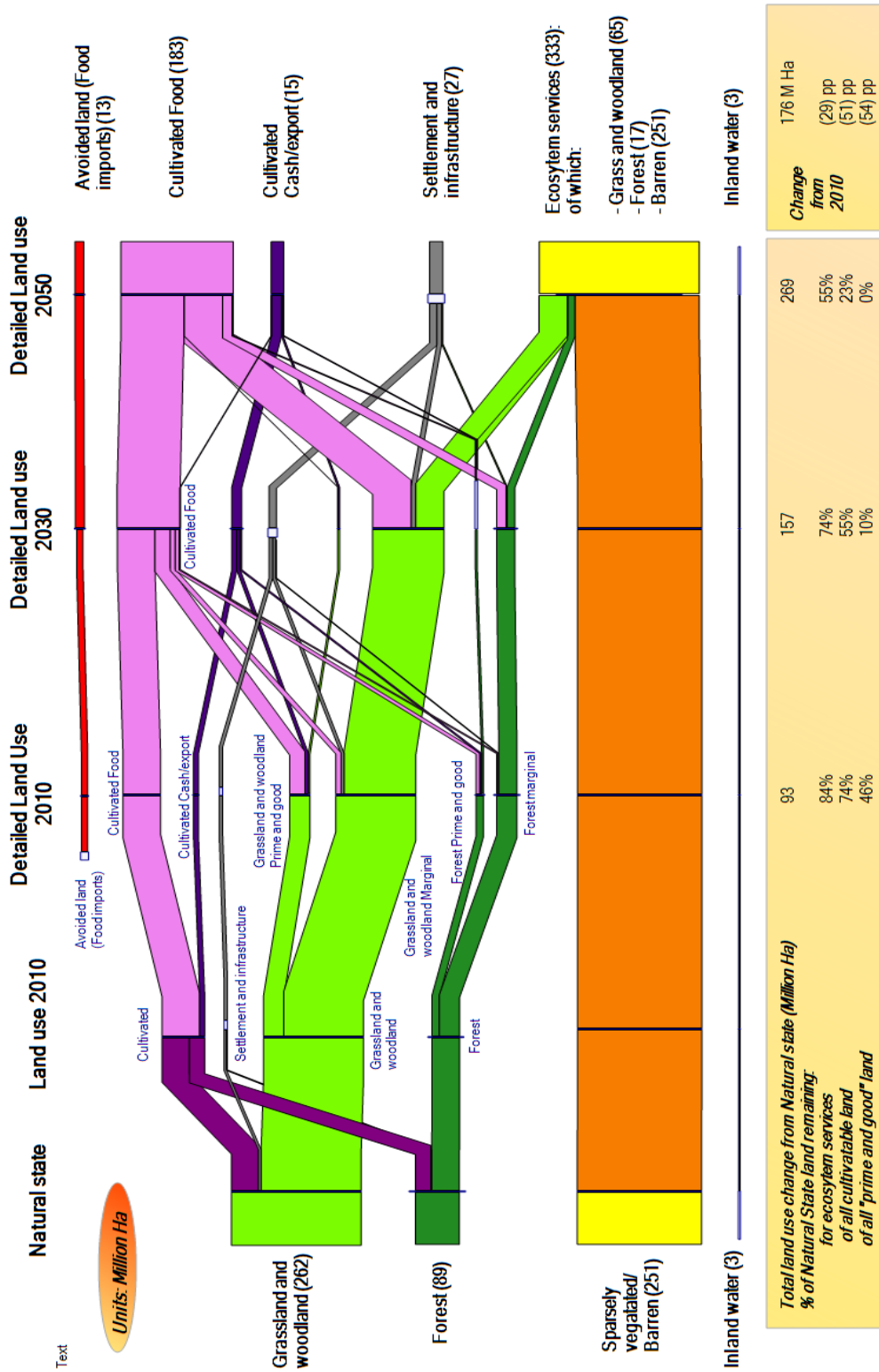


Figure 8: Land use evolution - Low development scenario

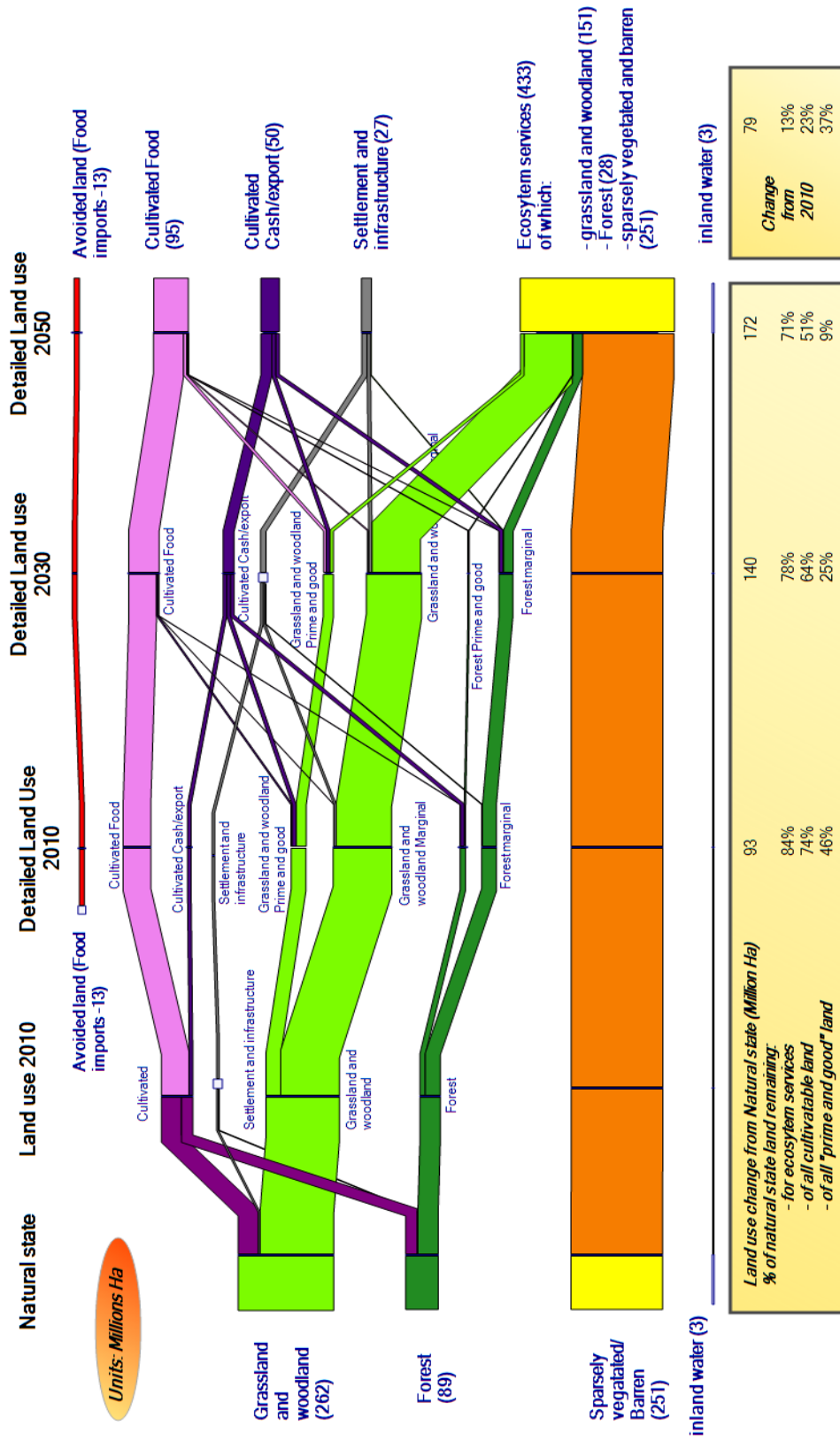


Figure 9: Land use evolution - High development scenario

5.4 Scenario Comparison: Key metric and Impacts

To evaluate the attractiveness of the radically different development pathways constructed to meet the region’s future calorie demand we need to assess both the resilience and feasibility of each scenario. Comparing four key output metrics driven by the scenario will help do so: land conversion, food security, ecosystem services and water usage.

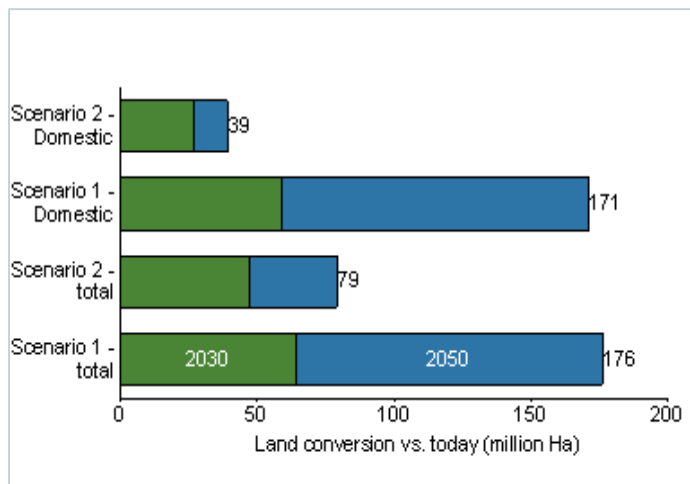
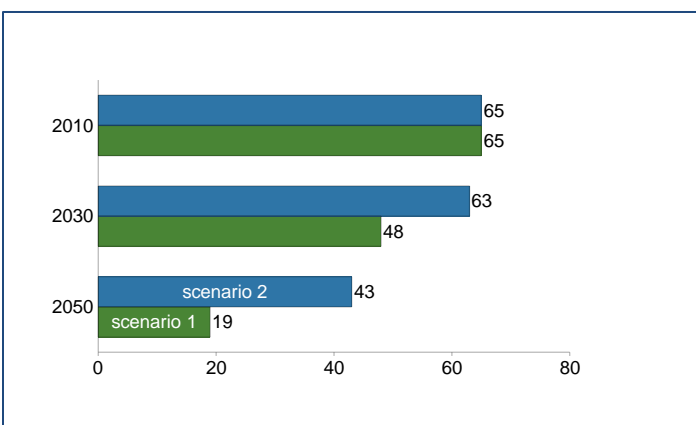


Figure 10: Magnitude of land conversion over time and by scenario

Land Conversion: The Business as usual scenario requires an additional 176 million ha of land conversion, adding more than two times today’s cultivated land and almost twice the 79 million ha required in the high investment scenario. In addition only 5 million ha of the land converted is for export crops in the low development case compared to

40 million ha (almost half of the land converted) in the high

development case.



Food security: To achieve food security (based on 3050 kcal/person/day) only 19% of the region’s maximum theoretical “capacity” is left in the business as usual scenario to produce sufficient calories by 2050, versus less than 43% in the high investment scenario (where the region also has an additional 35 million ha of land for export crops potentially available).

Figure 11 : Unused calorie potential as % of maximum theoretical capacity

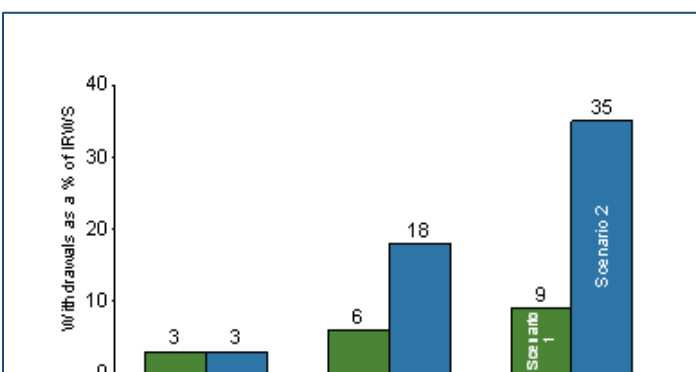


Figure 12: A ten fold increase in water withdrawals implies significant water stress issues

Water availability: Total withdrawals increase 3 fold in the business as usual case, driven by both domestic and agriculture but are still low at 9% of IRWS (internal renewable water sources). However, in the high investment

mixed input case, likely requirements to increase irrigated areas by some twenty fold to around 20 million ha, would result in a 10 fold increase in withdrawals to 35% of IRWS, implying a water stress indicator (WSI) of 0.48 indicating moderate water stress (Smakhtin et al, 2004).

Nonetheless, for both scenarios the increase in population of 2.5 times, by 2050, reduces the blue water per capita figure to below 1700m³/capita, which Schoul et al (2008) consider indicative of countries likely to suffer from water stress.

Environmental cost (figure 14): Land in its natural state supports ecosystem services delivering multiple benefits to human well-being, including nutrient recycling, pollination, maintenance of genetic diversity, social amenity and flood control and water supply protection (TEEB 2012 p25). Using the approximation, supported by TEEB (2013), that all services are lost when converting land from its natural state to agricultural use and using values from TEEB (2012, 13) an implied cost of land conversion for different types of land can be calculated and the impact of each scenario on ecosystem service value (ESSV) calculated. For the low development scenario, almost half of the region's natural state ESSV is lost (dropping from 68% of the natural state remaining today to 21% in 2050) or some \$84 billion. It is also worth noting the declines in ESSV accelerate during the period, being almost twice as fast after 2030 as good land is used up. This compares with a decline of \$50 billion for the high development scenario, which is evenly distributed across the period and leaves twice the ESSV, or 40% of the region's natural state ESSV, remaining in 2050. Nonetheless, achieving this requires not only inputs of water as seen above, but an estimated 6 million tonnes of fertiliser, based on an application rate of 50kg/ha (UNEP, 2011) on the 120 million ha of prime and good land, compared with less than 400,000 tonnes in the low development case.

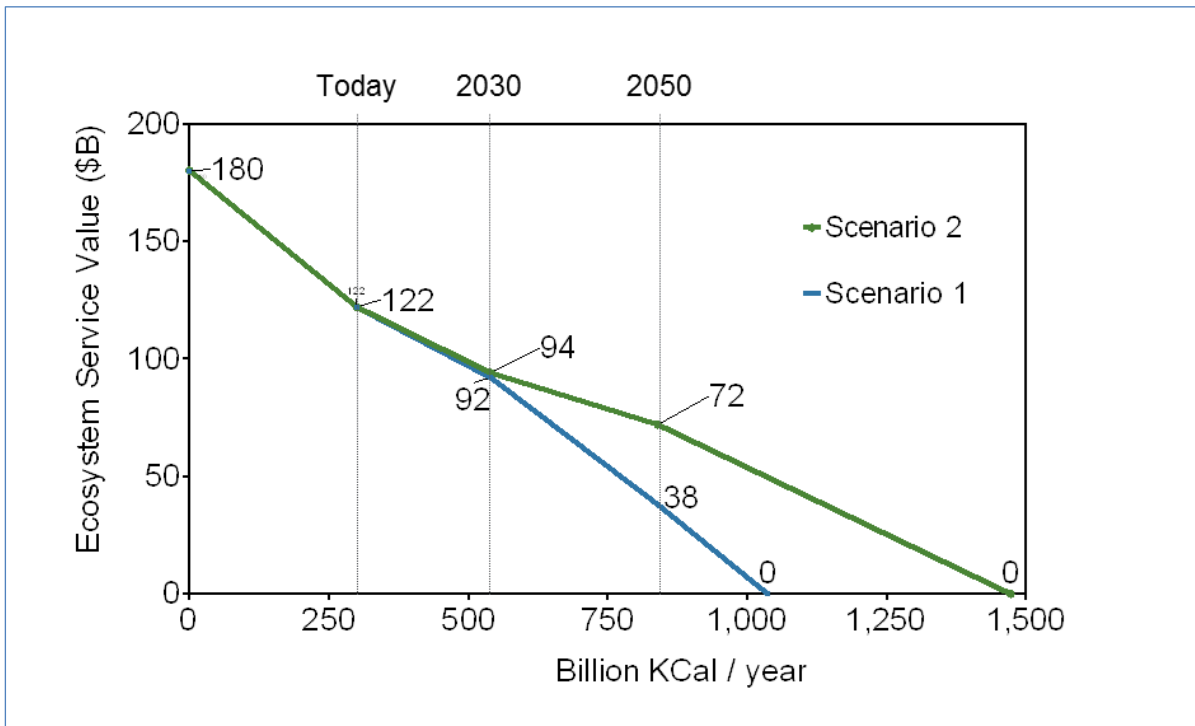


Figure 13: Land conversion results in major loss of ecosystem services value (ESSV)
 Indicative cost of land conversion, assuming all ESSV is lost and assuming an ESSV of some \$230/ha for Grass and woodland and \$1400/ha for forest area. TEEB (2012, 13)

6. Discussion, Implications and Key Measures

6.1 Discussion of Scenario Resilience and Feasibility

Based on these two scenarios, future food security in West Africa therefore appears highly precarious, with both scenarios having major apparent flaws.

In the low development “business as usual” case the land use of the region is totally transformed with 50% of all cultivatable land, an area about half the size of EU-27, converted, leaving less than a quarter of non-barren land in its natural state, and all its highly productive land in use. With 80% of the region’s calorie production capacity the region has few reserves to deal with natural variability in output, including from changes in rainfall patterns, or the expected 25% reduction in yields on rain-fed crops by 2080 from climate change impacts (Cline, 2007). In addition the sheer magnitude of the change will drive negative feedbacks that could reduce yields and calorie output: overgrazing and land degradation as “enclosure” of two-thirds of today’s grass and woodland reduces common land for low level grazing; reduced water supply buffering and flood control as lower vegetation densities associated

with conversion of natural state land to agriculture typically reduce the evapotranspiration rates from that land and reduce its capacity to store water (Weiss et al 2009). Thus resilience to natural and man-made stresses is low and the sheer scale of land conversion is likely to precipitate negative feedbacks making the scenario unsustainable

The high investment case, based on transforming yields through high input, advanced agriculture improves the outcome on land conversion, but the intensification requires a twelve-fold increase in water extraction that is likely to stretch the region's uneven water resources resulting in significant local shortages, and increased fertiliser usage of some 6 million tonnes p.a. will impact water quality through nitrogen runoff, and generate 20-80 tonnes of CO₂e. Finally, the ability of local soil to support this level of intensification has not been proved on a large scale. Even if the natural resource implications could be managed, the scale, political will, cooperation and affordability of this transformation requires major intervention from all stakeholders, as discussed below.

6.2 Implications and Key Measures

The region faces the stark imperative to triple its domestic calorie output, over the next 40 years to ensure adequate food security for its burgeoning population. This massive transformation requires a combination of land conversion and agricultural intensification (yield increases), resulting in a level of damage to eco-system services and resource depletion, under a wide range of scenarios that could threaten the resilience of the result. UNEP (2011) concurs, arguing that “business as usual is not an option” and that there is a chronic need for investment in agriculture in Africa, particularly in R&D to optimise crop management and increase yields and counter climate change impacts.

Action is required now to drive sustainable intensification and minimise impact of land conversion; the consequences of unchecked land conversion and stagnant yields are already being felt and likely to be irreversible by 2030 when, assuming business as usual, 90% of prime and good land could be used and over 50% of the region's natural forest converted. The key measures are shown in figure 11, and summarised below.

Drive sustainable intensification: Improving the region's food security requires investment in higher input farming to step change yields. However, 20th century methods based on high fertiliser and pesticide input, and water intensive irrigation may undermine critical eco-system services that support current yields (Foley et al,

UNEP (2011)), overstretch water resources, or simply be unaffordable to the region’s predominantly small holder farmers. There needs to be a different way. UNEP calls for support in developing diversified and resilient eco-agricultural systems that provide the critical eco-system services (including biodiversity, pollination, water supply and regulation and pest control) as well as adequate food. Realising this will need greatly enhanced expertise to optimise land management and crop selection, developed irrigation infrastructure, affordable and available fertilisers, and access to the best land. It means investments now in agricultural R&D, investment and inter-country cooperation to secure access to the region’s mostly shared river basins for irrigation, and financial and educational support for the region’s small holders, including a more holistic approach to soil management that makes fertiliser available and affordable (UNEP 2011).

Minimise impact of land conversion: Even with highly successful intensification of existing agriculture, the scenarios show that most of the suitable land for intensive agriculture will be needed to support domestic food supply by the middle of the century. At the same time competition for land will increase, from both urbanisation, cash earning export crops, and more insidious land “grabs” from land poor regions including Middle East and China. Of particular concern are the region’s forests, including high value biodiversity hotspots, which are likely to come under intense pressure as conditions for palm oil, coffee and cocoa are excellent, offering strong commercial returns (often supported by the IMF as part of its Structural Adjustment Programmes). The region needs a long term plan to prioritise and manage competing land-use, with clear governance that protects its most valuable eco-systems, as well as developing a long term system based approach to development planning.

Key measures to reduce eco-system services damage and resource depletion	
Drive Sustainable Intensification	Minimise impact of land conversion
Build expertise <ul style="list-style-type: none"> - Fund agricultural R&D - Develop eco-agricultural approach - Smallholder education/ training - Knowledge transfer 	Land use prioritisation: <ul style="list-style-type: none"> - Natural capital costing by land type - Identify prime and good land - Long and short term plan - Domestic calorie focus
Yield focus <ul style="list-style-type: none"> - optimal crop selection - high yield/resilient seed varieties - fertiliser management - Close yield gaps on cash crops - Renovation of old plantations - Mixed plantations 	Land use change governance: <ul style="list-style-type: none"> - Stop land “grabs” - Urban expansion controls - Export crop opportunity cost analysis - Protect biodiversity hotspots - reduce land degradation (overgrazing)

	<ul style="list-style-type: none"> - push land rehabilitation measures
Integrate water management <ul style="list-style-type: none"> - Irrigation infrastructure - improve irrigation efficiency - rain water harvesting 	Total system approach including: <ul style="list-style-type: none"> - reduce post-harvest losses (infrastructure) - design adequate, varied nutrition infrastructure (water supply, transport) - population planning (key lever, beyond scope of this paper)
Smallholder support <ul style="list-style-type: none"> - Fairtrade/ floor prices - Market access infrastructure 	

Figure 14: Table of Key Measures

6.3 The Right Tools

To implement the key measures above and ensure the right decisions are made, an enhanced set of tools is needed that works on both water and land at the right level of granularity, quantifies economic trade-offs (valuing natural capital) and provides easy communication (Figure 12). This paper illustrates one approach that starts to address some of these needs, specifically by visualising land use change using Sankey diagrams and using key metrics to quantify other environmental impacts. Much more work is needed to fulfil the requirements, however, especially to capture ecosystem service changes.

Requirement for new tools	
<i>Right system scope and granularity</i>	<ul style="list-style-type: none"> • Manage land use and water together in an integrated approach. • Work at multiple levels –regional, national, local. (eg water impacts can be very local but also are driven by total river basin’s supply which are often cross border)
<i>Quantified, economic trade-offs</i>	<ul style="list-style-type: none"> • Measure the ecosystem impact (loss of natural capital) from land use changes and intensification. (The Economics of Business and Biodiversity (TEEB, 2013) identified cattle ranching and farming in West Africa as one of the top 100 natural capital risks worth \$25 billion) • Identifies the optimal land for development based on both its potential calorie output and its natural state ecosystem service value; specifically prioritising high yield areas with low ecosystem service value. (c.f. Nelson et al (2010) methodology to assess biodiversity and water resource impacts from land use changes, building off the global database at grid cell level.) • Calculates the opportunity cost for export cash crops to ensure economic rents
<i>Easy Communication</i>	<ul style="list-style-type: none"> • Communicate scenario impacts through easy visualisation with key metrics to evaluate trade -offs

Figure 15: Requirement for new tools to drive optimal land use

7. Conclusion

The immediate conclusions from this paper are stark: for much of the world’s poor the combination of population growth, development need and global resource pressures means that food security through to 2050 will remain a huge challenge. Two example scenarios from West Africa show that neither an incrementalist “business as usual” approach, nor a conventional high input intensification route would deliver long term food security as the scale of damage to natural capital through land conversion and resource usage undermines resilience and, to some extent, the feasibility of the output.

The implications from this analysis are that to reduce eco-system services damage and resource depletion a range of key measures need to be introduced that, firstly, foster sustainable intensification, including investing in expertise, increase yield focus, integrating water management and supporting small holders and, secondly, limit damage from land conversion through clear land prioritisation and better land use change governance in the context of an overall long term development programme. Specifically, it quantifies the dangers of the current “land grabs”, especially where the region’s high quality land is effectively given away, and highlights global food companies’ responsibilities to invest in yield productivity – especially for crops based on land types with high ecosystem service value.

The work provides quantified support to the calls from the leading agencies (FAO, UNEP and others) for the development of diversified and resilient eco-agricultural systems. It argues that to implement these measures successfully a range of new tools needs to be developed to facilitate the evaluation of different development pathways and find the optimal trade-off between calorie generation and depletion of ecosystem services and natural capital, specifically water resources. The use of Sankey diagrams to visualise land use evolution, coupled with key metrics relating to ecosystem service values and water resources, are a useful start here which, when coupled with quantified inputs based largely off existing global databases, can bring real insights relevant to policy makers and business.

Appendix I – Methodological Considerations

The approach and methodological considerations can be divided into six steps as summarised below.

1. The relevance, focus and feasibility of the approach were determined from a review of existing literature. This identified that although many global studies cover the implications of food security on land and water resources, few focused on the world's poor regions, incorporated a full range of factors or provided easily understood visually compelling conclusions. At the same time extensive fundamental work has been done to develop relevant data bases and projections for the key drivers of food production, including calorie output and yields at country level and below. The approach therefore needed to take a regional approach, focused on the world's poor, but uses multiple existing data sources and forecasts to create quantified scenarios.
2. To provide more general insights, a case study approach was used because it develops both insights for that specific example and creates learning that can be generalised to be relevant elsewhere (Stake, 2000). As discussed, West Africa was chosen as it is both a significant, clearly identifiable region that is highly representative of world's poor, facing food security challenges.
3. A scenario approach was chosen where scenarios are defined as “plausible, challenging and relevant stories about how the future might unfold” (Raskin et al. 2005), and are not intended as forecasts or predictions which are simply not credible given the complexity of the systems and long timescales involved. The approach comprises two steps: firstly, the long term calorie consumption targets based on existing population growth forecasts and with per capita consumption levels consistent with food security were developed (section 4.1) as a *predictive* scenario (Borjeson et al 2006), as both can be relatively confidently predicted; and secondly, two credible and internally consistent scenarios for agricultural development that meet the proposed calorie targets in 2030 and 2050 were developed as *normative* scenarios, asking how this target can be reached in terms of land use change. This use of two very different but realistic scenarios with storylines “characterised by opposite driving force pathways” is seen as an effective tool to explore alternative future developments (Weiss et al 2009).

4. Quantified Inputs to the scenarios were based largely on existing public data from the major agencies (UN, FAO, GAEZ), which is available at country level. For the current situation, data, including population, calorie consumption import dependency, current land usage, soil quality and yields were taken directly from public databases. Then for each scenario inputs covering changes in food imports and land use for non-food and exports, yield improvements by land type, and implied land conversion to meet the calorie targets were defined using a combination of existing projections, soil technical limits (GAEZ) and the author's assumptions. (section 3.5)

5. The results were presented using a combination of Sankey diagrams to help easy visualisation, and key metrics defined to aid direct comparisons. Sankey diagrams are a specific type of flow diagram, often used to show energy or material transfers in closed systems, where the width of the lines is shown proportionally to the flow quantity. In this case they have been used to represent the evolution or "flow" of different land uses over time, starting from the land in its natural state and showing evolution of different categories of land into cultivation and settlement for today (2010) and 2030 and 2050, making explicit where different sources of land conversion come from. The visual emphasis this gives helps identify the dominant contributions to an overall flow (Sankey diagrams.com, (2013)) and provides clear, sometimes stark, visualisation of change in land use.

6. Comparison of key metrics of the two scenario approaches covering land use changes as well as impacts on other resources such as loss of ecosystem service value, water and fertiliser requirements to establish the scenario's resilience, feasibility and the implications for achieving food security including the likely key measures to achieve it and the required tools to optimise the approach.

Appendix II – Discussion of Scenario Inputs

- **Yield growth:** The assumptions are based on the theory discussed in section 3.3. For rain fed production (with no added fertiliser), historical rates of yield improvement of 0.7% p.a. are expected to continue through to 2030, and then slow to 0.5% p.a. to 2050 driving some 25% increase in yield by 2050. In the high input scenario, land classified as “prime and good” sustains a four-fold increase in productivity by 2050, through the use of irrigation, increased fertilisers and land management. (New land for domestic agriculture uses 75% “prime and good” land in line with existing cultivated land and a check was made to ensure that sufficient prime and good land is available).
- **Imports of calories:** West Africa is currently importing around 15% of its calorie requirements, mostly in the form of cereals (Riddell et al 2006), and effectively “avoiding” some 13 million hectares of domestic land conversion for agriculture, assuming current local yields. UNEP (2011) sees this level of import dependency as high, and argues that for Africa’s low income countries (all of West Africa), volatile and rising global food prices make increasing imports unaffordable and undesirable. In addition logistics costs can almost double the price of imports vs. local grain (Gubbels, 2011). This would increase the vulnerability to food crises for low income households which “depend on the market for food” (Gubbels 2011, p82). Gubbels goes on to argue that increased food sovereignty is critical in achieving long term resilience. Increasing import therefore is seen as both undesirable and unaffordable so imports have been assumed to remain at 2010 levels, reducing as a percentage of overall demand
- **Land for Exports:** Favourable growing conditions and the availability of cheap land in West Africa has already resulted in increased use of land for exports or non-food production, particularly cocoa, but also coffee, palm oil and cotton which account for some 10-15 million hectares, most of it based in forest lands, and largely responsible for the 20% decline in West African forests since 1990 (FAO, 2011 state of forests). Although demand is increasing for all these commodities, there will be strong pressure to limit further incursion into forests that are home to some of the world's most diverse and productive ecosystems, and multi-nationals, such as Mars, are already focused on improving yields on existing land (Business Week, 2012).

For the low development scenario, land grabs for exports are assumed to be curtailed as pressure on domestic land grows, and assumed to increase only 50% above 2010 levels, mostly accounted for by land deals already in the system. This lack of international investment is seen as consistent with an undeveloped domestic agriculture.

In the high development scenario, substantial international demand and investment is expected to continue and although growth depends on a range of largely unknowable factors (local governance, international policy on biofuels etc.), the assumed five-fold growth to 50 million ha is only two thirds the rate of the 8 million ha of documented land deals since 2008 (Anseeuw, 2012). These investments are assumed to be well managed, and so capable of providing both the finance and expertise to transform domestic agriculture (Friis et al).

- **Dietary change:** Urbanisation and increased wealth are associated with increased meat consumption which Wirsenius et al. (2010) anticipate will grow 30% globally by 2030. Its impact on calorie output is dramatic as about 5-10 times more cultivated land is required to produce feed for livestock to produce the same food energy content as cereal production (Fischer et al, TR02, p39). Lack of investment and agricultural development is likely to limit growth in domestic meat consumption and no significant increase from 2010 levels has been assumed.

In West Africa, many existing cattle are supported through low intensity grazing on grassland (Fischer et al, TR02, p.39). However, with major pressure on this land, feedstock is expected to increase its share of land from 4 to 6% by 2030 (Riddell et al, 2006) and occupy 10% of cultivated land (or between 10-15 million hectares) by 2050. As land used for animal feed delivers only 25% of the calorie potential of arable crops, there is a 7.5% reduction in effective yield.

- **Urban expansion:** Continuation of migration from rural areas is expected to drive rapid urbanisation and an almost fourfold increase in the urban population to 0.5 billion people by 2050 (70% of the population) (Aquastat database). Assuming a similar population density to today, urban developments will increase from 7 million hectares today, to occupy some 27 million hectares or 8% of potentially cultivable land by 2050.
- **Water withdrawal:** Domestic and commercial withdrawals are assumed to increase dramatically, driven by urbanisation and increasing access to safe water and sanitation, as well as economic growth, and are the same for both scenarios. A per person rate of 150 litres per day for the urbanised population has been assumed based off average usage in middle ranking economies (and half of typical European levels) giving an 18-fold increase in domestic water withdrawals. Commercial withdrawals also increase in line with domestic usage giving a total non-agricultural usage of some 50 km³.

Irrigation levels are also very low, but still account for some 80% of current usage. In the Low development scenario this is assumed to continue to grow at historical rates of 0.4% per annum. However, increasing irrigation is a key enabler to boosting yields on “prime and best” land. FAO’s assessment (Aquastat database), identifies 9 million ha suitable for irrigation, which is 9 times current usage, but still only around 10% of all prime and good land and if fully irrigated at current levels would use some 2.5 times the region’s “blue water” (Internal Renewable Water Sources - IRWS) . For the high development scenario, therefore, this potential is assumed to be fully utilised by 2030, and doubled by 2050 (in line with increasing land conversion). In addition, water productivity is expected to reduce usage by 35% by 2030. The result of these assumptions is that water withdrawals for irrigation increases 15 fold to 300 km³ and a total of 350 km³ or 35% of total IRWS. However, given that rainfall varies by a factor of ten across the region, it is not possible to predict with accuracy where irrigation is needed, and the assumption may well be an underestimate.

Appendix III - Other Impacts on Yield (Not Included in the Scenarios)

Three other factors are known to have impact on yields, but have not been included in the analysis at this stage for the reasons discussed below:

- a) **Land degradation:** degradation occurs because “unsustainable practices in irrigation and production may lead to increased salinization of soil, nutrient depletion and erosion” (UNEP 2013, p42). UNEP argues that “Africa is perhaps the continent most severely impacted by land degradation” with higher than average mean loss of yield of 8% from past soil erosion. Limiting land degradation has been an on-going battle for over 30 years, with widespread degradation already recorded by 1990, particularly in the Sahel, driven by changes in rainfall patterns and overgrazing. Thus, much of this degradation had already taken place before 2000 and is included in the starting point soil assessments by GAEZ used in the analysis. Looking forward, future degradation trends are uncertain and have not been included in the analysis for several reasons: although recent increased rainfall has improved vegetation, future direction of rainfall trends is unclear; rehabilitation through tree planting, sustainable farming practice and groundwater replenishment has achieved significant successes, with experts predicting wide scale reversal of land degradation (UNEP, 2006)
- b) **Food wastage:** reducing losses in the supply chain from “field to fork” is seen as a major way to increase effective output. Current estimates by Gustavsson et al. (2011) indicate that 150 kg/capita/year of food is lost in SSA, mostly in the supply chain, with losses varying between 18% for cereals to around 40% for fruit and vegetables. Losses are driven by premature harvesting to meet immediate cash or food needs and lack of suitable storage infrastructure and processing capacity. This represents a gap of between 5-40% versus best in class losses in the developed world. However, with widely varying results both by region and product, the ability to close the gaps is uncertain and Gustavsson et al. (2011) do not attempt to estimate potential reductions. Since UNEP, (2011) also argues that “further research in this area is urgent”, no assumption for food waste reduction has been included in the analysis.
- c) **Climate change:** Based on the results from the UK HadCM3 model for the 2050s for an emission pathway of the IPCC SRES A2 scenario, the increased percentage of land falling into arid and semi-arid climatic zones in Africa is relatively small at 2-3% of cultivatable land – effectively taking 7 million hectares out of use. In addition, modelling of the same scenario indicates

yield declines of 5% for low input crops but almost no impact when mixed input and adapted crops are used (Fischer et al, FAO TR02, p46-48). Cline (2007) models impacts through to 2080, where significantly higher temperatures and lower precipitation could reduce yields by some 30% for the northern parts of the region (Niger, Mali) and some 15-20% for Coastal countries (Cote D'Ivoire, Nigeria): adding carbon fertiliser reduces losses by around 10-15% in each case. In the timeframe of this analysis (2010 to 2050), climate change impacts appear small and have not been included, but longer term impacts are recognised as significant (section 5.1).

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