AWESOME

WATER-ECOSYSTEM-FOOD

DYNAMIC AND SPATIALLY DISTRIBUTED CROP WATER USE MODELING

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LIST OF ACRONYMS

BW	Blue Water
CORDEX	Coordinated Regional Downscaling Experiment
CHIRPS	Climate Hazard Group Infrared Precipitation with Station
CPC	Climate Prediction Centre
CWR	Crop Water Requirement
D	Abstraction
ET	Evapotranspiration
ET0	Reference evapotranspiration
ETa	Actual evapotranspiration
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GW	Green Water
Kc	Crop coefficient
Ks	Stress coefficient
NRB	Nile River Basin
P_{eff}	Effective precipitation
R	Runoff
RAW	Readily Available Water
RCP	Representative Concentration Pathway
SDGs	Social Development Goals
SSP	Shared Socio-Economic Pathways
TAW	Total Available Water
UN	United Nations
WEF	Water-Ecosystem-Food
WP	Work Package

EXECUTIVE SUMMARY

Task 2.3 within WP2 aims at calculating crops' water needs and crop production under current climate conditions and in future climate scenarios. The case study includes the main countries of the Nile River Basin (i.e., Egypt, Ethiopia, and Sudan), with a focus on Egypt, as the demo-sites of the AWESOME project are being implemented there. The analysis aims at evaluating if local crop production can satisfy the population demand under different climatic and demographic scenarios. To evaluate crop water needs and the amount of irrigation water used for agriculture, we adopt a spatially explicit approach, which allows accounting for potentially competing water uses (i.e., agricultural, domestic, and industrial) and ecosystem preservation. First, we set a baseline scenario to represent the current climate conditions and current crop distribution (averaged for the period 2011-2016) and quantify blue and green crop water requirements, which are the volumes of water needed to cover crop's evapotranspiration during the growing period without experiencing water stress. Green water (GW) requirements are met by the precipitation available, while blue water (BW) requirements are met by irrigation when precipitation alone cannot completely satisfy the crop requirements. Data have been retrieved by public datasets and official reports. Later, a crop reallocation algorithm was implemented to explore the self-sufficiency in agricultural production, for different diet and intensification scenarios. The analyses have been carried out using future climatic data for the average period around year 2050 (2048-2052) and year 2100 (2096-2100) under three different Representative Concentration Pathways (RCPs): RCP 4.5, RCP 2.6 and RCP 8.5. The climate data were produced within T2.2 of WP2 and presented in the previous Deliverable D2.2, while future population projections follow the Shared Socioeconomic Pathways (SSPs) and are presented in Deliverable D2.1. Our analysis shows that a strategic crop reallocation, coupled with a balanced diet and agricultural intensification, generates a positive impact on food self-sufficiency while preserving an excessive consumption of blue water both in the present and future scenarios.

1. INTRODUCTION

This report describes the results of the analyses conducted within Task T2.3 - Crop modelling of Work Package 2 (WP2) of the AWESOME project. WP2 focuses on the generation of plausible future scenarios for simulating water, food, and energy demands and projected climatic conditions, including the ecosystem services assessment and the analysis of related international policies. The output of WP2 will serve to evaluate the impacts of these projections on the Water, Energy, Food, and Ecosystems Nexus at the meso level in WP4, by providing input to the decision-analytic framework of the Nile River Basin (Figure 1).

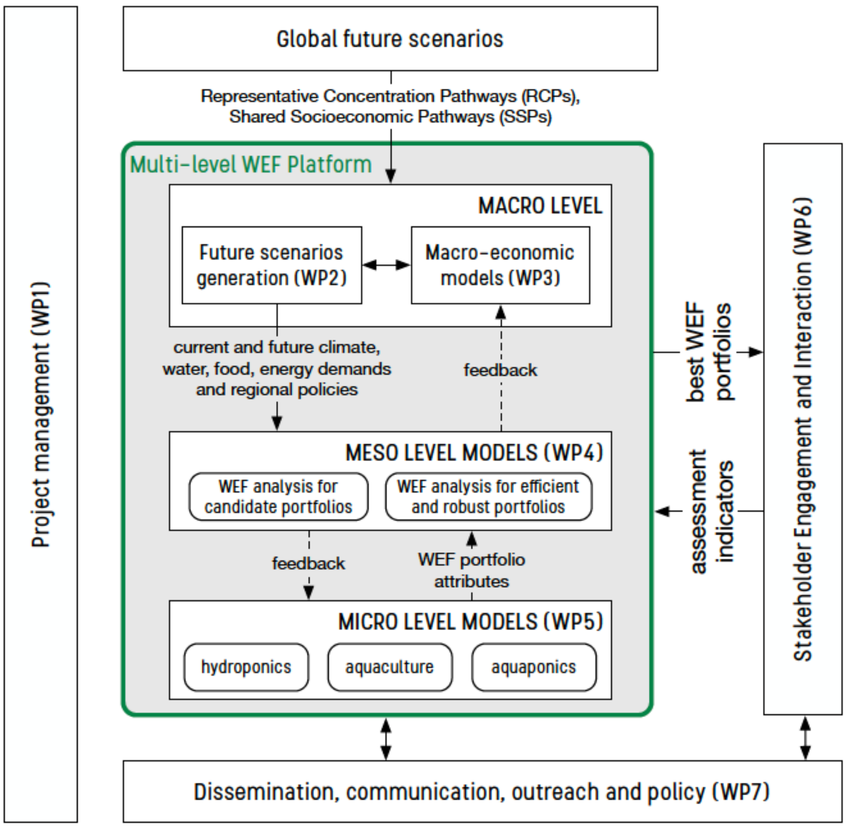

Figure 1 – AWESOME project structure.

The output of WP2 will also be used by WP3 to assess the economic impact of natural water shortage through a Computable General Equilibrium Model for a comprehensive analysis of macro-economic implications for the Mediterranean region focusing on WEF Nexus. In particular, WP3 will integrate outputs of WP2 in order to evaluate WEF Nexus at the regional and country scale. As a part of this framework, T2.3 aims at simulating current crop water demand, generating future projections coherently to the climate outputs of T2.2 and demographic projections from T2.1, and assessing current and future crop production and agricultural values, under current crop distribution and different crop reallocation scenarios. To these ends, the WATNEEDS[1] model is used to estimate the crops' water needs. WATNEEDS is a spatially distributed agro-hydrological model that assesses the daily water balance and provides results in terms of the volumes of water needed by the plant for each crop in each of the selected locations. The model works at a spatial resolution of 5 arcmins at the equator (approximatively 8 km at Cairo latitude) and can simulate both historical and future crop demands. We coupled hydrological outputs (BW volumes) of the WATNEEDS model to a crop reallocation algorithm that entails an increase in agricultural production, while preserving the consumption of irrigation water. Hydrological analyses have been conducted at the meso-scale on the hydrological Nile River Basin (NRB), in line with the study area of the AWESOME project. We provide a further focus for the three main countries of Egypt, Sudan and Ethiopia, that occupy the main cropland along the NRB. After this introduction, the case study from the perspective of agriculture, water resources and diet habits in Egypt, Ethiopia and Sudan is briefly described, before presenting the crop water assessment methodology (in Section 2). Section 3 illustrates the results for the current scenario (baseline) and the future scenarios following RCP 4.5, RCP 2.6, and RCP 8.5.

2. CASE STUDY AND METHODOLOGY

In this Section we provide an overview of the water resources and agriculture for the Nile River Basin, with a specific focus on Egypt, Sudan and Ethiopia. Further, we present in detail the adopted methodology, including the WATNEEDS model and the crop reallocation algorithm.

2.1 THE NILE RIVER BASIN

The Nile Basin covers an area of about 3.1 million km^2 and contains ten major sub-basins of Main Nile, Atbara, Blue Nile, White Nile, Baro-Akobo-Sobat, Bahr El Jebel, Bahr El Ghazal, Lake Albert, Victoria Nile, Lake Victoria. The River Nile share the water with eleven countries: Burundi, the Democratic Republic of the Congo, Rwanda, Uganda, the United Republic of Tanzania, Kenya, South Sudan, Ethiopia, Sudan, Eritrea and Egypt[2] and more than 50% of the population in these riparian countries live within the Nile Basin. The Nile region is characterized by high population density, approximately 257 million people living in the basin and the rapid population grow in this area is affecting more and more the renewable water resources of the Basin. Considering that the current exploitable water resources in the River Basin are 83.9 km^3/year[2], and the current agricultural withdrawal is on average 82 km^3/year[3], the water resources of the basin are already being intensively utilised. Economies of the Nile basin countries are mainly based on agriculture. Water consumption for the irrigated agricultural sector represents the most important source of water withdrawal in the Basin. The agricultural sector is responsible for nearly 75% of total water withdrawal in the Nile basin. Agriculture withdrawal accounts for 86% of water withdrawal, in both Egypt and Ethiopia, while in Sudan it accounts for 94%[4]. Approximately 4.9 million hectares of land is under irrigation in the basin, and around 97% of this land is located in Egypt and Sudan[3]. The Nile basin countries, particularly, Ethiopia, Sudan and Egypt, are experiencing massive population growth, leading to a decrease of the per capita water availability in the basin. Future further decrease in water availability in the Nile Basin is expected and well acknowledge[5–7]. Growing demand for food and, thus, irrigated agriculture is going to put more pressure on the shared water resources among the riparian countries[8]. The Nile Basin plays a fundamental role in the socio-economic development of the countries sharing the water resources of the River Nile[2], and the implementation of strategies increasing the productivity in the basin, while reducing the consumption of water becomes necessary for the sustainable sustenance of the population living in the basin.

2.2 EGYPT

2.2.1 Agriculture and water resources in Egypt

Since ancient times, Egyptian agriculture has been developed along the Nile riverbanks and in the Delta, while nowadays it represents the main contributor to the national economy covering about 13% of the national GDP in 2010[2]. The River Nile is the main water source and around 80% of the water consumption in the region is destined to the agricultural sector[3] (Figure 3). Irrigation is fundamental for crop growth and production as Egypt is characterized by very low rainfall rates. Mean evapotranspiration is less than 400 mm/year in the irrigated areas located along the river, in the river Delta and at the Aswan Dam[4], and it is null elsewhere. In 1958, Sudan and Egypt signed an agreement that, of the annual water flow of 84 km^3 Aswan Dam, guarantees 55.5 km^3 of water to Egypt and 18.5 km^3 to Sudan. Freshwater availability is threatened by climate change and the increase in withdrawal demand for industries, agriculture, and domestic use, linked to population growth along the Nile basin. The trend of availability of total renewable freshwater per capita, which includes river and groundwater water fluxes belonging to the water cycle, is decreasing and approaching the absolute water scarcity threshold of 500 m^3/cap/year (Figure 2) around 2030[9]. Currently the available water resources in Egypt are already overexploited, being the total withdrawal of freshwater resources the 114% of the total renewable water resources in the country (accounting of 57.5 km^3) [9]. The current water shortage in Egypt (13.5 km^3) is compensated by drainage reuse, but is expected to furtherly increase in the future[10].

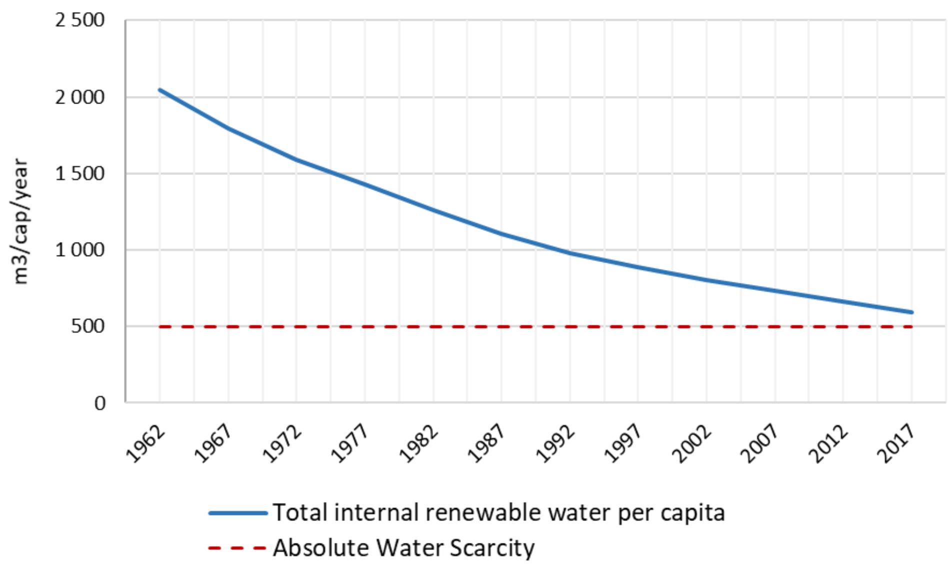

Figure 2 – Temporal trend of renewable freshwater resources in Egypt. Source: AQUASTAT[11].

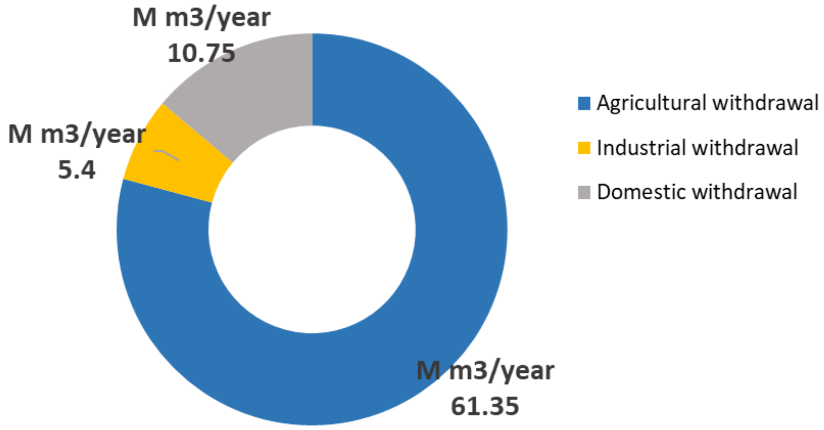

Figure 3 – Current water uses in Egypt per sector (year 2017). Source: AQUASTAT[11].

The main cultivated crops in the area are maize, rice, cotton, wheat, pulses, barley and sugar beet[12], and irrigation is needed especially for cereals, legumes, forages, sugar crops, fruits and vegetables. Specifically, the total cropland covers only 5% of the national territory[13], but this has not limited the development of large crop production to meet local and export demand, in particular for:

- wheat and maize, the top grain food sources for human consumption;
- onions, cultivated since ancient times, important for local consumption and export purposes;
- oranges, Egypt is one of the biggest exporters and producers;
- potatoes, used for local consumption and export towards E.U. mostly;
- tomatoes, the most produced vegetable crop in the country;
- rice, Egypt is the biggest producer in the Middle East, it has important export with competitive prices;
- cotton, for domestic and export demands, its cultivation has an important impact on employment;
- dates, Egypt is the top global producer as date palms possess high tolerance towards arid climate and saline water.

The country has been largely dependent on imports to provide sufficient food for its increasing population for several decades. To face this problem, the government has set, in its Sustainable

Development Strategy Towards 2030, the goal of increasing self–sufficiency for the consumption of cereals. Figure 4 shows the production, export, and import quantities per item, retrieved from FAOSTAT Food Balance Sheets[14], for the years 2000 and 2010. The increase in production follows the population growth trend, which is expected to nearly double in 2060, according to estimates of WP2 (se for reference D2.1 Demographic projections). Imports for maize and wheat are relevant both in 2000 and 2010, while imports for vegetables, sugarcane and sugar beets increase to meet the growing demand of these crops (Figure 4). Economic gain associated with crop production is calculated in terms of producer income in USD at the farm gate[15] and shown in Figure 4. Major gains derive from selling cereals, vegetables, and fruits. The most expensive crops for the farmers are groundnuts, followed by pulses and soybeans[15].

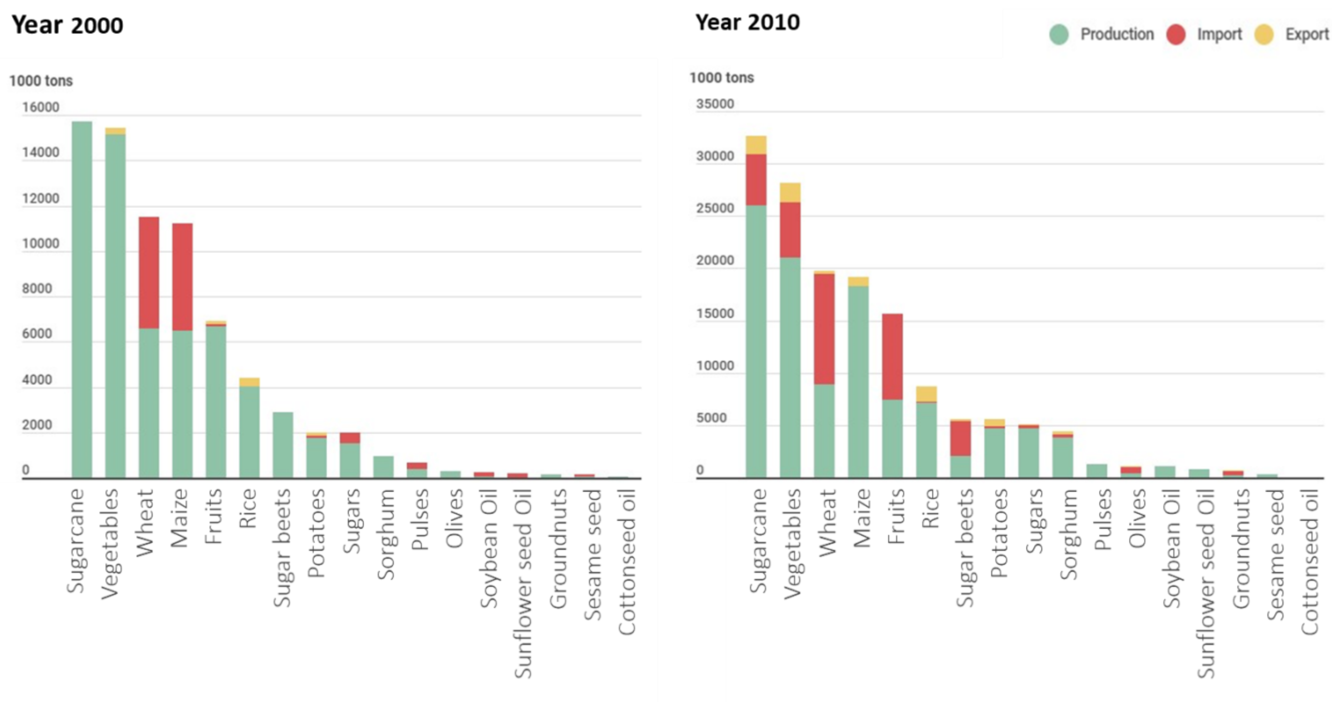

Figure 4 – Production, import, and export quantities per item (years 2000 and 2010). Source: FAOSTAT Food Balance Sheet[14]

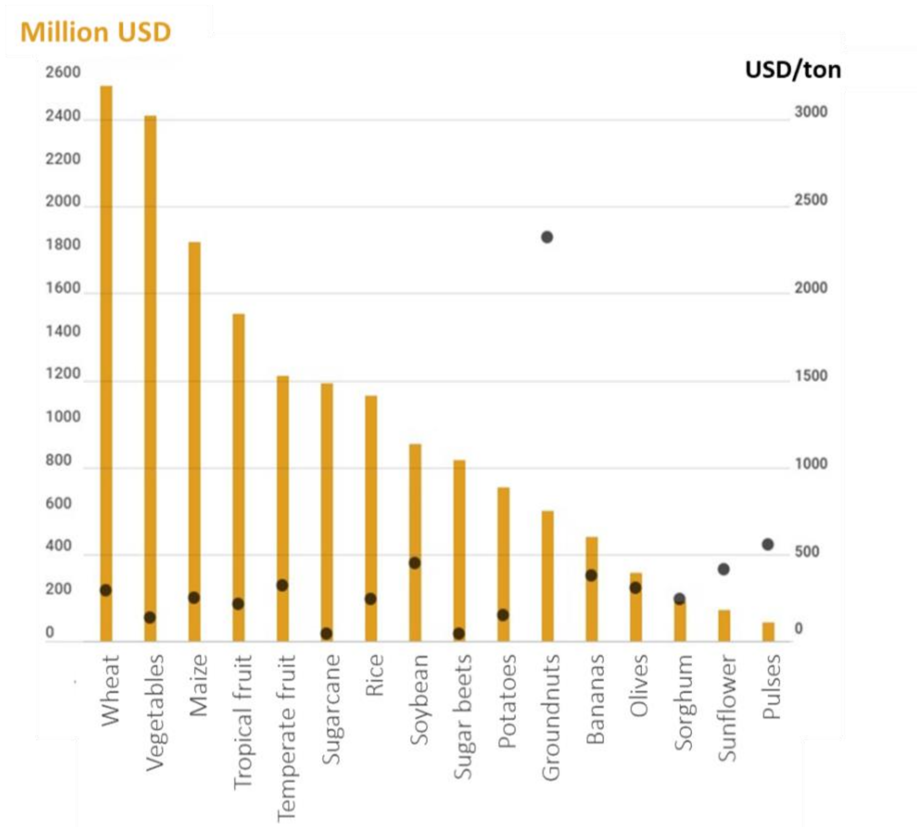

Figure 5 – Producers' gains (yellow bars) and intrinsic items' values (black dots) for the year 2010. Source: FAOSTAT[15]

2.2.2 Local diet in Egypt

Malnutrition is a global problem affecting mainly underdeveloped and developing countries, and it is defined by coexistence of both under nutrition and overweight issues[16]. Egypt is one of the 36 countries affected by 90% of global malnutrition[17]. Food security in the country declined over the past decade, because of aggravating poverty and political instability[18], as diet quality is heavily influenced by food subsidy policies[19]. Diet issues in Egypt affect prevalently children under 5 and women in fertile age[19]. Overweight problems, including type 2 diabetes, affect 15% of children and 80% of women, increasing the probability of disease development for children during pregnancy. Another malnutrition issue affecting women and 1/3 of children is iron-deficiency anaemia[19] .
The average local diet is based mainly on cereals, with a high percentage (around 10%) of sugar consumption (Figure 6 and Table 1). The total average kcal intake is of 3318 kcal/capita/day. The 81.8% of the total protein consumed (in average 92 g/capita/day) comes from vegetable products, and 18.2% from animal products[20].

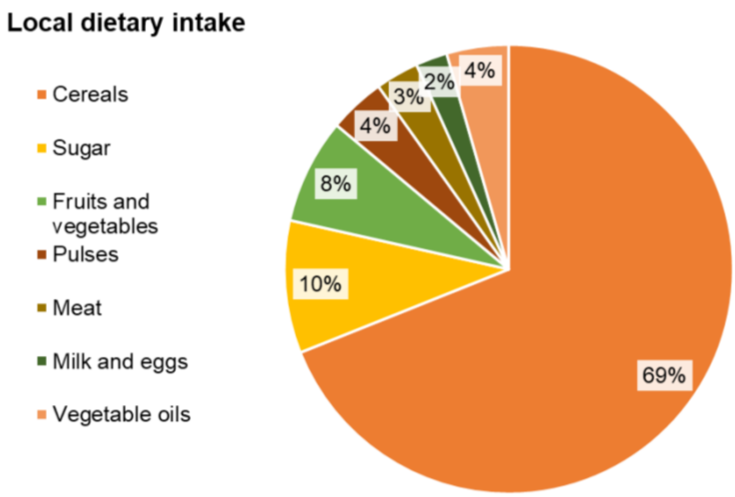

Figure 6 – Local dietary intake repartition. Source: FAOSTAT Food Balance Sheet[14].

Table 1 – Energy supply (%) and average intake per capita for the current diet in Egypt. Sources: FAOSTAT Food Balance Sheet[14].

Current Diet		
Food item	**Average intake per capita (kg/capita/day)**	**Energy supply (%)**
Whole grains and cereals	2138	66%
Sugars	283	9%
Animal origin protein sources	185	6%
Fruits (e.g., dates, bananas, apples, grapes)	177	5%
Vegetal origin protein sources	121	4%
Vegetables (e.g., greens, onions, tomatoes)	114	3%
Dairy foods	76	2%
Added fat from vegetal origin	64	2%
Tubers	62	2%
Added fat from animal origin	39	1%
Total	**3258**	

2.3 SUDAN AND ETHIOPIA

2.3.1 Agriculture, water resources and diet in Sudan

Crossed by the Nile River, the Republic of Sudan is the largest country in Africa, with over 39 million inhabitants. The country is characterized by a wide range of climates and large daily and seasonal temperature variations, with minimum temperatures around 5°C, and summer maximum temperatures often exceeding 44°C, in the desert and a large variation in annual rainfall[21], but a low long-term average precipitation, of only 250 mm/year[11]. In Sudan, agricultural sector is fundamental for the economy of the country. Sudan has the second largest irrigated farming system in all Africa, after Egypt[22], covering 1.9 million ha, irrigated mainly by the river Nile and its tributaries[21]. Accordingly to the Nile Water Agreement[23], Sudan has an annual guarantee of 18.5 km^3 of water from the average annual flow of the Nile at Aswan (accounting of 84 km^3), and the water withdrawal used for the agricultural sector account of 25.91 km^3/year, constituting the 51% of the total water withdrawal of the Nile River Basin[11]. The irrigated sub-sector contributes more than 50% of the total agricultural production, however the irrigated area constitutes only about 11% of the total cultivated land[22]. The arid climate and the rainfall variability has made irrigation supply more and more important for agricultural production over the past decates[21]. Major irrigation scheme in Sudan is the Gezira irrigation scheme, located between the Blue Nile and the White Nile. Together with its extension of Managil, the Gezira is the largest scheme in Sudan. Nearly 75% of the total irrigation area is in the Blue Nile sub-basin in Sudan. In the past decades, different policies[24] in Sudan promoted some important irrigation investments to increase irrigation performance, including the construction of the Aswan dam (1962-1970), the use of fertilizers and measures aiming at facilitating farmers' adoption of these technologies. Currently, many schemes are characterized by low cropping intensity due to water scarcity during the long dry season, thought they are fully equipped with infrastructure[22]. The main constraints preventing irrigation productivity and causing low yields in Sudan are sedimentation in the canals, low tenancy of irrigation plants and lack of formal credit due to financing problems[24].

The main crops grown under irrigation are wheat, sorghum, groundnuts, pulses, fruits and vegetables, and sugarcane. The local diet relies mainly on cereals like wheat and sorghum, covering respectively 20% and 24% of the total daily energy intake (2580 kcal/cap/day). About 47% of the land resources are under arid and semi-arid conditions with serious drought risks. For this reason, irrigation supply from the Nile is crucial for agriculture and for achieving food self-sufficiency. Sudan is a low-income food-insecure country, which has been ravaged by civil war for two decades. In Sudan more than 90% of the population suffer from poverty and food insecurity, with high presence of undernourishment especially in children under 5 years old[21]. Seasonal food shortage and large inequalities in the access to food often evolves into chronic food insecurity. The lack of micronutrients, such as vitamin A, iodine and iron, causing anemia, is very diffuse among children under 5 years and among women of reproductive age[21].

2.3.2 Agriculture, water resources and diet in Ethiopia

The Federal Democratic Republic of Ethiopia is characterized by climates ranging from dry semi-desert in the plains to humid and tropical in the deep valleys. There are important differences in precipitation levels, with a rainy season between mid-June and September and a dry season occasionally interrupted in February or March by another short rainy season[25]. Ethiopia has a substantial amount of water resources, with a total of exploitable water resources of 53 km^3/year[26]. Some major river basin contributing to the Nile system are the Abbay, Baro-Akobo, Mereb, and Tekeze basins, and they account for the 70% of the surface flow of the country[27]. As it provides water to Sudan, South Sudan, Somalia, Kenya and Eritrea, Ethiopia is considered to be the water tower of the Horn of Africa[27]. However, the limited financial resources, technical challenges, and lack of good governance in the water sector prevent from a complete development and proper utilization of the Ethiopian water resources[27].

Ethiopia is heavily dependent on the agricultural sector, which provides employment for 75% of the population and accounts for 48% of the country GDP[25]. The total area equipped for irrigation in Ethiopia is around 91,000 ha and lies in the Blue Nile sub-basin, in relatively high rainfall area. Both irrigated and rainfed agriculture are fundamental for the economy of the country, however most food crops are rainfed, because irrigation accounting for only about 3%. The growing population pressure on rainfed agriculture is increasing the importance of irrigated agriculture for the country's development. According to FAO estimates[14], the agricultural items most produced in Ethiopia are maize, sorghum and wheats, all mainly used for local human consumption. Ethiopia is the second most populated country in Sub-Saharan Africa, with a very young population and an annual growth rate of 2.44%. Almost half of the population suffers from undernourishment because the daily dietary energy intake is not sufficient to meet population requirements[28]. Food supplies also lack diversity. Prevalently women and children are affected by chronic energy deficiency and anemia, linked to low consumption of foods of animal origin[28].

2.4 METHODOLOGY

In the context of the water-ecosystem-food-energy (WEFE) nexus, with the aim to promote the transition to sustainable agriculture in the Mediterranean region, while producing more food with less water, land, and energy, AWESOME entails the application of WATNEEDS model[1] to estimate the crops water needs in a present-baseline scenario and in future climate scenarios. A redistribution of the current cropland has been implemented in present and future climate scenarios to optimize the use of local natural resources (i.e., land and water). The crop reallocation entails a reduction in the use of freshwater resources per unit of food produced while preserving crop diversity and maintaining crops that are suitable for the soil and climatic condition of the studied countries.

2.4.1 Spatial Domain

Hydrological analyses and crop reallocation have been conducted at the meso-scale, on the hydrological Nile River Basin (NRB), in line with the study area of the AWESOME project, and we evaluated the benefits of crop reallocation in terms of the increase in agricultural production, with respect to the current (baseline) cropland. The focus is on Egypt, as it is particularly relevant for the AWESOME project because the demo sites of the innovative technologies are being build there and this enables us to represent the case study both from the modelling and from experimental point of view. In addition, we investigated present and future reallocation scenarios also for Ethiopia and Sudan, to cover the main cropland along the Nile River Basin. The country self-sufficiency can be expressed in terms of percentage of satisfaction of the domestic demand for food through internal production and thus provides a measure of the country dependency on trade to feed the population[29,30]. We calculated the satisfaction of the crops demand at the country scale, in order to evaluate the country self-sufficiency towards the closure of the gap between domestic crop demand and production.

2.4.2 The WATNEEDS model

The WATNEEDS model simulates the vertical soil water balance at a daily time step and cell by cell at a 5 arc-minutes resolution and it has been used to calculate the yearly blue and green crop water requirements for the major crops cultivated in the study area – groundnuts, maize, potatoes, pulses, rice, sorghum, soybeans, sugar beet, sugarcane, sunflower, tropical fruit, temperate fruit, olives and wheat – that currently account for 92% of harvested area within the Nile River Basin, and the crop group of fodder grasses, used ad animal feed. Specifically, the soil water balance calculates the time variation of water storage within a specific cell (of 5 arc-min resolution) as the difference between water inputs and outputs. The equation used for each day in each cell is the following (Eq. 1):

$$\frac{\Delta W}{\Delta t} = P_t + I_t - ETa_{i,t} - D_t - R_t \quad (1)$$

where:

- $\frac{\Delta W}{\Delta t}$ is the time variation of water storage (mm/day);
- P_t is the daily effective precipitation (mm), retrieved from CHIRPS version 2.0 dataset[31];
- I_t is the irrigation supply (in mm, only for irrigated crops);
- R_t represents the sub-surface runoff (mm). Subsurface runoff occurs when soil saturation is reached and is calculated as the difference between the sum of the balance and is the total available water (TAW, i.e. the amount of water that a crop can uptake from the rooting zone);
- D_t represents the deep percolation (mm) and is the water that percolates downwards to the groundwater reservoirs if the moisture content exceeds a threshold value called field capacity. The deep percolation D_t is calculated using the maximum deep percolation flux D_{max}, the Soil Moisture S_t and the maximum Soil Moisture S_{max}, depending on the soil type[32] (Eq.2) .

$$D_{it} = \begin{cases} D_{max}\frac{S_t-(1-p)S_{max}}{S_{max}} & (1-p)\,S_{max} < S_t < S_{max} \\ 0 & S_t < (1-p)S_{max} \end{cases} \quad (2)$$

p (−) is the critical depletion factor (i.e., the fraction of TAW that a crop can uptake without experiencing water stress);

- $\mathrm{ETa}_{i,t}$ is the actual evapotranspiration of crop i at day t (mm), defined as in equation (3):

$$\mathrm{ETa_{i,t}} = \mathrm{kc_{i,t}} \cdot \mathrm{ks_t} \cdot \mathrm{ET_0} \tag{3}$$

where $\mathrm{kc}_{i,\mathrm{t}}$(-) is the crop coefficient of crop i on day t. The crop coefficient varies with the crop growth stages and the roots depth (Figure 7) and is retrieved from Allen et al.[33]. The parameter $\mathrm{ks_t}$ is the stress coefficient, which consists in a reduction factor for the crop coefficient that is introduced when the plant suffers from water deficit. It is calculated as a function of the soil water content in the root zone, following Allen et al.[1,33]. ET_0 is the reference evapotranspiration (mm), calculated following Hargreaves's approach[34]. The input data for the reference evapotranspiration are the solar radiation, and the maximum and minimum air temperature, taken from Harris et al.[35].
In conclusion, the potential evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants and, without stress condition, can be defined as follows:

$$\mathrm{ETp_{i,t}} = \mathrm{kc_{i,t}} \cdot \mathrm{ET_0} \tag{4}$$

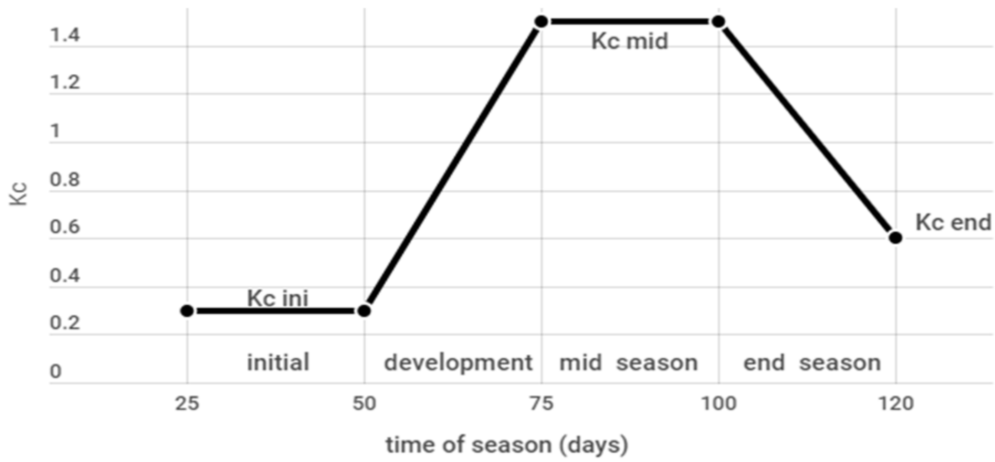

Figure 7 – Crop coefficient (kc) variation during growth stages[33].

Green crop water requirement is calculated by WATNEEDS as the amount of ETa (mm) that is met by precipitation. Blue water requirements are calculated as the amount of irrigation water required to compensate the difference between ETp (mm) and the green crop water requirement after accounting for vertical soil water balances. We calculated yearly irrigation water withdrawal from the main irrigation canals in Egypt (Table 2, Figure 8), assuming that each canal has an area of influence, from which water is available for withdrawal. Command areas (i.e., the area which can be irrigated from a scheme and is fit for cultivation[36]) have been identified through a nearest neighbour algorithm, based on the minimum Euclidean distance from each canal. Results shown in Table 2 provide an interesting comparison among the agricultural water consumption and withdrawal calculated by WATNEEDS and the main canal's discharge reported by National Report. In the majority of the cases, the water needed for agricultural production is comparable to these available from the canals network.

Nevertheless, in 3 canals - namely Menufia, Nasseri and Tawfiki - WATNEEDS results (theoretically) predict higher water demand than the water available from the closest canal. Thus, it can happen that:

(i) a different source of water (i.e. groundwater) could be used;

(ii) even if blue water is theoretically required farmers decide not to irrigate;

(iii) minor canals divert the water available not necessarily to the closest field (see calculation hypothesis of the nearest neighbour algorithm).

To be noticed, our reallocation model is based on the amount of consumptive water, independently from the source of irrigation water. Moreover, in the proposed potential reallocation scenarios the amount of water consumed per cell doesn't exceed the current water used (see Section 2.3.6).

Table 2 –Average yearly volume of irrigation water (km^3) withdrawal from the main irrigation canals in Egypt. We compare official data retrieved by The National Resources Plan of Egypt[37] to results provided by WATNEEDS[1]. We show the total actual withdrawal, including water losses with an irrigation efficiency of 60%, and in parenthesis we report the consumptive water (excluding the losses).

	Water withdrawal (km^3/yr)	
Irrigation canals	**National Egypt Data[37]**	**WATNEEDS results**
Asfoun	0.5	0.53 (0.371)
Beheria	6.1	3.006 (2.104)
East Naga	1	0.705 (0.494)
Ibrahimia	9.6	8.376 (5.863)
Ismaila	3.9	3.394 (2.376)
kelabia	1.2	1.302 (0.911)
Menufia	4.8	7.925 (5.547)
Nasseri	2.2	6.988 (4.891)
Sharkawia	0.7	0.838 (0.586)
Tawfiki	3.9	6.953 (4.867)
West Naga	2.8	3.075 (2.152)
Total	**36.7**	**43.09 (30.163)**

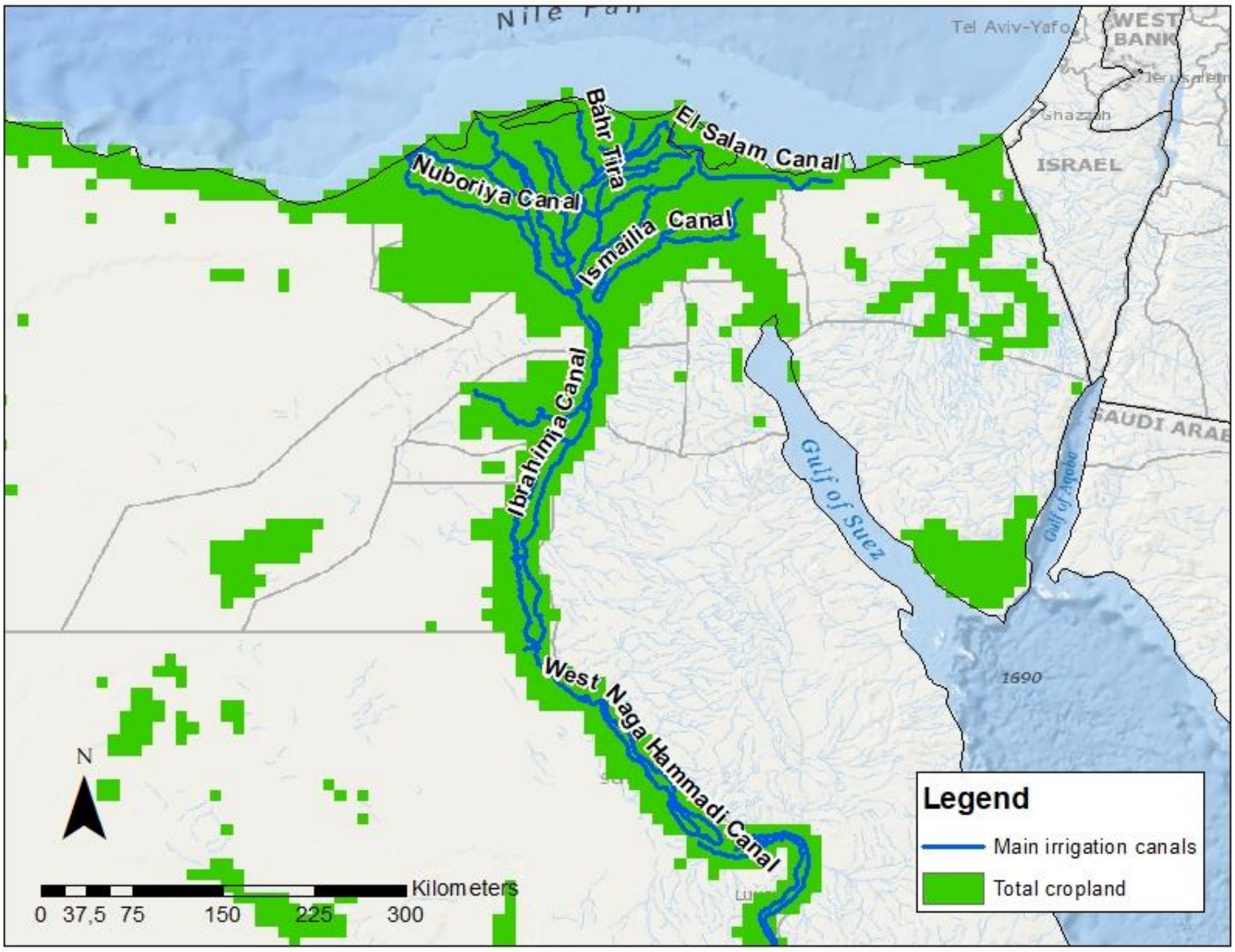

Figure 8 – Main irrigation canals in Egypt from where irrigation water is assumed to be withdrawn. The total cropland is provided by IFPRI[38].

2.3.4 Baseline scenario

We calculated yearly green and blue crop water requirements for the major cultivated crops in the NRB (i.e., wheat, maize, rice, sorghum, soybean, sunflower, olives, groundnuts, potatoes, temperate fruits, tropical fruits, banana, sugarcane, sugar beet, pulses, vegetables and fodder grasses) and considered average values for the five-year period from 2011 to 2016. To obtain data relative to crop-specific cultivated areas and yields, we combined two datasets, the IFPRI[38] and the MICA[39] datasets. The MIRCA dataset provides spatially distributed maps (5 arc-minutes resolution) of harvested areas and yields for 26 main crops, the IFPRI dataset has been also involved, as an integration to the MIRCA dataset, because it includes an exhaustive number of crops (e.g., tropical and temperate fruit, olives, vegetables and bananas) that represent an asset of NRB agriculture. Soil information and soil properties are taken from Bajties et al.[40] (5 arc-minutes resolution) and are kept constant also in future simulations. Present climatic data are retrieved from CHIRPS[41] for the period 2011-2016. The present demand for crops has been calculated on the basis of the current country diet and present population, retrieved from FAOSTAT Food Balance Sheets[14].

2.3.5 Future scenarios

Future climatic scenarios are chosen to compare the current crop water demand of the baseline scenario to future projections, which can potentially entail variation in the agricultural blue water demand and consumption. The analyses have been carried out using future climatic data for the average period around year 2050 (2048-2052) and year 2100 (2096-2100) under three different Representative Concentration Pathways (RCPs): RCP 4.5, RCP 2.6 and RCP 8.5. Climate projections at years 2050 and 2100 are obtained from downscaling of Africa COordinated Regional climate Downscaling EXperiment (CORDEX)[42] , that provides future climate projections at a detailed, regional scale, at a resolution of 0.05 degrees under different RCPs. The climate data and future climate scenarios have been described in detail in the report D2.2, previous deliverable of WP2. The demand for crops in the future has been calculated considering the future population projection, based on different SSPs provided by D2.1. SSP scenarios have been coherently coupled with the RCPS scenarios: RCP 4.5 is coupled with SSP2, RCP 2.6 with SSP1 and RCP 8.5 with SSP5.

2.3.6 Baseline crop reallocation

A redistribution of the current crops, with the aim of enhancing self-sufficiency in agricultural production and closing the production-demand gap at the country scale, is first assessed for Egypt, Sudan and Ethiopia, in the so-called baseline scenario. At a second stage crop reallocation has been performed within these countries for the future scenarios RCP 4.5, 2.6 and 8.5. We assessed the benefits that can be generated with a shift to a balanced diet and an increase in crop yields. The four considered diet and agricultural intensification scenarios have been resumed in Table 3, where a shift to the balanced diet suggested by Willett et al.[43] (Table 4) and agricultural intensification of the 3rd quantile with respect to the current yield maps[38,39], have also been considered. Different intensification and diet scenarios are useful to assess the benefits that can be generated from irrigation water savings and the advantages in achieving food self-sufficiency when a balanced diet is introduced. The shift to a balanced diet tackles both the problem of overnutrition, decreasing the average daily kcal intake, and anemia, increasing the iron supply, through a higher intake of protein from vegetal sources. In Figure 9, the water footprint related to the shift to the balanced diet of Willett et al.[43] in Egypt is reported.

Table 3 – Summary of the implemented scenarios of diet shift and yield intensification.

Allocation scenario	Description
D0I0	Current diet[14], current yield[38]
D0I1	Current diet[14], yield intensification (3rd quantile)[38]
D1I0	Balanced diet[43], current yield[38]
D1I1	Balanced diet[43], yield intensification (3rd quantile)[38]

Table 4 – Energy supply (%) and average intake per capita for the balanced diet according to Willett et. al.[43].

Balanced Diet[43]		
Food item	**Average intake per capita (kg/capita/day)**	**Energy supply (%)**
Whole grains and cereals	811	32%
Vegetal origin protein sources	575	17%
Added fat from vegetal origin	414	6%
Dairy foods	153	5%
Animal origin protein sources	151	6%
Fruits (e.g., dates, bananas, apples, grapes)	126	23%
Sugars	120	5%
Vegetables (e.g., greens, onions, tomatoes)	78	3%
Tubers	39	2%
Added fat from animal origin	36	1%
Total	**2503**	

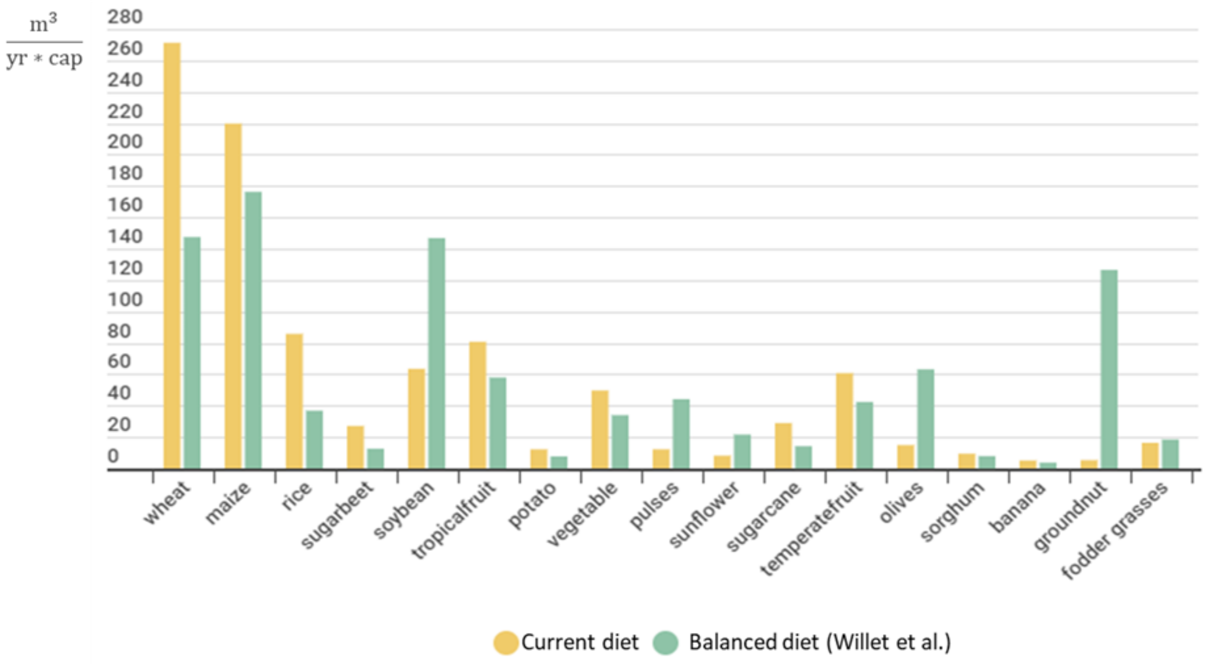

Figure 9 – Comparison of the crop water footprints of the current diet in Egypt and the balanced diet suggested by Willett et al.[43]. The crop water footprint is the total amount of water consumed per person and in a year (m^3/cap/yr) for production of a specific crop[44], and can be related to a specific diet. In the current Egyptian diet, the per capita water consumption results are high, as the consumption of cereal products is high in comparison to the balanced diet. On the other hand, the balanced diet of Willey et al.[43] promotes a higher intake of soybeans, olives and groundnut, which are water-costly crops for the arid climate of the Egyptian region.

Crop reallocation has been performed with an algorithm solving a linear optimization problem that maximizes the *water productivity* and optimizes the harvested areas. The *water productivity* is defined in Eq. (4) as the ratio between the spatially distributed yields (Y) and the blue water requirements (BW) per crop obtained as outputs of the WATNEEDS model:

$$water\ productivity = \frac{Y * X}{BW} \quad (5)$$

where X is the new allocated harvested area per crop, and thus the variable of the optimization problem. Selected constraints to the linear problem are: (1) the sum of newly allocated areas cannot exceed the currently available irrigated cropland; (2) for each crop, the new crop production obtained must at least guarantee the initial crop production, and if possible, increase the production towards the demand gap closure; (3) the new total volume of blue water (km^3) must not exceed the current blue water consumption - or at least the 5% more, when increase in production towards the satisfaction of the diet is considered. For Egypt, an additional constraint related to the minimum percentage of the demand satisfaction has been included: (4) for each crop, the new crop production must satisfy, in average, at least a fraction of the demand, that is the minimum fraction of the demand that has been found to be satisfied for all the crops. This fraction varies accordingly to the considered temporal scenario: 90% (in the present), the 53% (in the year 2050) and the 38% (in the year 2100) of the demand. This last constraint couldn't be applied (and satisfied) for Sudan and Ethiopia because of the low currently cultivated cropland for some of the crops used for the analysis. The total new crop production has finally been calculated as the sum of the new irrigated crop production and the rainfed production, that has been maintained constant, which contribute to increase the production towards the demand gap closing.

2.3.6.1 Trade modelling

Trade has been included in the analysis through two scenarios. A first Surplus-Deficit scenario has been developed, considering export as the surplus in production obtained with crop reallocation once the internal demand for a crop is completely satisfied (100% of demand gap closure). The crops selected for export purposes are those with higher economic value, the economic value of a crop is estimated as economic gain obtained by the producers retrieved from the producer prices[15]. The import has, instead, been calculated as the production needed to completely satisfy the demand, when internal production cannot completely meet it. A scenario of constant trade has also been included, considering export and import fluxes constant in time and equal to the present fluxes (FAO Food Balance Sheets[14]).

2.3.6.2 Irrigation Expansion and Yield Intensification

Over 87% of cultivated land in the NRB is under rainfed agriculture, however, the largest consumer of renewable water resources is irrigated agriculture[45]. The 97% of irrigated land is located in Egypt and The Sudan, while the remaining 3% is located in the upstream countries. Because of their reliance on rainfed agriculture, in the past, riparian countries in the NRB have paid little attention to development of irrigation infrastructure. This situation has changed, and many upstream countries now plan to expand their irrigated areas and, in 2003, African countries signed the Maputo Declaration, on Agricultural and Food Security, agreeing to invest 10% of their budget to agricultural research and development. Past studies[46–48] have suggested sustainable intensification practices for improving water productivity and reducing the yield gap in Africa. According to Tadele[47] crops cultivated in Africa have an inferior yield with respect to other continents, due to low soil fertility and little water availability causing an insufficient soil moisture. Crop yields can be increased if associated to improvements in water, soil and plant management, which also represent an opportunity for employment. Increase in soil fertility can be obtained, for instance, with the introduction of some new generation fertilizers like biochar, carbon produced from vegetal biomass carbonization[47], or application of fertilizers containing nitrogen, phosphate, and potash, the main nutrients needed by plants[46]. Inter-cropping strategies between cereals and legumes can be also useful in tackling issues related insect pests and parasites[47]. Improving in the water management can be obtained transitioning from less to more efficient irrigation system. Mainly medium- to large-scale irrigation schemes consist of gravity supply schemes and traditional river diversions[45]. Yields are typically high in Egypt (where programs of irrigation schemes improvements and soil fertility management have already been launched by the government[45]), but are quite low in Sudan, for instance. The availability of water and fertile soils are potential to increase agricultural productivity in these schemes. However, improvement of irrigation water-use efficiency alone, may not be sufficient to enhance future water availability in the basin. Multsch et al.[49] showed that a 5–20% increased efficiency in both gravity and pressurized irrigation systems is insufficient to meet future water demand. Similarly, expansion of the irrigation area alone would likely not be sufficient to fulfil the future food demand in the basin due to the limited availability of surface water. The most convenient solution to enhance sustainably productivity in the NRB is, thus, exploring multiple water-saving options of irrigation expansion and agricultural intensification. In Sudan and Ethiopia currently cropland is very poorly irrigated (only 11% and 4%, respectively[22,50]) – on the contrary in Egypt already the 98% of the cropland is irrigated[51]–, for this reason, we considered a feasible scenario of irrigation expansion for these countries consisting in expanding irrigation following the potential irrigation schemes, provided by the Eastern Nile Technical Regional Office (ENTRO)[52]. Expansion areas are referred to the major basins of Abbay, Baro Akobo and the Tekeze in Ethiopia, and the Blue Nile and the Tekeze-Atbara in Sudan and increase the current available cropland of 1.8 million ha in Ethiopia and 0.51 million ha in Sudan. To calculate the new irrigated hectares per cell, we assumed an irrigation fraction for the new irrigated lands equal to the current fraction, calculated as the average ratio of the irrigated area (ha) and the total area (ha) in a cell (9% in Ethiopia and 13% in Sudan). For this expansion scenario, the constraint of the optimization problem (Section 2.4.5), relative to the total new harvested area (1) consists in not exceeding current irrigated cropland plus an irrigation expansion mask, made considering the potential expansion areas[52]. Moreover, as an increase of blue water proportioned to the new harvested hectares is expected, the new total volume of blue water (2) has been constrained to not exceed the total exploitable water resources of the country[26], accounting also for environmental flows[53]. Crop reallocation in Sudan and Ethiopia has been performed only considering an irrigation expansion in the future scenarios, because no feasible solution for the current cropland could be found without exceeding the current blue water consumption.

2.3.6.3. Crop reallocation over the NILE RIVER BASIN

The crop reallocation has also been performed over the entire Nile River Basin (NRB), for the baseline and future scenarios. We found the optimal configuration of crops that guarantees the current production and preserves or reduces the consumption blue water, without causing other environmental implication (e.g., loss of biodiversity and land degradation). Trough the maximization of the *water productivity,* the algorithm sustainably allocates agricultural land where it is most convenient to cultivate, without exceeding the current water consumption for agricultural use. We first run the algorithm over the current irrigated land and second, we considered future plans of irrigation expansion[54]. We considered two intensification scenarios (I0 an I1) in order to assess the benefits that can be obtained increasing agricultural yields. Our results show the surplus of agricultural area that is obtained when the current production is totally guaranteed. This excess of land can lead to an increase in agricultural production, that is proportioned to the yields. Environmental implication (e.g., soil degradation, monocropping, exploitation of water resources, etc.), might results when reallocation is performed with the aim of increasing production, without considering the boundary of the diet demand. Indeed, in this case, the algorithm might allocate extensively single specific crops, that are characterized by high water productivity (e.g., sugarcane), with the effect of reducing biodiversity or soil fertility. For this reason, we privileged the choice to maintain the production constant and report the proportion of area that can be saved in all the scenarios. Nevertheless, we also report a hypothetical crop distribution that is obtained when the total production per crop wants to be increased, following the strategy of maximizing water productivity. In reallocation performed over the NRB, the administrative and political boundaries (and, thus, political agreements related to food trade) of each single countries have not been considered, as reallocation is done with the aim of optimizing the overall agricultural resources within the Basin, prioritizing a production that is sustainable from an environmental point of view. Trade and diet demand analyses related to single countries within the basin have instead been considered in the analyses done at the country scale. This scenario offers instead a hypothetical optimal distribution of crops at the basin scale, that privileges a sustainable allocation of agricultural resources, despite the internal agreements among countries in the NRB, related to trade and food production. We offer a scientific assessment of the potential areas where it is more convenient to cultivate, and our results provide a useful tool that might be used to shape future agreements among states, that strategically arbitrate food trade from production (surplus) to consumption (deficit) areas.

3. RESULTS

In this section, the main results obtained from the coupling of the WATNEEDS model and the crop reallocation algorithm are reported for the baseline (present) and the future scenarios RCP 2.6, RCP 4.5, and RCP 8.5. In Section 3.1 the results for Egypt are reported, while in Sections 3.2 and 3.3 the respective results for Sudan and Ethiopia, and for the NRB.

3.1 EGYPT

3.1.1 Baseline scenario

Table 5 shows the results in terms of harvested areas, percentage of demand closure and water volumes for the assessment of baseline scenario, based on the current crop distribution and present climatic and population data (see Section 2). In Figure 10 we report maps showing the current harvested areas per for the five main cultivated crops in Egypt and the total harvested area and in Figure 11 we report the map of the total BW consumption in the baseline. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link. The percentage of demand closure has been calculated as the fraction of actual demand for crops of the population that can be satisfied through domestic agricultural production. A 100% of demand closure indicates that the domestic production of a specific item can entirely satisfy the population demand for that crop. The total cropland area is 5,467,880 ha, the crops more extensively cultivated are cereals and fodder grasses, followed by vegetables. The total annual volume of water required by the 17 crops resulted 30.14 km^3/y, which is mainly covered by the blue water volume (28.06 km^3/y), while the green water volume resulted of only 2.16 km^3/y, because of the low precipitation rates characterizing Egyptian climate. Figure 11 shows the spatially explicit total blue water volume consumed annually for the baseline scenario. Results confirm that the contribution of irrigation is fundamental to sustain agricultural production as it provides 95% of the total crop water requirement for the area. The most water-consuming crops are cereals and sugarcane. Wheat and maize require 5.7 and 5.8 km^3 of irrigation water per year each, rice 4.0 km^3, and sugarcane 2.1 km^3. Looking at surplus-deficit trade scenario (Table 5), it emerges that the internal production cannot alone satisfy the population diet demand, especially for maize, wheat, soybeans, sunflowers, sugar beets, pulses and olives; confirming thus the necessity of relying on imports to close the remaining 28% of demand gap to completely satisfy the average diet demand (surplus-deficit trade scenario). Also, when constant trade fluxes are considered (in the constant trade scenario), there is an average gap in the demand satisfaction of around 15%, this means that when current imports and exports are accounted, the population demand is not totally met. Trade is able to increase the satisfaction of the demand for maize (from 52.78% to 100%), wheat (from 43.36% to 100%), rice (from 97.96% to 100%), soybean (from 1.89% to 100%), pulses (from 47.00% to 100%), sugarcane (from 98.00% to 100%) and sunflower (from 8.00% to 16.82%) through imports, but at the same time it slightly reduces the satisfaction of the demand for the main exported crops, i.e., tropical fruits (from 100% to 83.26%), groundnuts (from 100% to 83.21%), olives (from 52% to 48%), temperate fruits (from 80% to 47%), vegetables (from 100% to 94%) and potatoes (from 100% to 98%).

Table 5 – Harvested areas (ha), production (tonnes), percentage of demand gap closure and water volumes (km^3) for the baseline scenario.

Baseline scenario						
Crops	Area (ha) – MIRCA, IFPRI datasets[31,32]	Production (tonnes)	Demand gap closure (%)		BW (km^3)	GW (km^3)
			Constant Trade	Trade Surplus-deficit		
Wheat	1302290.25	8,034,210.01	100	43.36	5.64	0.62
Maize	946157.38	7,198,587.14	100	52.78	5.84	0.15
Rice	542465.25	5,172,591.85	100	97.96	3.96	0.36
Sugar beets	132429.41	6,878,535.73	62.13	60.01	0.93	0.02
Soybeans	10625.40	31,790.64	100	1.89	3.96	0.36
Tropical fruit	392674.50	8,459,799.33	98.58	100	2.42	0.32
Potatoes	147532.47	3,876,923.60	83.26	100	0.55	0.04
Vegetables	563819.31	17,294,189.59	94.83	100	1.34	0.19
Pulses	60709.59	248,219.13	100	47.00	0.25	0.01
Sunflower	13429.30	33,150.02	16.82	8.00	0.02	0.00
Sugarcane	134758.50	15,652,396.58	100	98.00	2.07	0.00
Temperate fruit	154813.19	2,990,231.50	47.22	80.00	1.25	0.15
Olives	53733.10	435,917.51	48.09	52.00	0.01	0.07
Sorghum	146133.38	773,914.03	100	100	0.70	0.00
Banana	23366.60	1,067,894.15	83.81	82.00	0.14	0.02
Groundnuts	65197.11	202,505.15	83.21	100	0.09	0.01
Fodder grasses	688363.94	48,007,813.04	100	100	2.81	0.13
Total/Mean	**5467882.40**	**-**	**85.72**	**71.94**	**28.06**	**2.08**

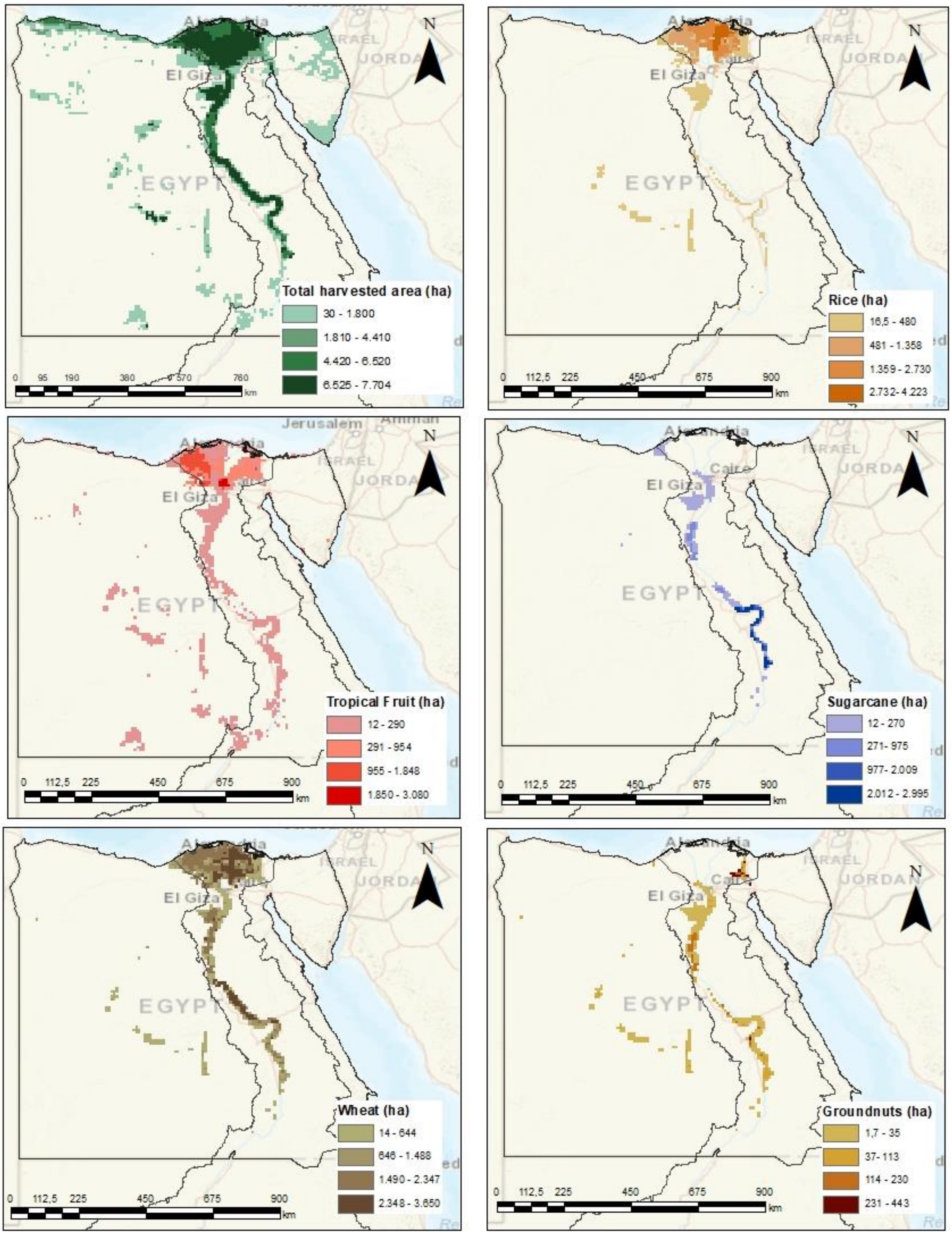

Figure 10– Current total irrigated harvested area and single crops' harvested areas for the five main cultivated crops in Egypt.

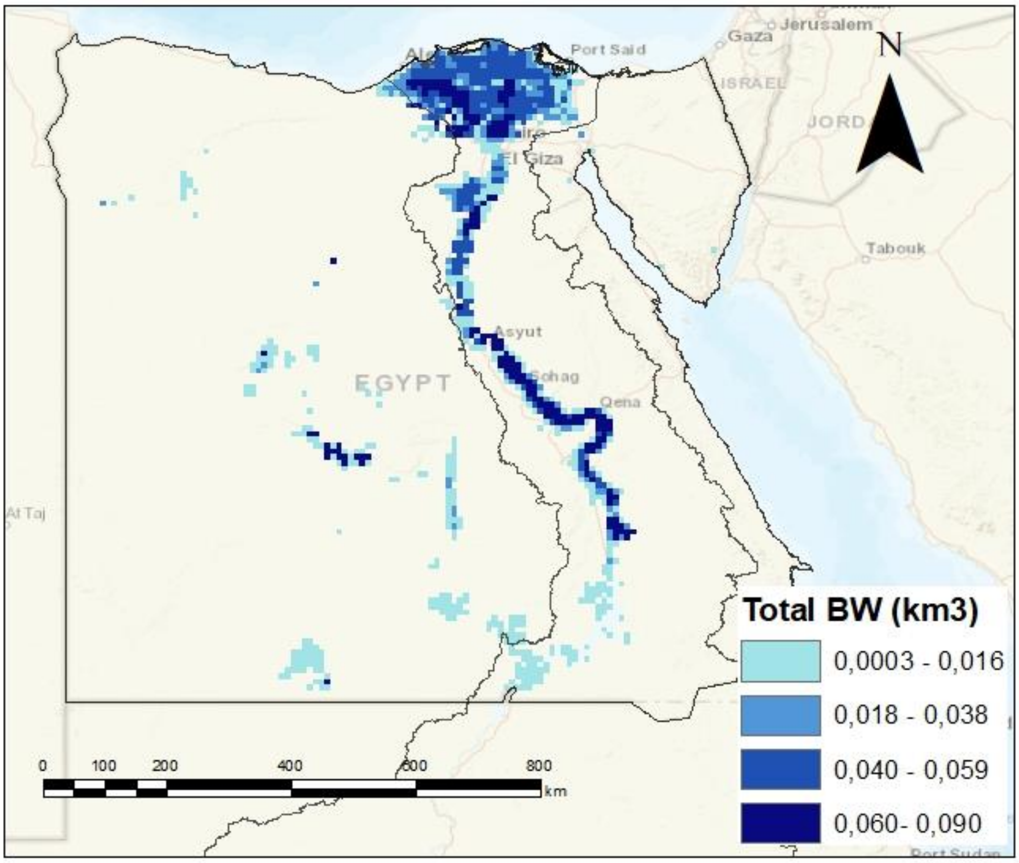

Figure 11 – Current total annual consumptive blue water (km^3) used under the baseline scenario.

3.3.2 Future scenarios

As documented in detail in the previous deliverable D2.2, future climate data show that the maximum and minimum temperatures undergo a significant upward shift. The alteration of the hydrological cycle caused by global warming also affects precipitation. The coastal area undergoes a decrease in precipitation, especially in 2100, whereas rainfall slightly increases in many desertic areas. Considering population projections, as reported in D2.1, under SSP2 a strong population increase is expected in Egypt: from 94 million people in 2010, 159 million are expected in 2050, and 223 million in 2100. The WATNEEDS modelling results for the different RCP scenarios and SSP projections are reported in the following sub-sections. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link.

3.3.2.1 RCP 4.5

Under the business-as-usual RCP 4.5 scenario, global warming is predicted to cause an increase in Egypt's temperatures. In the Southern regions, the increase of maximum temperature reaches 0.7°C in 2050 and 2°C in 2100. In 2050, this increase is limited to +0.4°C around the Delta. The percentage of demand closed by internal production per item and the blue water volumes obtained from the future scenarios under RCP 4.5 and SSP2 projections are reported in Table 7 for 2050 and in Table 8 for 2100. The future blue water demand associated with IFPRI cropland distribution is of 27.17 km^3/year in 2050 and 27.87 km^3/year in 2100, and green water demand of 0.75 km^3/year in 2050 and 0.47 km^3/year in 2100. Thus, there is a reduction in blue and green water demands in the future with respect to the baseline scenario and, on the contrary, a slight increase between 2050 and 2100. This is coherent with the trend of the crop water requirement (CWR, see Figure 12) that shows a decrease in the future with respect to 2010 and an increase from 2050 to 2100, for most of the crops analysed. This reduction in water volumes demand is linked to a decrease in the difference between maximum and minimum temperatures, indicated by ΔT (Table 6). For instance, from year 2010 to 2050 the maximum temperature ($Tmax_{mean}$) increases in average by +1.3 °C, while the minimum temperature ($Tmin_{mean}$) increases by +1.5°C. As result ΔT_{mean} in 2050 is lower than in 2010, while it slightly increases from 2050 to 2100. The crop water requirement, the blue and green water demands are sensitive to the variations in ΔT, as the reference evapotranspiration (ET_0), calculated following the formula of Hargreaves[34], depends on $(T_{max} - T_{min})^{0.5}$.

Table 6 – Average minimum and maximum temperature (Tmin, Tmax) in °C and average temperature variation (ΔT) in Egypt for RCP 4.5, for the years 2010, 2050 and 2100.

	2010	2050	2100
$Tmin_{mean}$	16.98	18.43	20.01
$Tmax_{mean}$	28.66	29.99	31.73
ΔT_{mean}	11.70	11.22	11.33

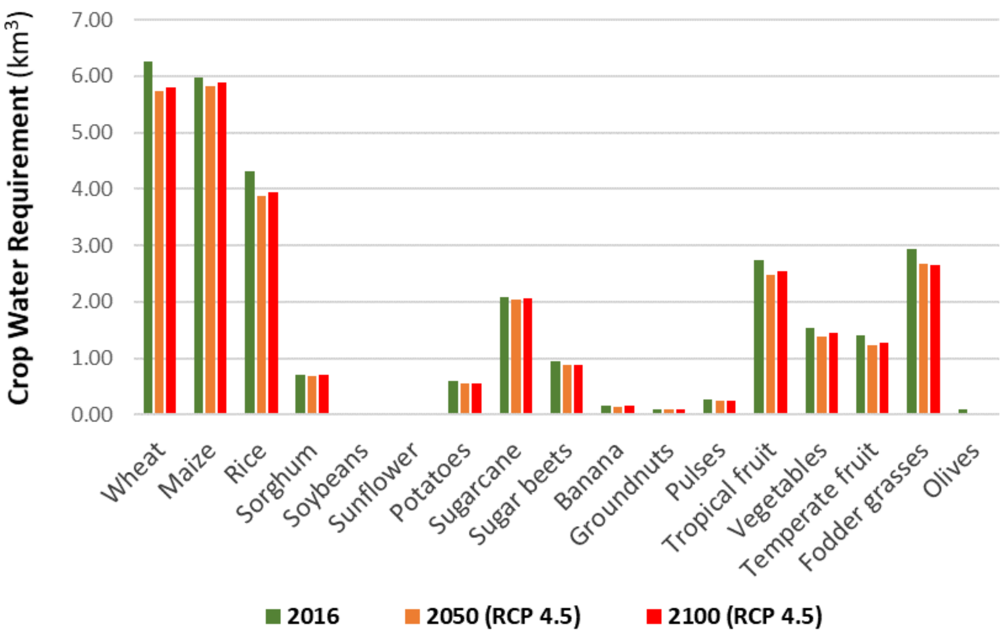

Figure 12 – Mean Crop Water Requirements (CWR) basing on the IFPRI cropland[38] under the baseline and the business-as-usual scenarios (RCP 4.5), considering three different temporal windowed cantered respectively in the years of 2016, 2050, and 2100. CWR is calculated per each crop as the sum of blue and green water requirements.

Table 7 – Main results in terms of percentage of gap closure of agricultural demand and blue water demand for the future business-as-usual scenario (RCP 4.5), considering the *average year* 2050. The production per crop is not reported as it remains the same of the baseline, only the demand changes accordingly to the scenario considered, due to increase in population.

2050 scenario (RCP 4.5)			
Crops	**Demand gap closure (%)**	**Water volumes (km^3)**	
		GW	**BW**
Fodder grasses	100	0.09	2.58
Sunflower	90.1	0.00	0.02
Olives	72.5	0.02	0.01
Groundnuts	71	0.00	0.08
Tropical fruit	65.1	0.09	2.40
Sugarcane	57.7	0.01	2.03
Rice	57.6	0.11	3.77
Banana	48.1	0.01	0.14
Potatoes	47.2	0.02	0.53
Sugar beets	47.2	0.02	0.85
Sorghum	35.3	0.01	0.67
Maize	31	0.15	5.67
Temperate fruit	30.7	0.04	1.20
Wheat	25.5	0.14	5.61
Vegetables	21.4	0.04	1.35
Pulses	4.5	0.01	0.23
Soybeans	1.1	0.00	0.03
Total/Mean	**47.41**	**0.75**	**27.17**

Table 8 – Main results in terms of percentage of closure of agricultural demand and blue water demand business-as-usual scenario (RCP 4.5), considering the *average year* 2100. The production per crop remains the same of the baseline, only the demand changes accordingly to the scenario considered, due to increase in population.

2100 scenario (RCP 4.5)			
Crops	**Demand gap closure (%)**	**Water volumes (km³)**	
		GW	**BW**
Fodder grasses	100	0.03	2.62
Sunflower	64.7	0.00	0.02
Olives	52	0.02	0.02
Groundnuts	51	0.00	0.09
Tropical fruit	46.7	0.06	2.47
Rice	41.4	0.08	3.86
Sugarcane	41.3	0.00	2.07
Banana	34.6	0.01	0.14
Potatoes	33.9	0.01	0.54
Sugar beets	33.9	0.00	0.88
Sorghum	25.2	0.00	0.70
Maize	22.3	0.03	5.87
Temperate fruit	22	0.04	1.23
Wheat	18.3	0.12	5.67
Vegetables	15.3	0.04	1.42
Pulses	3.2	0.01	0.24
Soybeans	0.8	0.00	0.03
Total/Mean	**35.68**	**0.46**	**27.87**

The future projections show that under the business-as-usual scenario there will be an increase of temperature extremes and a decrease in precipitation during the cropping seasons, which is exactly the season is which the green water is particularly needed. This means that the crop production will be more dependent on blue water, compared to the present baseline scenario.

3.3.2.2 RCP 2.6

Under the RCP 2.6 scenario, global warming will cause a more intense increase in the country's temperature in the first half of the century. Table 9 shows the variation of the average temperatures in Egypt according to this scenario. The percentage of demand closed by internal production per item and the blue water volumes obtained from the future scenarios under RCP 2.6 and SSP1 projections are reported in Table 10 for the year 2050 and in Table 11 for the year 2100. The future blue water demand associated with IFPRI cropland distribution is of 27.18 km^3/year in 2050 and 26.50 km3/year in 2100. This reduction is coherent with the average difference maximum and minimum temperatures, implied by RCP 2.6 scenario, and with the trend of the crop water requirement (Figure 13) that shows a decrease of CWR from 2050 to 2100, and with respect to the present. The future projections under RCP 2.6 show that there will be an intense increase of temperature extremes and a slight increase in precipitation in the first half of the century (thought their high interannual variability), as shown by the mesh plots of T2.2, which causes a reduction in the total volume of green water and a decrease of blue water volume, with respect to the baseline.

Table 9 – Average minimum and maximum temperature (Tmin, Tmax) in °C and average temperature variation (ΔT) in Egypt for RCP 2.6, for the *average years* 2010, 2050 and 2100.

	2010	2050	2100
$Tmin_{mean}$	16.98	27.29	27.54
$Tmax_{mean}$	28.66	36.52	36.30
ΔT_{mean}	11.70	16.39	16.31

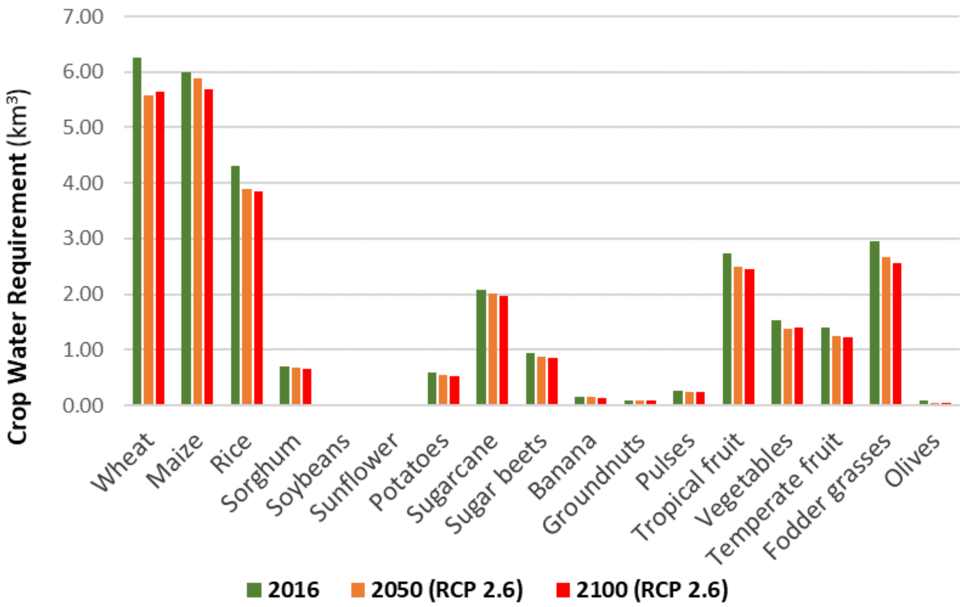

Figure 13 – Mean Crop Water Requirements (CWR) basing on the IFPRI cropland[38] for the future scenario (RCP 2.6), considering the *average year* 2050.

Table 10 – Main results in terms of percentage of gap closure of agricultural demand and blue water demand for the future scenario (RCP 2.6), considering the *average year* 2050. The production per crop remains the same of the baseline, only the demand changes accordingly to the scenario considered, due to increase in population.

2050 scenario (RCP 2.6)			
Crops	**Demand gap closure (%)**	**Water volumes (km³)**	
		GW	**BW**
Maize	31.07	0.05	5.83
Wheat	25.53	0.18	5.39
Rice	57.67	0.12	3.77
Fodder grasses	100	0.05	2.62
Tropical fruit	90.19	0.09	2.40
Sugarcane	57.57	0.00	2.02
Vegetables	58.60	0.06	1.33
Temperate fruit	47.23	0.05	1.20
Sugar beets	35.33	0.01	0.88
Sorghum	72.45	0.00	0.69
Potatoes	65.12	0.02	0.53
Pulses	27.93	0.01	0.24
Banana	48.17	0.01	0.14
Groundnuts	71.08	0.00	0.09
Soybeans	1.11	0.00	0.03
Olives	30.71	0.02	0.01
Sunflower	4.55	0.00	0.01
Mean/Total	**48.49**	**0.66**	**27.18**

Table 11 – Main results in terms of percentage of gap closure of agricultural demand and blue water demand future scenario (RCP 2.6), considering the *average year* 2100. The production per crop remains the same of the baseline, only the demand changes accordingly to the scenario considered, due to increase in population.

2100 scenario (RCP 2.6)			
Crops	**Demand gap closure (%)**	**Water volumes (km^3)**	
		GW	**BW**
Wheat	18.34	0.24	5.41
Maize	22.32	0.07	5.62
Rice	41.43	0.18	3.67
Sorghum	52.04	0.00	0.66
Soybeans	0.80	0.00	0.03
Sunflower	3.27	0.00	0.02
Potatoes	46.78	0.02	0.52
Sugarcane	41.36	0.00	1.97
Sugar beets	25.38	0.01	0.83
Banana	34.60	0.01	0.14
Groundnuts	51.06	0.00	0.08
Pulses	20.06	0.01	0.23
Tropical Fruit	64.79	0.10	2.34
Vegetables	42.10	0.06	1.33
Temperate Fruit	33.93	0.06	1.16
Fodder grasses	100	0.07	2.50
Olives	22.06	0.02	0.01
Mean/Total	**36.49**	**0.87**	**26.50**

3.3.2.3 RCP 8.5

RCP 8.5 scenario is considered the worst climate change scenario in terms of emissions and global warming, and shows the highest variation in temperatures, as reported by Table 12. It has been coupled with SSP5 to obtain the future demand for food under this scenario. Results obtained in term of demand gap closure and water volumes are reported in Table 13 for 2050 and in Table 14 for 2100. The future blue water demand associated with IFPRI cropland distribution for the future scenario RCP 8.5 is of 27.14 km^3/year in 2050 and 28.85 km^3/year in 2100. An increase in the blue water demand is coherent with the average difference maximum and minimum temperatures or RCP 8.5 and with the results obtained in future scenario RCP 4.5. Figure 14 shows the crop water requirements in the future, in comparison to the baseline. It can be observed that, similarly to RCP 4.5, a reduction in CWR from 2016 to 2050 occurs, and an increase from 2050 to 2100. On the other hand, the future projections under RCP 8.5 show an intense increase of temperature extremes and a decrease in precipitation (and higher variability), which causes an increase in the volume of green water and a consequent increase of blue water volume.

Table 12 – Average minimum and maximum temperature (Tmin, Tmax) in °C and average temperature variation (ΔT) in Egypt for RCP 8.5, for the years 2010, 2050 and 2100.

	2010	2050	2100
$Tmin_{mean}$	16.98	28.60	30.60
$Tmax_{mean}$	28.66	37.59	39.63
ΔT_{mean}	11.70	16.15	15.79

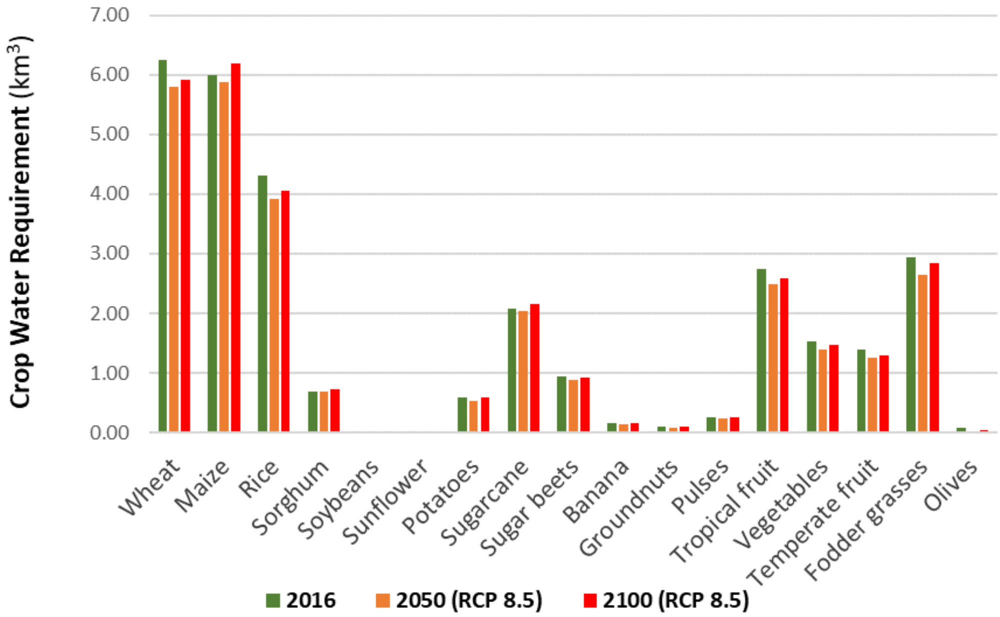

Figure 14 – Mean Crop Water Requirements (CWR) basing on the IFPRI cropland[38] for future scenario (RCP 8.5), considering the year 2050.

Table 13 – Main results in terms of percentage of gap closure of agricultural demand and blue water demand for future scenario (RCP 8.5), considering the year 2050

2050 scenario (RCP 8.5)			
Crops	**Demand gap closure (%)**	**Water volumes (km^3)**	
		GW	**BW**
Wheat	25.53	0.29	5.50
Maize	31.07	0.06	5.81
Rice	57.67	0.22	3.71
Sorghum	72.45	0.00	0.69
Soybeans	1.11	0.00	0.03
Sunflower	4.55	0.00	0.02
Potatoes	65.12	0.01	0.53
Sugarcane	57.57	0.01	2.03
Sugar beets	35.33	0.01	0.87
Banana	48.17	0.01	0.14
Groundnuts	71.08	0.00	0.09
Pulses	27.93	0.00	0.23
Tropical Fruit	90.19	0.11	2.39
Vegetables	58.60	0.07	1.32
Temperate Fruit	47.23	0.07	1.18
Fodder grasses	100	0.06	2.59
Olives	30.71	0.02	0.01
Mean/Total	**48.49**	**0.94**	**27.14**

Table 14 – Main results in terms of percentage of gap closure of agricultural demand and blue water demand for the future scenario (RCP 8.5), considering the year 2100.

2100 scenario (RCP 8.5)			
Crops	**Demand gap closure (%)**	**Water volumes (km^3)**	
		GW	**BW**
Wheat	18.34	0.14	5.79
Maize	22.32	0.03	6.16
Rice	41.43	0.09	3.96
Sorghum	52.04	0.00	0.72
Soybeans	0.80	0.00	0.03
Sunflower	3.27	0.00	0.02
Potatoes	46.78	0.01	0.57
Sugarcane	41.36	0.00	2.16
Sugar beets	25.38	0.01	0.92
Banana	34.60	0.01	0.15
Groundnuts	51.06	0.00	0.09
Pulses	20.06	0.01	0.25
Tropical Fruit	64.79	0.07	2.52
Vegetables	42.10	0.04	1.43
Temperate Fruit	33.93	0.04	1.26
Fodder grasses	100	0.04	2.80
Olives	22.06	0.02	0.02
Mean/Total	**36.49**	**0.50**	**28.85**

3.1.3 Cropland Reallocation

In this section, the main results obtained from crop reallocation that maximizes *water productivity* towards the closure of demand gap, are reported, in terms of percentage of closure of diet demand and volume of blue water, under a baseline scenario and future projections (RCP 4.5, 2.6, 8.5) of climate. Four diet and intensification scenarios (described in Section 2) have been considered and compared. The economic gain, associated with the economic value per crop, has also been calculated for each reallocation scenario and compared to the baseline crop distribution. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link.

3.1.3.1 Baseline (Present) scenario

Table 15-Table 18 report the main results for each diet and intensification scenario for the present, while Figure 15 shows the economic value associated with each crop under the baseline reallocation scenario. Table 15 reports the blue water consumption for agricultural production after crop reallocation. Table 16 and Table 17 report respectively the percentage of demand satisfied by internal crop production for the two considered trade scenarios. In Table 18 the total production per crop is reported for each scenario and compared to the baseline. The percentage of demand closure for the Surplus-Deficit Trade scenario has been calculated as the fraction of actual demand for crops of the population that can be satisfied through domestic agricultural production, after reallocation (Table 16). For the constant Trade scenario the constant import and export fluxes have been summed to the domestic production to adjust the fraction of demand that can be covered by internal production after crop reallocation. The calculated domestic production (Table 18) remains the same in the two trade scenarios. From the baseline scenario before reallocation (Table 5), it emerged that the internal production cannot satisfy the population diet demand for important crops (e.g., cereals, soybean, sugarcane, sunflowers, sugar beets). On the contrary, through reallocation the production of these crops has been increased, reaching self-sufficiency in production for almost all of them. In particular, in the present scenario cropland reallocation increases the production of crops characterized by high water and that have high production gaps, i.e., wheat (57%), maize (47%), soybean (98%), and sunflower (92%). When the balanced diet of Willett et al.[43] is considered, the production of crops, that should be consumed in lower quantities accordingly to a daily balanced diet, is reduced (for instance sugarcane production is reduced of 50%, Table 18), while an increase in production of other crops that are more present in the diet (e.g.

soybean, pulses, sunflower and groundnuts) can be seen. Crop reallocation coupled with intensification (and diet shift) enables the complete closure of demand (100%), in the Surplus-Deficit Trade scenario (D0I1 and D1I1, Table 15), and around the 95% in the Constant Trade scenario (D0I1 and D1I1, Table 16). Concerning the consumption of blue water, in a baseline scenario, the maximization of the Water Productivity reaches the best results when the only intensification is applied (D0 I1, Table 15), consuming only 26.55 km^3 of water. The scenario consuming more water (D1I0) enhances to increase production towards the satisfaction of the balanced diet, with a blue water increase of only 5% with respect to the baseline. In Figure 15 we report the spatial distribution of harvested areas after baseline reallocation for the five main irrigated crops in Egypt.

Table 15 – Agricultural blue water consumption (BW) after crop reallocation in the baseline-present scenario, in different diet and intensification conditions.

Reallocation Baseline				
Crops/Scenario	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	11.27	7.37	6.5	3.74
Maize	8.71	7.66	6.46	5.66
Rice	0.56	0.86	0.17	0.18
Sugar beet	0.6	0.69	0.29	0.34
Soybean	2.45	5.01	6.41	10.45
Tropical Fruits	1.57	1.57	1.13	1.03
Potato	0.19	0.3	0.17	0.19
Vegetables	1.17	0.74	0.6	0.41
Pulses	0.26	0.39	0.83	1.19
Sunflower	0.1	0.11	0.37	0.31
Sugarcane	0.28	0.53	0.04	0.16
Temperate Fruits	1.16	1	0.78	0.73
Olives	0.47	0	2.62	1.19
Sorghum	0.28	0.05	0.2	0.01
Banana	0.03	0.11	0.02	0.09
Groundnuts	0.06	0.08	2.66	2.71
Fodder grasses	0.25	0.08	0.22	0.12
Tot	**29.41**	**26.55**	**29.49**	**28.49**

Table 16 - Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the baseline-present, in different diet and intensification conditions.

Reallocation baseline:				
Trade Surplus-deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	91.31	100	90.27	100
Maize	90.46	100	94.87	100
Rice	100	100	90.00	100
Sugar beet	94.14	100	100	100
Soybean	95.24	100	97.20	100
Tropical Fruits	90.00	100	90.00	100
Potato	90.36	100	100	100
Vegetables	95.41	100	100	100
Pulses	90.71	100	90.00	100
Sunflower	90.00	100	90.00	100
Sugarcane	90.22	100	100	100
Temperate Fruits	90.00	100	90.00	100
Olives	93.20	100	92.86	100
Sorghum	90.01	100	90.00	100
Banana	90.00	100	90.00	100
Groundnuts	90.00	100	90.05	100
Fodder grasses	93.91	100	100	100
Tot	**92.06**	**100**	**93.84**	**100**

Table 17 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the baseline-present, in different diet and intensification conditions.

Reallocation baseline				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	100	100	100	100
Maize	100	100	100	100
Rice	98.62	98.62	86.78	96.78
Sugar beet	96.27	100	100	100
Soybean	100	100	100	100
Tropical Fruits	87.83	97.83	86.97	96.97
Potato	71.84	81.49	70.57	70.57
Vegetables	90.71	100	100	100
Pulses	100	100	100	100
Sunflower	99.09	100	93.43	100
Sugarcane	91.75	100	100	100
Temperate Fruits	57.00	67.00	42.69	52.69
Olives	89.13	95.93	91.90	99.04
Sorghum	90.01	100	90.00	100
Banana	91.99	100	92.77	100
Groundnuts	69.73	79.73	89.20	99.16
Fodder grasses	93.91	100	100	100
Tot	**89.88**	**95.33**	**90.84**	**95.01**

Table 18- Production (tonnes) after crop reallocation for the baseline-present, in different diet and intensification conditions.

Reallocation baseline					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	16,917,068.76	18,527,846.14	9,093,179.93	10,073,462.06	8,034,210.01
Maize	12,338,680.45	13,639,886.82	10,376,168.01	10,937,011.66	7,198,587.14
Rice	5,280,548.74	5,280,548.74	2,041,247.21	2,268,052.46	5,172,591.85
Sugar beet	10,791,186.21	11,463,124.34	5,333,078.80	5,333,078.80	6,878,535.73
Soybean	1,602,945.94	1,683,076.75	3,782,984.99	3,891,802.15	31,790.64
Tropical Fruits	4,970,282.30	5,522,535.89	3,569,656.75	3,966,285.28	8,459,799.33
Potato	3,167,387.64	3,505,466.40	2,205,051.44	2,205,051.44	3,876,923.60
Vegetables	16,578,334.85	21,671,914.18	14,285,973.68	15,057,484.78	17,294,189.59
Pulses	474,670.50	710,685.74	1,705,346.65	2,463,278.49	248,219.13
Sunflower	386,094.19	428,993.54	1,024,634.57	1,138,482.86	33,150.02
Sugarcane	14,441,719.24	16,006,725.69	7,844,151.10	7,844,151.10	15,652,396.58
Temperate Fruits	3,354,874.75	3,727,638.61	2,340,025.14	2,600,027.93	2,990,231.50
Olives	778,942.18	835,785.70	3,290,675.85	3,543,808.14	435,917.51
Sorghum	566,093.63	628,924.73	475,026.09	527,806.77	773,914.03
Banana	1,174,704.66	1,305,227.40	845,787.36	939,763.73	1,067,894.15
Groundnuts	150,972.53	167,747.25	3,623,881.40	4,024,457.84	202,505.15
Fodder grasses	7,676,017.26	8,173,933.50	9,239,153.56	9,239,153.56	48,007,813.04

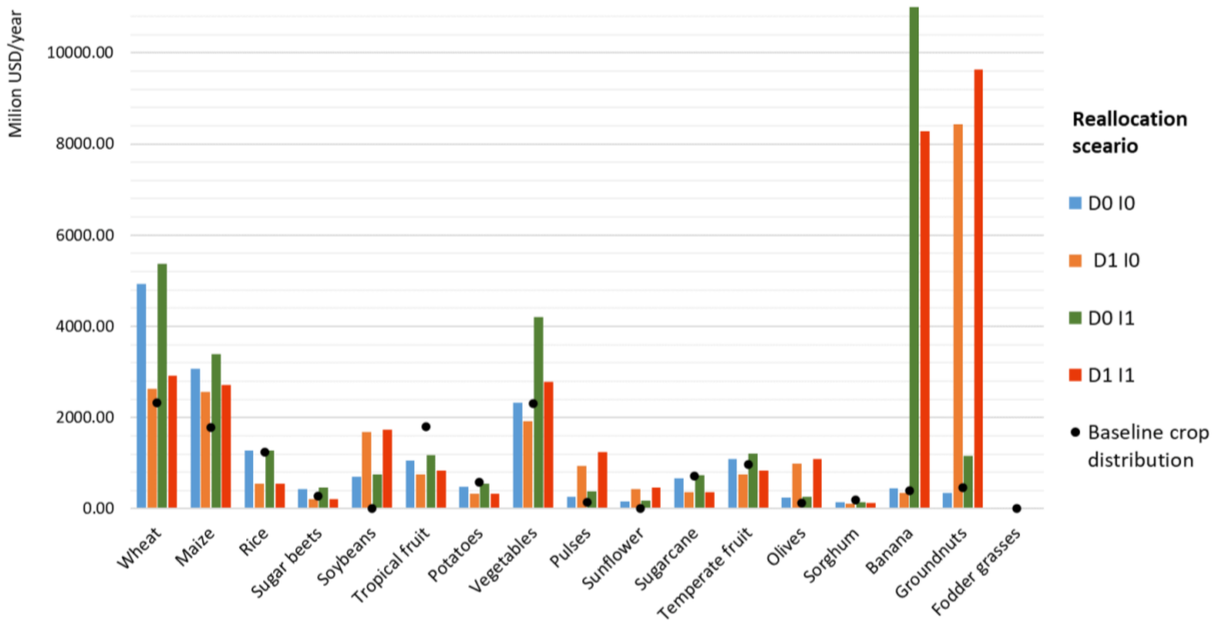

Figure 15 – Economic value of each crop, calculated in terms of producers 'gain[15], under four different reallocation scenarios, in the present, and compared to the baseline (black dots).

The shift to the balanced diet of Willett et al.[43] tackles both the problem of overnutrition and anemia, decreasing the average daily kcal intake for the first, while increasing the vegetal protein intake for the second; however, no strong differences in the blue water required by the two diets is observed. This occurs because growing some of the crops included in the Willett et al.[43] diet (e.g., soybean, pulses, cereals, olives, groundnuts; Figure 9) might be water-costly due to the arid climatic condition of the Egyptian region. A possible solution to this issue might be substituting them with other crops that are more suitable for Egypt's climate and soil. Nevertheless, in the baseline scenario, the diet shift increases the economic gain associated with crops that are most present in Willett's diet[43] (e.g. vegetables, banana, wheat, maize), while the intensification shift increases the economic value of crops that are produced in higher quantities under an intensification scenario (e.g. groundnuts, soybeans). High economic income is generated from the production of groundnuts (in the scenarios D1I0 and D1I1) and banana (in D0I1 and D1I1, in Figure 14). When the production of these valuable crops increases reaching the closure of the demand, the associated economic income can increase up to 10 times, and this offers the possibility to increase exports and gains. The modelling outcomes show that the coupling between a balanced diet and yield intensification leads to the most convenient results from an economic point of view.

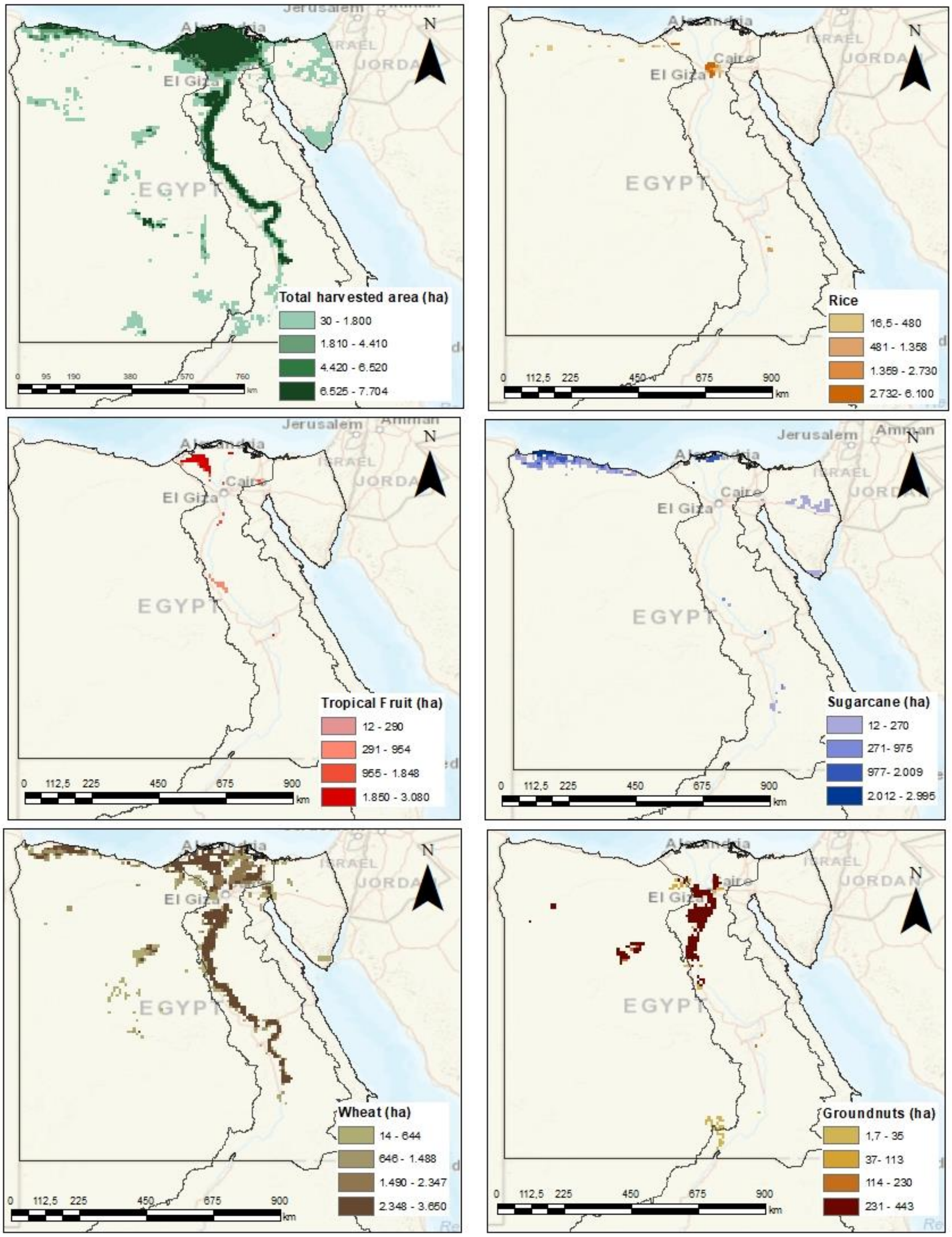

Figure 16 - Total harvested area and harvested areas (ha) for the five main irrigated crops, after baseline reallocation, for the scenario D0I0.

3.1.3.2 Future scenario RCP 4.5

Table 19-Table 26 report the main results for each diet and intensification scenarios for the future RCP 4.5 scenario, while Figure 17 and Figure 18 show the economic value associated with each crop under the reallocation scenario. The results show that crop reallocation succeeds in reducing the blue water demand when intensification is applied. The maximum blue water saving is obtained for the scenario D1I0, for the year 2050 (Table 19), while D1I1 for 2100 (Table 23). High performance in satisfaction of the demand based on the diet have been obtained when intensification is introduced (D0I1 and D1I1, Table 20, Table 21 and Table 24, Table 25), reaching the best performance when intensification is coupled with a balanced diet (D1I1), reaching an average of demand satisfaction of 84%, in 2050 (Table 20), and 67%, in 2100 (Table 24) for the Surplus-Deficit Trade scenario and of 89%, in 2050 (Table 21), and 71%, in 2100 (Table 25) for the Constant Trade scenario. The strong increase of demand due to population growth in the future and the simultaneous increase in temperature predicted by RCP 4.5, make yield intensification fundamental to enhance future self-sufficiency and the additional contribution of a balanced diet will add nutrition benefits, by reducing an excessive intake of kcal and balancing the protein intake. Overall, depending on the reallocation scenario considered, crop reallocation enhances an increase in production for crops that are fundamental to close the demand gap. Considering a scenario with a shift to a balanced diet (D1I0), new allocated areas increase the production of vegetables, groundnuts, pulses, olives, that are more present in the balanced diet of Willett et al.[43] with respect to the current baseline crop distribution and decrease, for instance, the production of sugarcane (of 55% in D1I0, Table 22 and Table 26). While considering an intensification scenario (D0I1), crops with high yield increase (wheat, sunflower, sugar beet, sugarcane, vegetables, temperate fruit) offer higher production, towards the closure of the demand gap (Table 22 and Table 26). When intensification is coupled with diet shift (D1I1) the benefits of both diet shift and intensification are applied to define the new reallocated areas. Moreover, crop reallocation in future projection RCP 4.5 shows that economic gain increases when reallocation is applied (Figure 17 and Figure 18), also without intensification or diet shift (D0I0), however, the highest gain is reached again in D1I1 scenario; thus, when both a balanced diet and yield intensification are applied. The maximum overall gain obtained by crop production after reallocation is almost 28 billion USD/year for 2050, and about 29 billion USD/year for 2100 (D1I1 scenario), as compared to 13 billion USD/year if crop reallocation is not performed.

Table 19 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 4.5 (*average year* 2050), in different diet and intensification conditions.

2050 scenario (RCP 4.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	11.27	9.88	6.65	4.99
Maize	8.12	7.45	5.93	5.05
Rice	0.65	0.63	0.18	0.33
Sugar beet	0.37	0.71	0.16	0.32
Soybean	2.21	2.68	5.47	7.04
Tropical Fruits	1.54	2.64	0.96	1.50
Potato	0.20	0.41	0.12	0.23
Vegetables	1.04	1.37	1.06	0.96
Pulses	0.26	0.22	0.78	0.89
Sunflower	0.09	0.18	0.38	0.77
Sugarcane	0.77	0.82	0.23	0.51
Temperate Fruits	1.13	1.69	0.84	1.43
Olives	0.52	0.00	2.73	1.30
Sorghum	0.22	0.00	0.14	0.00
Banana	0.04	0.18	0.02	0.11
Groundnuts	0.05	0.01	2.52	3.31
Fodder grasses	0.12	0.09	0.30	0.09
Tot	**28.60**	**28.94**	**28.47**	**28.83**

Table 20 - Percentage of demand satisfaction after crop reallocation in the Surplus-Deficit Trade scenario, for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 4.5)				
Trade Surplus-deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	54.34	62.07	53.15	65.08
Maize	53.32	54.00	54.27	54.95
Rice	78.05	78.05	53.00	100
Sugar beet	55.66	100	57.93	100
Soybean	56.46	58.88	55.71	53.54
Tropical Fruits	53.00	100	53.00	100
Potato	53.24	100	53.01	100
Vegetables	51.77	100	87.89	100
Pulses	53.00	53.51	53.00	53.00
Sunflower	53.00	100	53.01	100
Sugarcane	53.00	100	53.00	100
Temperate Fruits	53.00	86.56	53.00	100
Olives	59.64	56.93	54.89	53.10
Sorghum	53.00	100	53.00	100
Banana	53.00	100	53.00	100
Groundnuts	53.00	53.01	53.00	53.02
Fodder grasses	62.79	100	100	100
Tot	**55.84**	**82.53**	**58.46**	**84.28**

Table 21 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 4.5)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	89.17	96.90	100	100
Maize	89.06	89.74	98.84	99.52
Rice	77.23	77.23	51.10	98.10
Sugar beet	56.91	100	60.62	100
Soybean	100	100	82.85	80.68
Tropical Fruits	51.72	98.72	51.22	98.22
Potato	42.33	89.10	35.68	82.67
Vegetables	49.01	100	83.85	100
Pulses	100	100	67.95	67.95
Sunflower	58.35	100	55.03	100
Sugarcane	53.90	100	54.83	100
Temperate Fruits	33.57	67.13	25.15	72.15
Olives	57.24	54.54	54.33	52.53
Sorghum	53.00	100	53.00	100
Banana	54.17	100	54.63	100
Groundnuts	41.07	41.08	52.51	52.52
Fodder grasses	62.79	100	100	100
Tot	**62.91**	**89.08**	**63.62**	**88.49**

Table 22 - Production (tonnes) after crop reallocation for the RCP 4.5, year 2050, in different diet and intensification conditions.

2050 scenario (RCP 4.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	17,101,207.47	19,533,704.59	9,094,186.43	11,134,632.22	8,034,210.01
Maize	12,352,383.62	12,510,118.45	10,081,508.04	10,206,579.17	7,198,587.14
Rice	6,999,659.88	6,999,659.88	2,041,615.10	3,852,103.97	5,172,591.85
Sugar beet	10,836,300.40	19,469,191.09	5,246,754.33	9,057,803.72	6,878,535.73
Soybean	1,613,898.59	1,683,035.55	3,682,311.59	3,538,694.29	31,790.64
Tropical Fruits	4,971,178.08	9,379,581.29	3,570,300.10	6,736,415.28	8,459,799.33
Potato	3,169,484.91	5,953,751.63	1,985,389.67	3,745,101.83	3,876,923.60
Vegetables	15,278,627.97	35,437,602.81	17,746,641.93	24,101,805.68	17,294,189.59
Pulses	471,055.25	475,556.84	1,705,654.00	1,705,654.00	248,219.13
Sunflower	386,163.77	728,610.89	1,025,059.87	1,933,621.20	33,150.02
Sugarcane	14,408,649.48	27,186,131.10	7,061,008.35	13,322,657.26	15,652,396.58
Temperate Fruits	3,355,479.39	5,479,973.46	2,340,446.88	4,415,937.50	2,990,231.50
Olives	846,551.48	808,171.34	3,303,895.23	3,195,746.25	435,917.51
Sorghum	566,134.27	1,068,177.87	475,111.71	896,437.18	773,914.03
Banana	1,174,916.38	2,216,823.35	845,939.79	1,596,112.81	1,067,894.15
Groundnuts	150,999.74	151,037.40	3,622,968.70	3,623,877.79	202,505.15
Fodder grasses	8,717,058.74	13,882,766.03	15,691,956.28	15,691,956.28	48,007,813.04

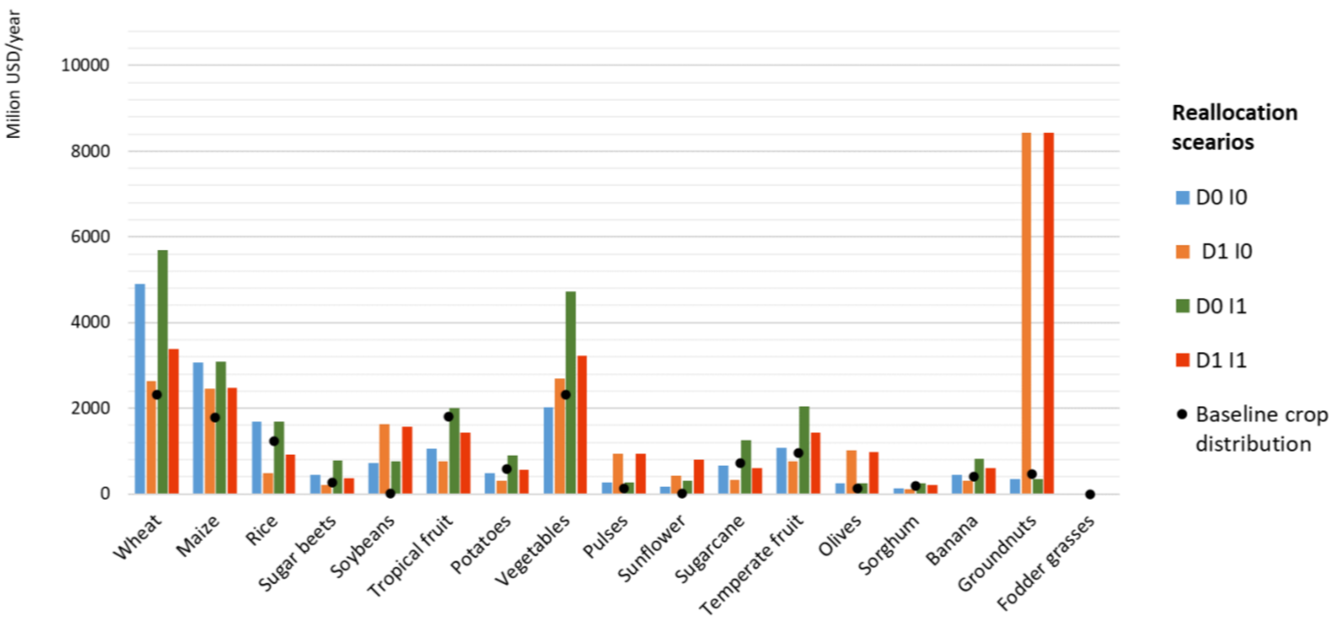

Figure 17 – Economic value of each crop in 2050, calculated in terms of producers 'gain[15], under four different reallocation future scenario (under RCP 4.5), and compared to the baseline (black dots).

Table 23 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 4.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	11.41	9.08	6.52	4.16
Maize	8.59	7.14	6.23	5.26
Rice	0.58	0.58	0.19	0.37
Sugar beet	0.40	1.10	0.18	0.46
Soybean	2.38	3.27	5.86	7.87
Tropical Fruits	1.49	1.53	1.05	1.61
Potato	0.20	0.68	0.13	0.38
Vegetables	1.04	1.83	0.85	1.28
Pulses	0.28	0.23	0.87	0.87
Sunflower	0.09	0.40	0.39	0.87
Sugarcane	0.62	1.45	0.25	0.70
Temperate Fruits	1.20	1.15	0.80	0.80
Olives	0.56	0.00	2.77	1.20
Sorghum	0.21	0.10	0.15	0.00
Banana	0.04	0.25	0.03	0.19
Groundnuts	0.10	0.12	2.58	3.30
Fodder grasses	0.14	0.37	0.52	0.37
Tot	**29.31**	**29.28**	**29.38**	**29.68**

Table 24- Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 4.5)				
Trade Surplus-deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	39.02	38.54	38.18	38.00
Maize	38.22	38.00	39.22	39.10
Rice	55.48	55.48	38.00	100
Sugar beet	40.71	100	42.20	100
Soybean	40.51	40.45	40.20	38.26
Tropical Fruits	38.00	38.39	38.00	69.00
Potato	38.05	100	38.01	100
Vegetables	36.86	100	52.20	100
Pulses	38.30	38.00	38.00	38.00
Sunflower	38.00	100	38.02	71.29
Sugarcane	38.00	100	38.00	100
Temperate Fruits	38.00	38.00	38.00	38.00
Olives	42.18	41.13	38.87	38.02
Sorghum	38.00	38.89	38.00	38.00
Banana	38.00	100	38.00	100
Groundnuts	38.00	38.05	38.00	38.00
Fodder grasses	47.04	100	100	100
Tot	**40.14**	**65.00**	**42.99**	**67.39**

Table 25- Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 4.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	64.03	63.55	84.19	84.01
Maize	63.90	63.67	71.23	71.11
Rice	54.89	54.89	36.64	98.64
Sugar beet	41.61	100	44.13	100
Soybean	85.59	85.53	59.69	57.75
Tropical Fruits	37.08	37.47	36.72	67.72
Potato	30.22	92.17	25.56	87.55
Vegetables	34.88	100	49.29	100
Pulses	77.18	76.88	48.74	48.74
Sunflower	41.85	100	39.47	72.74
Sugarcane	38.64	100	39.32	100
Temperate Fruits	24.04	24.04	17.99	17.99
Olives	40.46	39.41	38.47	37.61
Sorghum	38.00	38.89	38.00	38.00
Banana	38.84	100	39.17	100
Groundnuts	29.43	29.48	37.65	37.64
Fodder grasses	47.04	100	100	100
Tot	**46.33**	**70.94**	**47.43**	**71.74**

Table 26- Production (tonnes) after crop reallocation for the RCP 4.5, year 2100, in different diet and intensification conditions.

2100 scenario (RCP 4.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	17,092,403.74	16,881,820.13	9,093,895.63	9,050,625.35	8,034,210.01
Maize	12,327,398.26	12,254,923.34	10,141,164.32	10,110,321.06	7,198,587.14
Rice	6,926,701.87	6,926,701.87	2,037,759.51	5,362,525.02	5,172,591.85
Sugar beet	11,034,380.16	27,103,116.94	5,320,911.22	12,609,394.62	6,878,535.73
Soybean	1,611,947.24	1,609,764.59	3,698,614.39	3,520,380.93	31,790.64
Tropical Fruits	4,961,790.00	5,012,099.37	3,563,557.58	6,470,602.82	8,459,799.33
Potato	3,153,333.25	8,288,234.77	1,981,573.55	5,213,567.03	3,876,923.60
Vegetables	15,144,162.48	48,884,508.16	14,672,525.97	33,960,104.85	17,294,189.59
Pulses	473,877.52	470,165.67	1,702,432.87	1,702,432.87	248,219.13
Sunflower	385,434.50	1,014,301.31	1,023,515.94	1,918,941.09	33,150.02
Sugarcane	14,381,438.70	37,845,891.33	7,047,673.61	18,546,509.50	15,652,396.58
Temperate Fruits	3,349,142.56	3,349,142.56	2,336,026.94	2,336,026.94	2,990,231.50
Olives	833,455.03	812,844.76	3,257,114.02	3,185,707.75	435,917.51
Sorghum	565,065.13	578,285.41	474,214.46	474,214.46	773,914.03
Banana	1,172,697.54	3,086,046.17	844,342.23	2,221,953.24	1,067,894.15
Groundnuts	150,714.57	150,918.95	3,616,117.14	3,615,842.87	202,505.15
Fodder grasses	9,091,650.24	19,326,238.54	21,844,817.50	21,844,817.50	48,007,813.04
Tot	**102,655,592.81**	**193,595,003.86**	**92,656,256.88**	**142,143,967.90**	**126,358,668.99**

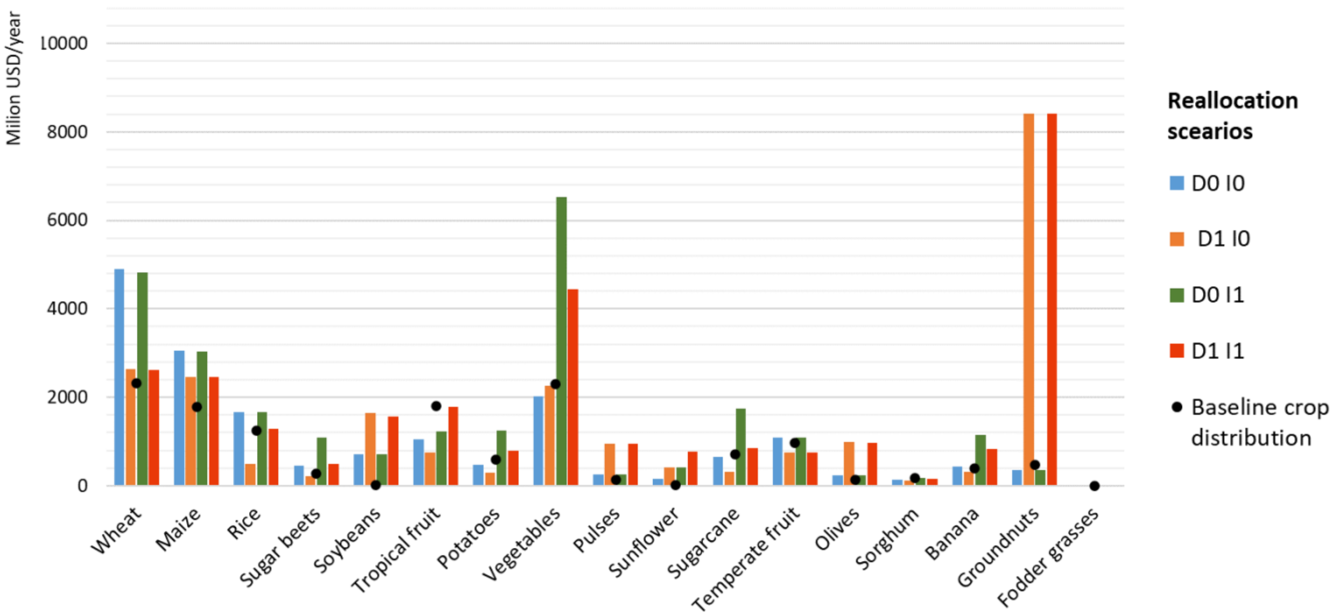

Figure 18 – Economic value of each crop in 2100, calculated in terms of producers 'gain[15], under four different reallocation future scenario (under RCP 4.5), and compared to the baseline (black dots).

3.1.3.3 Future scenario RCP 2.6

Table 27-Table 34 report the main results for each diet and intensification scenarios for future RCP 2.6 scenario, Figure 19 and Figure 20 show the economic value associated to each crop under reallocation scenarios. Analogously to the results obtained for future scenario RCP 4.5, the best results in term of blue water savings from crop reallocation are obtained for the scenario D1 I1 for 2050 (Table 27), and D0I1 in 2100 (Table 31). The demand results satisfied by 84% in 2050, and 68% in 2100, in average in D1I1 scenario (Table 28 and Table 32, respectively), considering a Surplus-Deficit Trade scenario. While internal production after reallocation results to satisfy the 88% in 2050, and 72% in 2100, in average in D1I1 scenario (Table 29 and Table 33, respectively), considering a Constant Trade scenario. In 2050, important increase in production can be seen for pulses, wheat and sugar beet, for all four scenarios, while banana and vegetable production is enhanced more evidently in D1 scenarios (Table 30). In 2100, important increase in soybean and sunflower production can be seen for all the scenarios, while groundnuts and olives are privileged when the balanced diet is applied (D1,Table 34). Reallocation performed for the year 2100 gives slightly better results in term of economic gain, thanks to a decisive increase in groundnuts production, reaching an overall income of about 29,6 billion USD/year (D1I1), against about 26,3 billion USD/year in 2050 (D1I1). High economic income is generated especially from the production of bananas and groundnuts (in the scenarios D1I0 and D1I1, Table 30 and Table 34), as they are the main cash crops, that can generate highest benefits in terms of economic gain associated to their export.

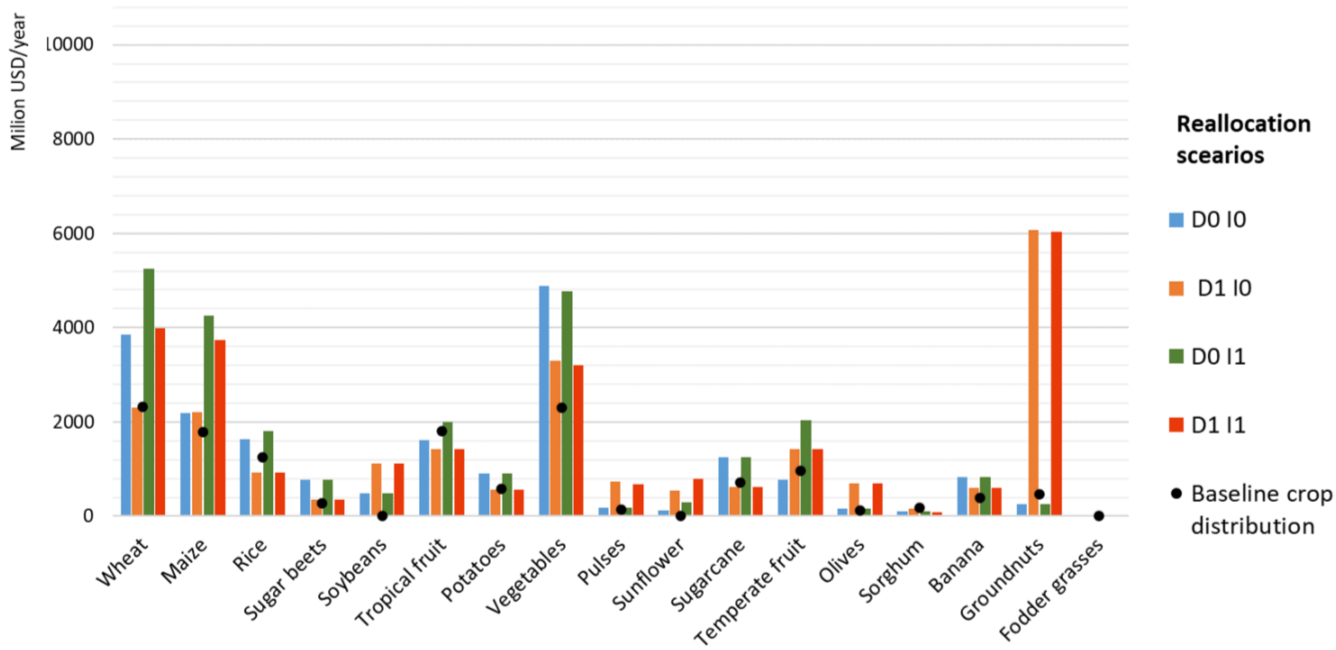

Figure 19 – Economic value of each crop in 2050, calculated in terms of producers 'gain[15], under four different reallocation future scenario (under RCP 2.6), and compared to the baseline (black dots).

Table 27 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 2.6)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	10.94	9.91	6.34	4.68
Maize	8.61	7.44	6.35	5.31
Rice	0.60	0.59	0.18	0.32
Sugar beet	0.42	0.88	0.18	0.41
Soybean	2.34	3.16	5.68	7.50
Tropical Fruits	1.43	2.59	0.94	1.54
Potato	0.21	0.46	0.14	0.26
Vegetables	1.01	1.21	0.80	0.81
Pulses	0.25	0.14	0.87	0.89
Sunflower	0.10	0.16	0.36	0.67
Sugarcane	0.49	0.69	0.15	0.41
Temperate Fruits	1.16	1.35	0.81	1.37
Olives	0.50	0.00	2.74	0.92
Sorghum	0.20	0.00	0.16	0.00
Banana	0.03	0.18	0.03	0.08
Groundnuts	0.10	0.06	2.51	3.50
Fodder grasses	0.13	0.23	0.44	0.30
Tot	**28.53**	**29.04**	**28.69**	**28.97**

Table 28– Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 2.6)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	54.11	63.52	53.07	64.24
Maize	53.30	53.02	54.56	55.08
Rice	77.62	77.62	53.00	100
Sugar beet	56.75	100	59.06	100
Soybean	56.50	58.96	56.32	54.06
Tropical Fruits	53.00	100	53.00	100
Potato	53.46	100	53.02	100
Vegetables	51.32	100	80.00	100
Pulses	53.42	53.00	53.00	53.00
Sunflower	53.00	100	53.00	100
Sugarcane	53.00	100	53.00	100
Temperate Fruits	53.00	70.23	53.00	100
Olives	56.15	54.57	54.18	53.49
Sorghum	53.00	100	53.00	100
Banana	53.00	100	53.00	100
Groundnuts	53.00	54.74	53.01	53.25
Fodder grasses	56.39	100	100	100
Tot	**55.30**	**81.51**	**58.07**	**84.30**

Table 29 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 2.6)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	88.94	98.35	100	100
Maize	89.03	88.75	99.13	99.65
Rice	76.81	76.81	51.10	98.10
Sugar beet	58.00	100	61.75	100
Soybean	100	100	83.46	81.20
Tropical Fruits	51.72	98.72	51.22	98.22
Potato	42.55	89.10	35.69	82.67
Vegetables	48.55	100	75.96	100
Pulses	100	100	67.95	67.95
Sunflower	58.35	100	55.02	100
Sugarcane	53.90	100	54.83	100
Temperate Fruits	33.57	50.80	25.15	72.15
Olives	53.76	52.17	53.62	52.92
Sorghum	53.00	100	53.00	100
Banana	54.17	100	54.63	100
Groundnuts	41.07	42.81	52.51	52.76
Fodder grasses	56.39	100	100	100
Tot	**62.34**	**88.09**	**63.24**	**88.57**

Table 30- Production (tonnes) after crop reallocation for the RCP 2.6, year 2050, in different diet and intensification conditions.

2050 scenario (RCP 2.6)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	17,028,551.95	19,989,908.38	9,079,293.14	10,990,399.55	8,034,210.01
Maize	12,347,048.74	12,281,859.83	10,134,632.86	10,230,875.16	7,198,587.14
Rice	6,961,335.87	6,961,335.87	2,041,615.10	3,852,103.97	5,172,591.85
Sugar beet	11,048,692.24	19,469,191.09	5,349,247.59	9,057,803.72	6,878,535.73
Soybean	1,615,103.73	1,685,509.51	3,722,389.88	3,573,418.84	31,790.64
Tropical Fruits	4,971,178.08	9,379,581.29	3,570,300.10	6,736,415.28	8,459,799.33
Potato	3,182,594.54	5,953,751.63	1,985,474.95	3,745,101.83	3,876,923.60
Vegetables	15,144,709.71	36,003,316.49	16,153,719.40	24,405,664.25	17,294,189.59
Pulses	474,784.79	471,055.25	1,705,654.00	1,705,654.00	248,219.13
Sunflower	386,163.77	728,610.89	1,024,819.24	1,933,621.20	33,150.02
Sugarcane	14,408,649.48	27,186,131.10	7,061,008.35	13,322,657.26	15,652,396.58
Temperate Fruits	3,355,479.39	4,446,488.56	2,340,446.88	4,415,937.50	2,990,231.50
Olives	797,084.35	774,568.90	3,261,251.51	3,219,198.16	435,917.51
Sorghum	566,134.27	1,068,177.87	475,111.71	896,437.18	773,914.03
Banana	1,174,916.38	2,216,823.35	845,939.79	1,596,112.81	1,067,894.15
Groundnuts	150,999.74	155,970.10	3,623,050.96	3,639,952.41	202,505.15
Fodder grasses	7,828,564.39	13,882,766.03	15,691,956.28	15,691,956.28	48,007,813.04
Tot	**101,441,991.43**	**162,655,046.14**	**88,065,911.74**	**119,013,309.42**	**126,358,668.99**

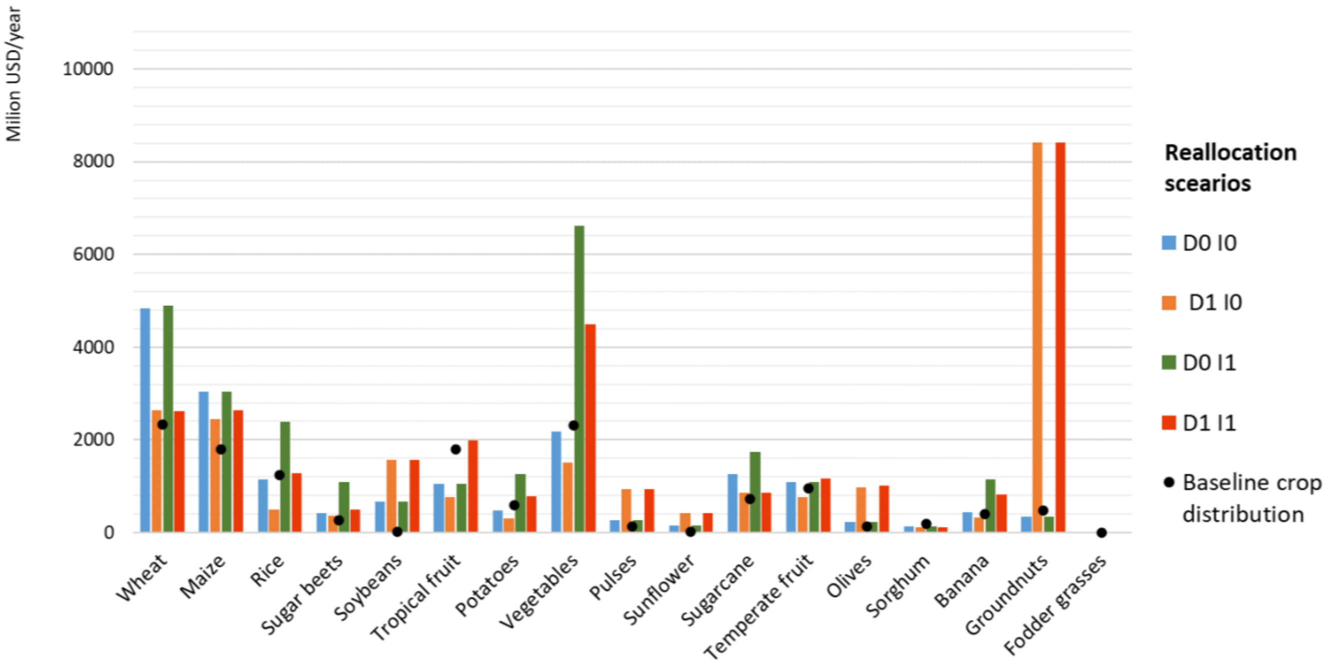

Figure 20 – Economic value of each crop in 2100, calculated in terms of producers 'gain[15], under four different reallocation future scenario (under RCP 2.6), and compared to the baseline (black dots).

Table 31 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 2.6)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	10.86	8.67	6.19	4.05
Maize	8.26	7.15	6.09	5.17
Rice	0.62	0.60	0.18	0.35
Sugar beet	0.33	1.32	0.16	0.46
Soybean	2.24	2.86	5.61	7.06
Tropical Fruits	1.38	1.30	0.93	1.09
Potato	0.20	0.60	0.11	0.39
Vegetables	1.02	1.70	0.78	1.17
Pulses	0.26	0.16	0.79	0.84
Sunflower	0.08	0.32	0.38	0.78
Sugarcane	0.71	1.50	0.23	0.78
Temperate Fruits	1.14	1.15	0.79	0.74
Olives	0.50	0.00	2.62	1.30
Sorghum	0.18	0.15	0.14	0.00
Banana	0.04	0.17	0.03	0.17
Groundnuts	0.10	0.15	2.45	3.38
Fodder grasses	0.11	0.18	0.56	0.25
Tot	**28.03**	**27.99**	**28.03**	**27.98**

Table 32– Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 2.6)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	39.01	38.50	38.11	38.00
Maize	38.28	38.08	39.28	39.03
Rice	55.92	55.92	38.00	100
Sugar beet	40.79	100	42.36	100
Soybean	40.53	42.30	40.34	38.43
Tropical Fruits	38.00	38.38	38.00	50.96
Potato	38.19	100	38.01	100
Vegetables	36.88	100	50.22	100
Pulses	38.30	38.00	38.00	38.00
Sunflower	38.00	100	38.01	74.47
Sugarcane	38.00	100	38.00	100
Temperate Fruits	38.00	38.00	38.00	38.00
Olives	42.24	39.48	38.87	38.27
Sorghum	38.00	38.12	38.00	66.02
Banana	38.00	100	38.00	100
Groundnuts	38.00	39.27	38.00	38.00
Fodder grasses	41.79	100	100	100
Tot	**39.88**	**65.06**	**42.89**	**68.19**

Table 33 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 2.6)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	64.03	63.52	84.12	84.01
Maize	63.95	63.75	71.29	71.05
Rice	55.34	55.34	36.64	98.64
Sugar beet	41.69	100	44.30	100
Soybean	85.61	87.38	59.84	57.92
Tropical Fruits	37.08	37.46	36.72	49.68
Potato	30.36	92.17	25.56	87.55
Vegetables	34.90	100	47.31	100
Pulses	77.17	76.88	48.74	48.74
Sunflower	41.85	100	39.46	75.92
Sugarcane	38.64	100	39.32	100
Temperate Fruits	24.04	24.04	17.99	17.99
Olives	40.52	37.76	38.46	37.87
Sorghum	38.00	38.12	38.00	66.02
Banana	38.84	100	39.17	100
Groundnuts	29.43	30.69	37.65	37.64
Fodder grasses	41.79	100	100	100
Tot	**46.07**	**71.01**	**47.33**	**72.53**

Table 34- Production (tonnes) after crop reallocation for the RCP 2.6, year 2100, in different diet and intensification conditions.

2100 scenario (RCP 2.6)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	17,090,956.50	16,867,507.47	9,077,215.13	9,050,625.35	8,034,210.01
Maize	12,344,228.05	12,279,643.47	10,157,249.95	10,093,797.08	7,198,587.14
Rice	6,981,794.64	6,981,794.64	2,037,759.51	5,362,525.02	5,172,591.85
Sugar beet	11,055,275.76	27,103,116.94	5,341,645.38	12,609,394.62	6,878,535.73
Soybean	1,612,882.85	1,683,182.05	3,712,181.99	3,535,785.51	31,790.64
Tropical Fruits	4,961,790.00	5,011,506.11	3,563,557.58	4,779,184.09	8,459,799.33
Potato	3,165,613.24	8,288,234.77	1,981,651.20	5,213,567.03	3,876,923.60
Vegetables	15,152,416.74	49,991,775.89	14,115,641.80	33,728,061.86	17,294,189.59
Pulses	473,824.92	470,165.67	1,702,432.87	1,702,432.87	248,219.13
Sunflower	385,434.50	1,014,301.31	1,023,074.44	2,004,565.33	33,150.02
Sugarcane	14,381,438.70	37,845,891.33	7,047,673.61	18,546,509.50	15,652,396.58
Temperate Fruits	3,349,142.56	3,349,142.56	2,336,026.94	2,336,026.94	2,990,231.50
Olives	834,639.49	780,149.33	3,256,596.56	3,206,934.58	435,917.51
Sorghum	565,065.13	566,817.38	474,214.46	823,854.51	773,914.03
Banana	1,172,697.54	3,086,046.17	844,342.23	2,221,953.24	1,067,894.15
Groundnuts	150,714.57	155,737.80	3,616,182.42	3,615,847.81	202,505.15
Fodder grasses	8,076,971.08	19,326,238.54	21,844,817.50	21,844,817.50	48,007,813.04
Tot	**101,754,886.27**	**194,801,251.43**	**92,132,263.56**	**140,675,882.84**	**126,358,668.99**

3.1.3.4 Future scenario RCP 8.5

Table 35-Table 42 report the main results for each diet and intensification scenarios for the future RCP 8.5 scenario, and Figure 21 and Figure 22 show the economic value associated to each crop under reallocation scenarios. Both in 2050 and 2100, the production of soybean, sunflowers, wheat, pulses and olives visibly increases for all the four scenarios (Table 38 and Table 42). This enables to increasing the percentage of demand gap closure. The demand results satisfied by 84% in 2050, and 67%, in 2100, in average in D1I1 scenario (Table 35 and Table 40,respectively), considering a Surplus-Deficit Trade scenario. The demand results satisfied by 88%, in 2050, and 71%, in 2100, in average in D1I1 scenario (Table 37 and Table 41, respectively), considering a Constant Trade scenario. The highest saving in blue water, among the four diet and intensification scenarios, is reached in the scenario D1I1 for 2050 (Table 35), and D0I1 in 2100 (Table 39). However, with respect to the other RCPs, RCP 8.5 resulted the one characterized by the highest consumption of irrigation water, reaching up to 30.74 km^3in 2100 (Table 39). On the other hand, under RCP 8.5 show an intense increase of temperature extremes and a decrease in precipitation is expected, with a consequent increase of blue water volume. These results make RCP 8.5 the less sustainable among the other future scenarios, under a water consumption point of view. The overall economic income obtained from crop production after reallocation is about 27,4 billion USD/year (D1I1) in 2050, and almost 30 billion USD/year in 2100 (D1I1). Again, the highest increase in economic income is generated from the production of groundnuts (in the scenarios D1I0 and D1I1).

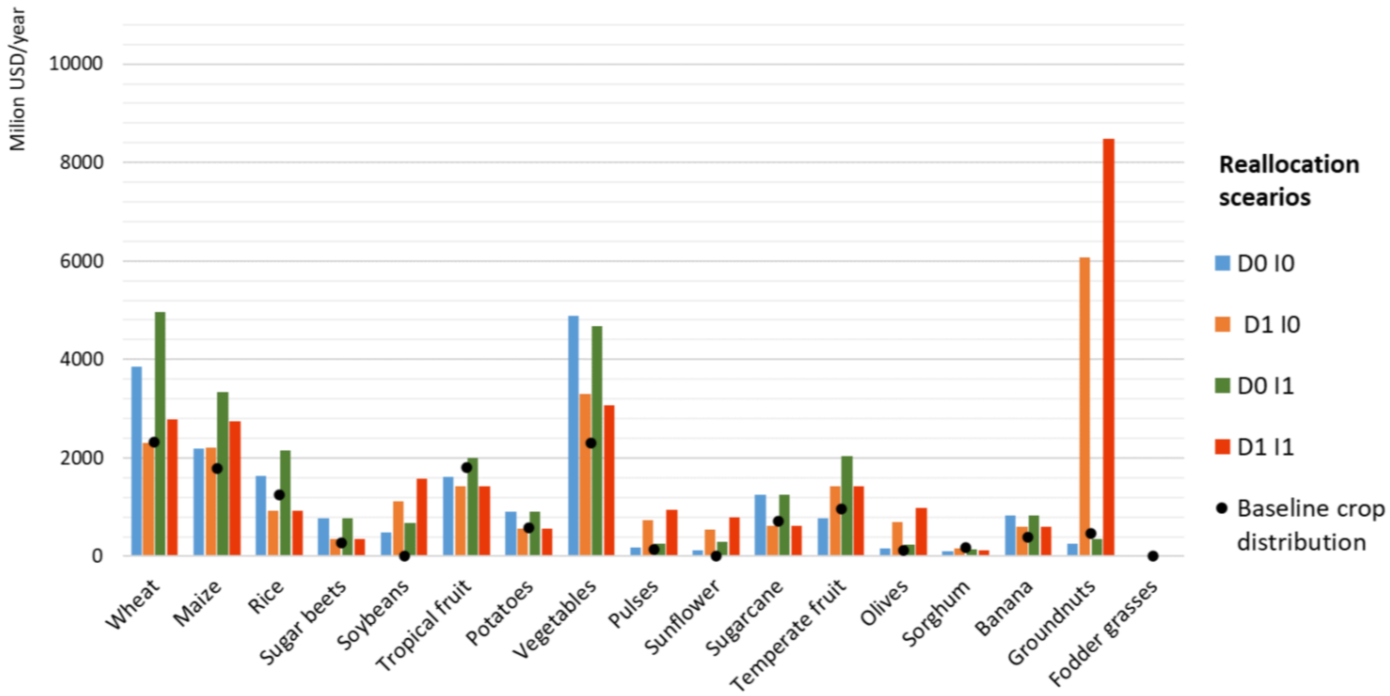

Figure 21 – Economic value of each crop in 2050, calculated in terms of producers 'gain[15], under four different reallocation future scenario (under RCP 8.5), and compared to the baseline (black dots).

Table 35 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 8.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	10.98	10.05	6.37	4.66
Maize	8.55	7.63	6.44	5.34
Rice	0.64	0.61	0.18	0.33
Sugar beet	0.42	0.90	0.18	0.37
Soybean	2.19	2.65	5.80	7.12
Tropical Fruits	1.46	2.73	0.90	1.54
Potato	0.21	0.44	0.12	0.26
Vegetables	1.11	1.09	0.77	0.71
Pulses	0.27	0.16	0.86	0.89
Sunflower	0.07	0.16	0.36	0.50
Sugarcane	0.94	1.00	0.21	0.68
Temperate Fruits	1.16	1.42	0.81	1.40
Olives	0.44	0.00	2.74	1.37
Sorghum	0.19	0.00	0.16	0.00
Banana	0.03	0.12	0.04	0.12
Groundnuts	0.11	0.00	2.52	3.51
Fodder grasses	0.19	0.09	0.29	0.09
Tot	**28.98**	**29.05**	**28.76**	**28.88**

Table 36- Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 8.5)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	54.30	62.76	53.17	60.98
Maize	53.33	54.09	54.91	55.06
Rice	77.94	78.07	53.00	100
Sugar beet	57.62	100	57.65	100
Soybean	56.25	60.02	56.55	56.29
Tropical Fruits	53.00	100	53.00	100
Potato	53.30	100	53.01	100
Vegetables	51.25	100	73.79	100
Pulses	53.41	53.82	53.00	53.00
Sunflower	53.00	100	53.00	100
Sugarcane	53.00	100	53.00	100
Temperate Fruits	53.00	68.94	53.00	100
Olives	55.52	56.76	54.92	53.74
Sorghum	53.00	100	53.00	100
Banana	53.00	100	53.00	100
Groundnuts	53.00	53.02	53.01	53.72
Fodder grasses	54.40	100	100	100
Tot	**55.19**	**81.62**	**57.71**	**84.28**

Table 37- Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

2050 scenario (RCP 8.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	89.12	97.58	100	100
Maize	89.07	89.82	99.48	99.63
Rice	77.13	77.26	51.10	98.10
Sugar beet	58.87	100	60.35	100
Soybean	100	100	83.69	83.43
Tropical Fruits	51.72	98.72	51.22	98.22
Potato	42.40	89.10	35.68	82.67
Vegetables	48.48	100	69.75	100
Pulses	100	100	67.95	67.95
Sunflower	58.35	100	55.02	100
Sugarcane	53.90	100	54.83	100
Temperate Fruits	33.57	49.51	25.15	72.15
Olives	53.13	54.36	54.35	53.18
Sorghum	53.00	100	53.00	100
Banana	54.17	100	54.63	100
Groundnuts	41.07	41.08	52.51	53.22
Fodder grasses	54.40	100	100	100
Tot	**62.26**	**88.08**	**62.86**	**88.74**

Table 38- Production (tonnes) after crop reallocation for the RCP 8.5, year 2050, in different diet and intensification conditions.

2050 scenario (RCP 8.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	17,087,410.77	19,749,688.76	9,096,942.84	10,432,932.91	8,034,210.01
Maize	12,354,340.57	12,529,662.07	10,199,310.08	10,228,248.39	7,198,587.14
Rice	6,990,455.09	7,001,827.23	2,041,615.10	3,852,103.97	5,172,591.85
Sugar beet	11,217,713.97	19,469,191.09	5,221,960.71	9,057,803.72	6,878,535.73
Soybean	1,607,917.81	1,715,657.21	3,738,157.95	3,720,632.41	31,790.64
Tropical Fruits	4,971,178.08	9,379,581.29	3,570,300.10	6,736,415.28	8,459,799.33
Potato	3,173,193.32	5,953,751.63	1,985,432.11	3,745,101.83	3,876,923.60
Vegetables	15,124,338.27	35,501,064.63	14,899,570.16	24,165,909.52	17,294,189.59
Pulses	474,688.94	478,377.21	1,705,654.00	1,705,654.00	248,219.13
Sunflower	386,163.77	728,610.89	1,024,819.24	1,933,621.20	33,150.02
Sugarcane	14,408,649.48	27,186,131.10	7,061,008.35	13,322,657.26	15,652,396.58
Temperate Fruits	3,355,479.39	4,364,487.87	2,340,446.88	4,415,937.50	2,990,231.50
Olives	788,150.53	805,715.07	3,305,376.48	3,234,634.69	435,917.51
Sorghum	566,134.27	1,068,177.87	475,111.71	896,437.18	773,914.03
Banana	1,174,916.38	2,216,823.35	845,939.79	1,596,112.81	1,067,894.15
Groundnuts	150,999.74	151,044.33	3,623,101.55	3,671,982.46	202,505.15
Fodder grasses	7,551,735.93	13,882,766.03	15,691,956.28	15,691,956.28	48,007,813.04

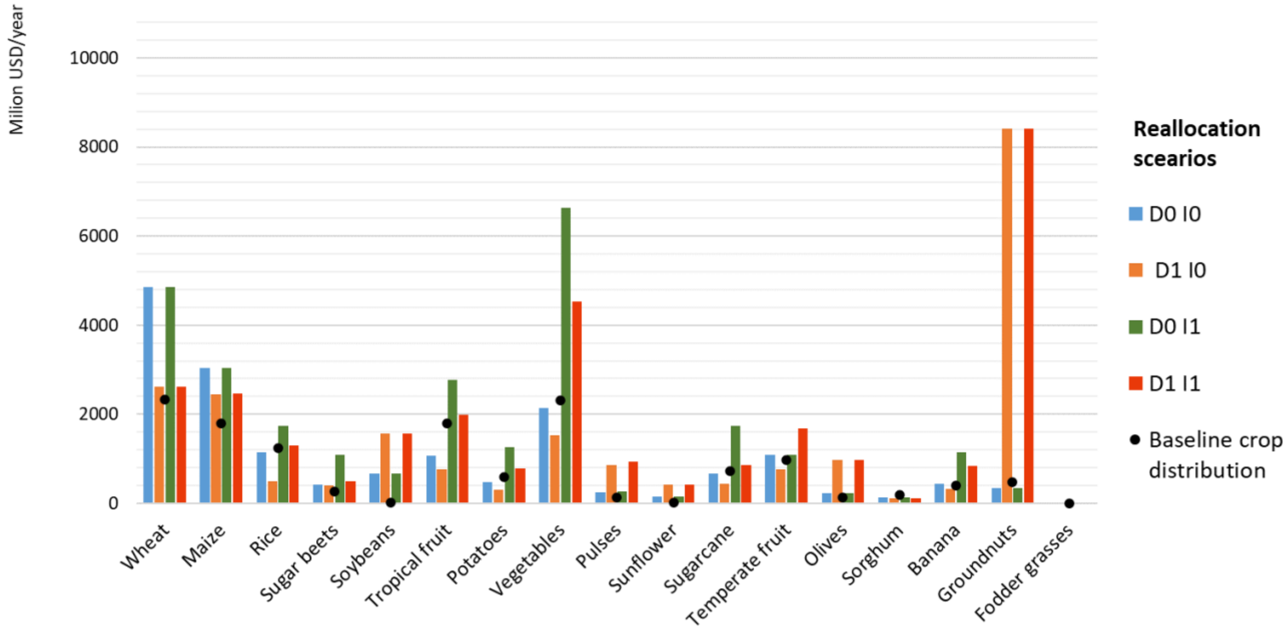

Figure 22 – Economic value of each crop in 2100, calculated in terms of producers 'gain[15], under four different reallocation future scenarios (under RCP 8.5), and compared to the baseline (black dots).

Table 39 – Agricultural blue water consumption (BW) after crop reallocation for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 8.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	11.87	9.28	6.74	4.33
Maize	8.95	7.74	6.59	5.54
Rice	0.66	0.64	0.19	0.38
Sugar beet	0.40	1.59	0.18	0.57
Soybean	2.50	3.56	6.09	8.43
Tropical Fruits	1.47	1.48	1.01	1.49
Potato	0.22	0.72	0.13	0.39
Vegetables	1.05	1.84	0.83	1.26
Pulses	0.28	0.23	0.91	0.91
Sunflower	0.09	0.39	0.40	0.87
Sugarcane	0.50	1.18	0.23	0.70
Temperate Fruits	1.23	1.05	0.84	0.83
Olives	0.57	0.00	2.94	1.03
Sorghum	0.20	0.09	0.15	0.00
Banana	0.04	0.21	0.01	0.19
Groundnuts	0.10	0.10	2.64	3.45
Fodder grasses	0.13	0.38	0.56	0.38
Tot	**30.26**	**30.47**	**30.43**	**30.74**

Table 40- Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 8.5)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	38.94	38.52	38.05	38.00
Maize	38.12	38.00	39.11	39.04
Rice	55.89	55.89	38.00	100
Sugar beet	40.60	100	41.86	100
Soybean	40.38	40.58	40.22	38.26
Tropical Fruits	38.00	38.38	38.00	66.41
Potato	38.25	100	38.01	100
Vegetables	36.86	100	52.43	100
Pulses	38.00	38.00	38.00	38.00
Sunflower	38.00	100	38.00	73.22
Sugarcane	38.00	100	38.00	100
Temperate Fruits	38.00	38.00	38.00	38.00
Olives	41.38	43.79	38.85	38.02
Sorghum	38.00	38.79	38.00	38.00
Banana	38.00	100	38.00	100
Groundnuts	38.00	39.26	38.00	38.00
Fodder grasses	46.48	100	99.03	100
Tot	**40.05**	**65.25**	**42.91**	**67.35**

Table 41- Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

2100 scenario (RCP 8.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	63.95	63.54	84.05	84.01
Maize	63.79	63.67	71.12	71.05
Rice	55.30	55.30	36.64	98.64
Sugar beet	41.50	100	43.80	100
Soybean	85.46	85.66	59.72	57.76
Tropical Fruits	37.08	37.46	36.72	65.13
Potato	30.42	92.17	25.56	87.55
Vegetables	34.87	100	49.52	100
Pulses	76.88	76.88	48.74	48.74
Sunflower	41.85	100	39.45	74.67
Sugarcane	38.64	100	39.32	100
Temperate Fruits	24.04	24.04	17.99	17.99
Olives	39.66	42.07	38.44	37.61
Sorghum	38.00	38.79	38.00	38.00
Banana	38.84	100	39.17	100
Groundnuts	29.43	30.69	37.65	37.64
Fodder grasses	46.48	100	99.03	100
Tot	**46.25**	**71.19**	**47.35**	**71.69**

Table 42- Production (tonnes) after crop reallocation for the RCP 8.5, year 2100, in different diet and intensification conditions.

2100 scenario (RCP 8.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	17,058,286.61	16,875,442.84	9,061,460.13	9,050,625.35	8,034,210.01
Maize	12,292,095.77	12,254,923.34	10,113,244.74	10,094,859.54	7,198,587.14
Rice	6,977,568.37	6,977,568.37	2,037,759.51	5,362,525.02	5,172,591.85
Sugar beet	11,003,092.29	27,103,116.94	5,278,442.60	12,609,394.62	6,878,535.73
Soybean	1,606,902.30	1,614,675.40	3,701,124.75	3,520,739.58	31,790.64
Tropical Fruits	4,961,790.00	5,011,418.16	3,563,557.58	6,227,887.76	8,459,799.33
Potato	3,170,004.83	8,288,234.77	1,981,686.12	5,213,567.03	3,876,923.60
Vegetables	15,142,644.58	50,327,541.60	14,736,637.55	34,221,464.86	17,294,189.59
Pulses	470,165.67	470,165.67	1,702,432.87	1,702,432.87	248,219.13
Sunflower	385,434.50	1,014,301.31	1,022,883.86	1,970,960.62	33,150.02
Sugarcane	14,381,438.70	37,845,891.33	7,047,673.61	18,546,509.50	15,652,396.58
Temperate Fruits	3,349,142.56	3,349,142.56	2,336,026.94	2,336,026.94	2,990,231.50
Olives	817,741.89	865,422.38	3,254,998.02	3,185,553.81	435,917.51
Sorghum	565,065.13	576,741.20	474,214.46	474,214.46	773,914.03
Banana	1,172,697.54	3,086,046.17	844,342.23	2,221,953.24	1,067,894.15
Groundnuts	150,714.57	155,720.90	3,616,134.24	3,615,851.16	202,505.15
Fodder grasses	8,983,116.67	19,326,238.54	21,632,792.94	21,844,817.50	48,007,813.04

3.2 SUDAN AND ETHIOPIA

In this Section, we provide the main results obtained for Sudan and Ethiopia, considering the main crops cultivated in the NRB. Results are provided for each country in terms of harvested area per crop, percentage of satisfaction of the crop demand, and blue and green water volumes, obtained as outputs of the WATNEEDS[1] model, first considering the current crop distribution and, secondly, the new crop redistribution after performing the crop reallocation.

3.2.1 Baseline Scenario

Table 43 and Table 44 report respectively results for Sudan and Ethiopia countries for the baseline scenario. The total cultivated cropland in Sudan, accordingly to the current crop distribution[38,39], resulted of 9,270,588.82 ha (Table 43) , while in Ethiopia of 10,985,048.7 ha (Table 44). Only a small percentage of the total cultivated land is irrigated (around 11% in Sudan[22] and around 4% in Ethiopia[50]). In Figure 23 and Figure 24 we report the spatial distribution of current harvested areas for the five main irrigated crops in Sudan and Ethiopia, respectively. The main irrigated crops in Sudan are sunflower, wheat, maize, sugarcane, groundnuts, vegetables and pulses; while cultivated areas of banana, soybean and tropical fruit are totally rainfed (*, in Table 43) and very low (<50 ha). In Ethiopia the main irrigated crops are sugarcane, fruit, vegetables, maize, wheat and potatoes; only groundnuts are entirely rainfed (*, in Table 44). Total blue water volumes resulted respectively of 8.21 km^3 in Sudan (Table 43) and 1.84 km^3 in Ethiopia (Table 44). These values are low (also if compared to results obtained for the Egypt country), because of the low percentage of irrigation land, that enables to satisfy only small percentages of the population demand for crops, especially for those crops that are most present in the local diets: wheat (2.87%), rice (14%), sunflower in Sudan (4.90%) (Table 43, Surplus-deficit trade scenario) and wheat (22%), maize (22%), rice (0.70%), potatoes (15%) in Ethiopia (Table 44, Surplus-deficit trade scenario). Only with the contribute of constant trade flows, the percentage of demand satisfaction increases up to 40% for wheat, 65% for maize, 100% for rice and 40% for sunflower in Sudan, thanks to imports (Table 43, Constant trade scenario). In Ethiopia trade enables to increase the demand satisfaction for wheat (50%) and rice (61%) (Table 44, constant trade scenario). On the other hand, Sudan and Ethiopia allow the cultivation of a limited range of crops (e.g., cereals, groundnuts and pulses), due to their climatic conditions. Thus, exploring alternative solution for optimizing crop production and reducing the production-demand gap becomes fundamental to approach self-sufficiency in those countries. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link for Sudan and at this link for Ethiopia.

Table 43 – Percentage of demand gap closure, production (tonnes) and water volumes (green and blue) demand for the baseline scenario, in Sudan.

Sudan Baseline						
Crops	**Area (ha)**	**Production (tonnes)**	**Demand gap closure (%)**		**BW (km^3)**	**GW (km^3)**
			Trade Surplus-Deficit	**Constant Trade**		
Wheat	117,610.63	215,723.29	2.87	40.02	0.91	0.04
Maize	68,780.82	50,660.82	30.00	65.91	0.27	0.17
Rice	4,705.04	7,487.79	14.39	100	0.02	0.01
Sugar beet	0.00	0.00	0.00	0.00	0.00	0.00
Soybean*	0.85	1.47	100	100	0.00	0.00
Tropical Fruits*	42.51	21.66	0.01	0.01	0.00	0.00
Potato	16,227.91	111,403.68	23.92	25.63	0.09	0.00
Vegetables	1,406,349.84	3,226,645.69	64.96	65.06	0.20	0.02
Pulses	122,668.96	212,493.51	52.33	76.80	0.28	0.00
Sunflower	21,281.06	14,258.69	4.90	40.65	0.08	0.05
Sugarcane	70,390.06	5,719,621.55	100	100	1.10	0.08
Temperate Fruits	1,406,349.84	3,226,645.69	100	100	0.62	0.14
Olives	68,780.82	50,660.82	100	100	0.31	0.02
Sorghum	4,710,693.18	2,818,841.52	37.70	39.92	1.35	0.89
Banana*	3.03	13.61	0.01	0.01	0.00	0.00
Groundnuts	1,107,315.82	818,386.74	100	100	0.54	0.01
Fodder grasses	149,388.45	0.00	100	100	2.42	0.27
Tot	**9,270,588.82**	**-**	**48.88**	**62.00**	**8.21**	**1.70**

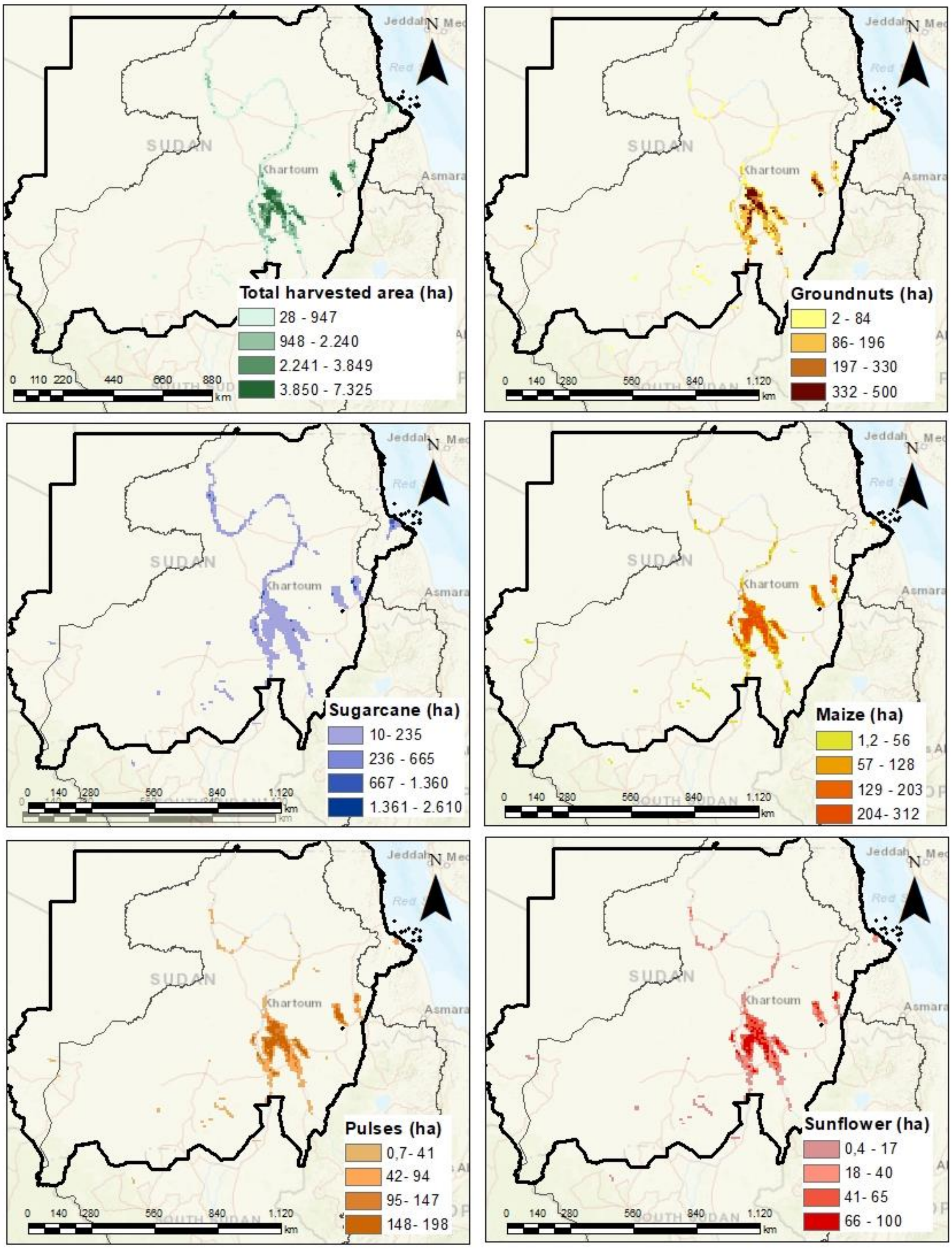

Figure 23 – Current total harvested area and single crops' harvested areas (ha) for the five main irrigated crops in Sudan.

Table 44 – Percentage of demand gap closure, production (tonnes) and water volumes (green and blue) demand for the baseline scenario, in Ethiopia.

Ethiopia Baseline						
Crops	**Area (ha)**	**Production (tonnes)**	**Demand gap closure (%)**		**BW (km^3)**	**GW (km^3)**
			Trade Surplus-Deficit	**Constant Trade**		
Wheat	760,098.79	937,388.66	22.90	50.07	0.11	0.08
Maize	1,184,206.90	2,086,356.87	22.88	22.94	0.16	0.33
Rice	3,424.21	2,708.75	0.70	61.45	0.01	0.01
Sugar beet	0.00	0.00	0.00	0.00	0.00	0.00
Soybean	6,918.67	23,111.32	100	100	0.01	0.00
Tropical Fruits	239,654.69	181,309.16	100	100	0.02	0.01
Potato	46,171.56	402,397.65	15.35	20.43	0.21	0.05
Vegetables	2,851,285.80	5,728,246.98	100	100	0.07	0.07
Pulses	967,687.63	657,594.30	35.54	17.27	0.04	0.01
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00
Sugarcane	26,537.21	2,606,001.63	100	100	0.18	0.17
Temperate Fruits	2,851,285.80	5,728,246.98	100	100	0.75	0.77
Olives	1,184,206.90	2,086,356.87	100	100	0.25	0.15
Sorghum	850,178.27	1,061,842.09	37.13	41.33	0.03	0.07
Banana	0.00	0.00	0.00	0.00	0.00	0.00
Groundnuts*	13,392.25	8,767.07	9.11	8.07	0.00	0.00
Fodder grasses	0.00	0.00	0.00	0.00	0.00	0.00
Tot	**10,985,048.7**	**-**	**43.73**	**48.32**	**1.84**	**1.73**

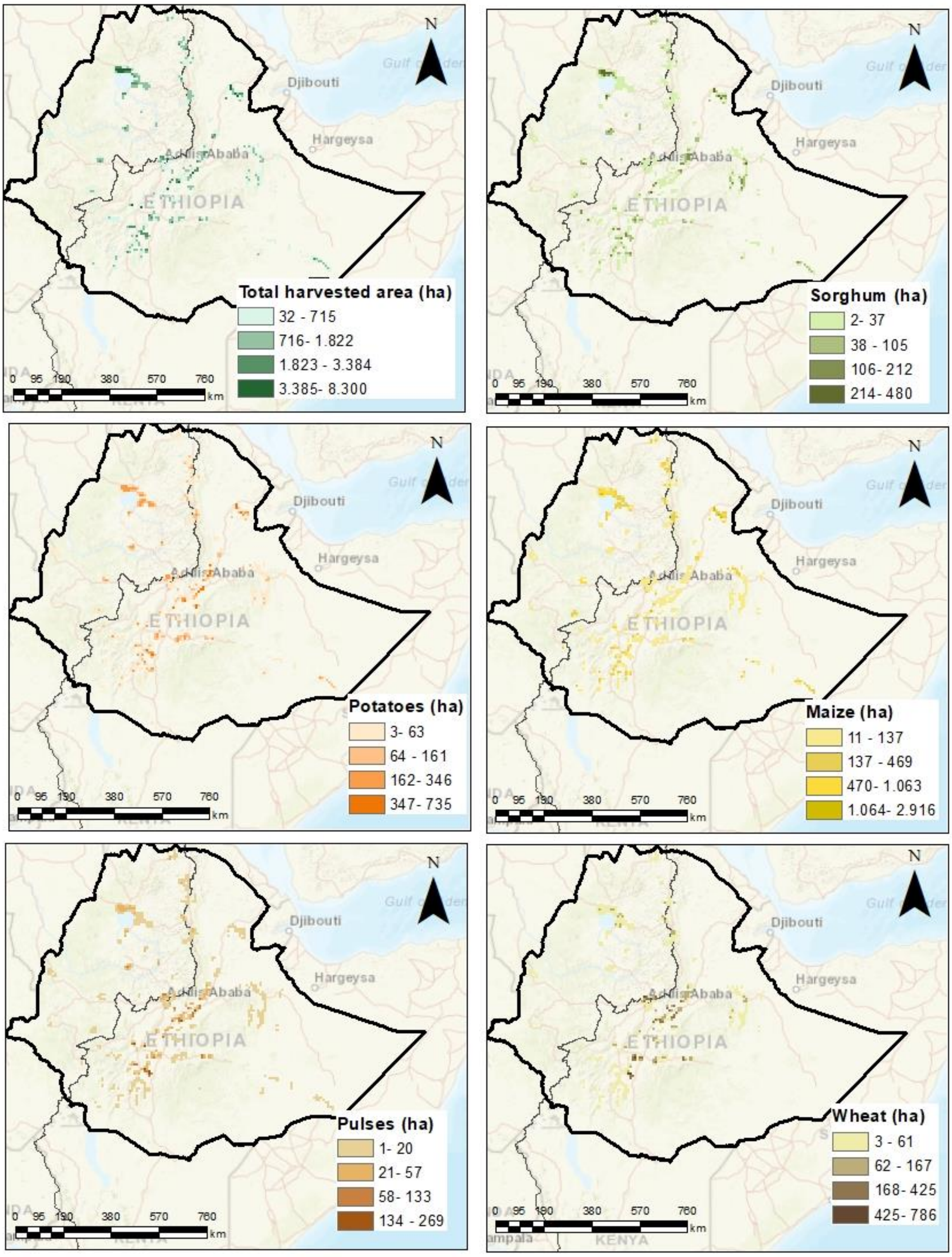

Figure 24 - Current total harvested area and single crops' harvested areas (ha) for the five main irrigated crops in Ethiopia.

3.2.2 Baseline Crop Reallocation (Present)

In this section, the main results obtained from the baseline crop reallocation that maximizes *water productivity* are reported for the countries of Sudan and Ethiopia. Crop reallocation has been performed with the aim of increasing domestic agricultural production towards the country self-sufficiency. After crop reallocation, we assessed the domestic production, the percentage of the demand satisfaction and the consumption of blue water. Four scenarios that include diet shift and agricultural intensification (described in Section 2) have been considered and compared. Results are reported in terms of blue water consumption (Table 45 and Table 49) and percentage of closure of diet demand for the scenario of Trade-Surplus and Deficit (Table 46 and Table 50) and for the scenario Constant Trade (Table 47 and Table 50). In line with the current crop distribution (Table 43), in Sudan, after reallocation, banana, soybeans and tropical fruits result cultivated only as rainfed crops and, thus, their blue crop water requirement resulted zero. Similarly, in Ethiopia, after reallocation, groundnuts are cultivated only as rainfed, while bananas, sunflowers and sugar beet and fodder grasses are not cultivated in Ethiopia (Table 44). The percentage of satisfaction of the demand remains almost the same as in the baseline scenario, with a slight increase when intensification is applied and a slight decrease (D0I1, Table 46) when the balanced diet is considered (Table 46 and Table 51). This means that, when intensification is not applied, the production is maintained mainly equal to the current scenario, while a reduction of blue water is obtained. Only when intensification is applied an increase in vegetable production is obtained (Table 48 and Table 52). Highest savings in blue water consumption have been obtained for sugarcane and sorghum in Sudan (Table 45), and for olives, temperate fruit and maize in Ethiopia (Table 49). For both countries, the highest saving in blue water is reached in the scenarios with intensification: the maximum reduction of BW consumption obtained for the baseline reallocation is of 80% in Ethiopia and 75% in Sudan (D0I1 and D1I1, Table 45 and Table 49). Same values in crop production and blue crop water requirements are obtained among the scenarios with same agricultural yields. Blue water consumption resulted of 3.39 km^3,in Sudan, and 0.98 km^3, in Ethiopia, in D0I0 and D1I0, and 2.02 km^3, in Sudan, and 0.37 km^3, in Ethiopia, in D0I1 and D1I1 (Table 45 and Table 49). New allocated crop areas that are required to satisfy at least the current demand for crops, and reduce blue water consumption, remain the same when the diet is changed, but vary when agricultural intensification is applied. This happens because, only when intensification is applied, an increase in production per unit of blue water consumed is obtained for the crops with higher water productivity (in this case vegetables), with a consequent variation in the areas (and in the volume of blue water) needed to guarantee at least the current production. Figure 25 and Figure 26 show the crop distribution that optimizes blue water consumption after baseline reallocation, for Sudan and Ethiopia, respectively, for the scenario D0I0. With respect to the baseline (Figure 23 and Figure 24), single crops areas are reallocated in few areas, in the current irrigated cropland, characterized by higher water productivity. These results are in line with the low amount of cropland that is currently available for irrigation in these countries, that limit increase in production and optimal reallocation of harvested areas. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link for Sudan and at this link for Ethiopia.

Table 45 – Agricultural blue water consumption (BW) after crop reallocation for baseline, in Sudan, in different diet and intensification conditions. Results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when baseline reallocation is considered.

Sudan Reallocation Baseline			
Crops	**BW (km³)**		
	D0I0-D1I0	**D0I1-D1I1**	**BASELINE**
Wheat	0.93	0.46	0.91
Maize	0.08	0.01	0.27
Rice	0.02	0.01	0.02
Sugar beet	0.00	0.00	0.00
Soybean	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00
Potato	0.06	0.03	0.09
Vegetables	0.07	0.51	0.20
Pulses	0.22	0.09	0.28
Sunflower	0.03	0.00	0.08
Sugarcane	0.97	0.47	1.10
Temperate Fruits	0.14	0.06	0.62
Olives	0.30	0.14	0.31
Sorghum	0.07	0.01	1.35
Banana	0.00	0.00	0.00
Groundnuts	0.49	0.24	0.54
Fodder grasses	0.00	0.00	2.42
Tot	**3.39**	**2.02**	**8.21**

Table 46 - Percentage of demand satisfaction after crop reallocation in the trade scenario of Surplus-Deficit, for the baseline in Sudan, in different diet and intensification conditions.

Sudan Reallocation Baseline				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	2.87	2.87	3.14	3.14
Maize	29.83	29.83	4.68	4.68
Rice	13.77	13.77	0.83	0.83
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	23.92	23.92	11.04	11.04
Vegetables	53.15	100	85.86	100
Pulses	49.99	49.99	28.77	28.77
Sunflower	4.90	4.90	3.22	3.22
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	37.56	37.56	67.36	67.36
Banana	0.00	0.00	0.00	0.00
Groundnuts	100	100	75.17	75.17
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**47.73**	**50.86**	**45.34**	**46.28**

Table 47 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the baseline in Sudan, in different diet and intensification conditions.

Sudan Reallocation Baseline				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	40.01	40.01	43.89	43.89
Maize	65.74	65.74	10.31	10.31
Rice	100	100	7.68	7.68
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	25.63	25.63	11.83	11.83
Vegetables	53.25	100	86.02	100
Pulses	74.46	74.46	42.86	42.86
Sunflower	40.65	40.65	26.71	26.71
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	39.78	39.78	71.35	71.35
Banana	0.00	0.00	0.00	0.00
Groundnuts	100	100	75.17	75.17
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**62.64**	**65.75**	**51.72**	**52.65**

Table 48- Production (tonnes) per crop, obtained after baseline relocation in Sudan. In the scenarios D0I0 and D1I0 (without intensification) the production per crop remains the same of the baseline.

Sudan Reallocation Baseline		
Production (tonnes)		
Crops	**D0I0-D1I0**	**D0I1-D1I1**
Wheat	215,723.29	215,723.29
Maize	50,660.82	50,660.82
Rice	7,487.79	7,487.79
Sugar beet	0.00	0.00
Soybean	1.47	1.47
Tropical Fruits	21.66	21.66
Potato	111,403.68	111,403.68
Vegetables	3,226,645.69	13,778,744.18
Pulses	212,493.51	212,493.51
Sunflower	14,258.69	14,258.69
Sugarcane	5,719,621.55	5,719,621.55
Temperate Fruits	3,226,645.69	3,226,645.69
Olives	50,660.82	50,660.82
Sorghum	2,818,841.52	2,818,841.52
Banana	13.61	13.61
Groundnuts	818,386.74	818,386.74
Fodder grasses	0.00	0.00

Table 49 – Agricultural blue water consumption (BW) after crop reallocation for baseline, in Ethiopia, in different diet and intensification conditions. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when baseline reallocation is considered.

Ethiopia Reallocation Baseline			
Crops	**BW (km^3)**		
	D0I0-D1I0	**D0I1-D1I1**	**BASELINE**
Wheat	0.01	0.00	0.11
Maize	0.00	0.00	0.16
Rice	0.00	0.00	0.01
Sugar beet	0.00	0.00	0.00
Soybean	0.01	0.01	0.01
Tropical Fruits	0.02	0.01	0.02
Potato	0.16	0.06	0.21
Vegetables	0.00	0.00	0.07
Pulses	0.04	0.01	0.04
Sunflower	0.00	0.00	0.00
Sugarcane	0.10	0.04	0.18
Temperate Fruits	0.57	0.21	0.75
Olives	0.07	0.02	0.25
Sorghum	0.00	0.00	0.03
Banana	0.00	0.00	0.00
Groundnuts	0.00	0.00	0.00
Fodder grasses	0.00	0.00	0.00
Tot	**0.98**	**0.37**	**1.84**

Table 50 - Percentage of demand satisfaction after crop reallocation in Surplus-Deficit Trade scenario for the baseline in Ethiopia, in different diet and intensification conditions.

Ethiopia Reallocation Baseline				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	22.90	22.90	13.69	13.69
Maize	22.88	22.88	11.82	11.82
Rice	0.70	0.70	0.12	0.12
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.24	2.24
Tropical Fruits	100	100	100	100
Potato	15.35	15.35	4.44	4.44
Vegetables	100	100	86.42	100
Pulses	35.54	35.54	31.71	31.71
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	37.13	37.13	75.66	75.66
Banana	0.00	0.00	0.00	0.00
Groundnuts	9.11	9.11	0.34	0.34
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**43.74**	**43.74**	**36.84**	**37.64**

Table 51 - Percentage of demand satisfaction after crop reallocation in the Constant Trade scenario for the baseline in Ethiopia, in different diet and intensification conditions.

Ethiopia Reallocation Baseline				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	50.07	50.07	29.93	29.93
Maize	22.94	22.94	11.86	11.86
Rice	61.45	61.45	10.47	10.47
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.24	2.24
Tropical Fruits	100	100	100	100
Potato	20.43	20.43	5.91	5.91
Vegetables	100	100	84.17	100
Pulses	17.27	17.27	15.41	15.41
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	41.33	41.33	84.22	84.22
Banana	0.00	0.00	0.00	0.00
Groundnuts	8.07	8.07	0.31	0.31
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**48.33**	**48.33**	**37.91**	**38.84**

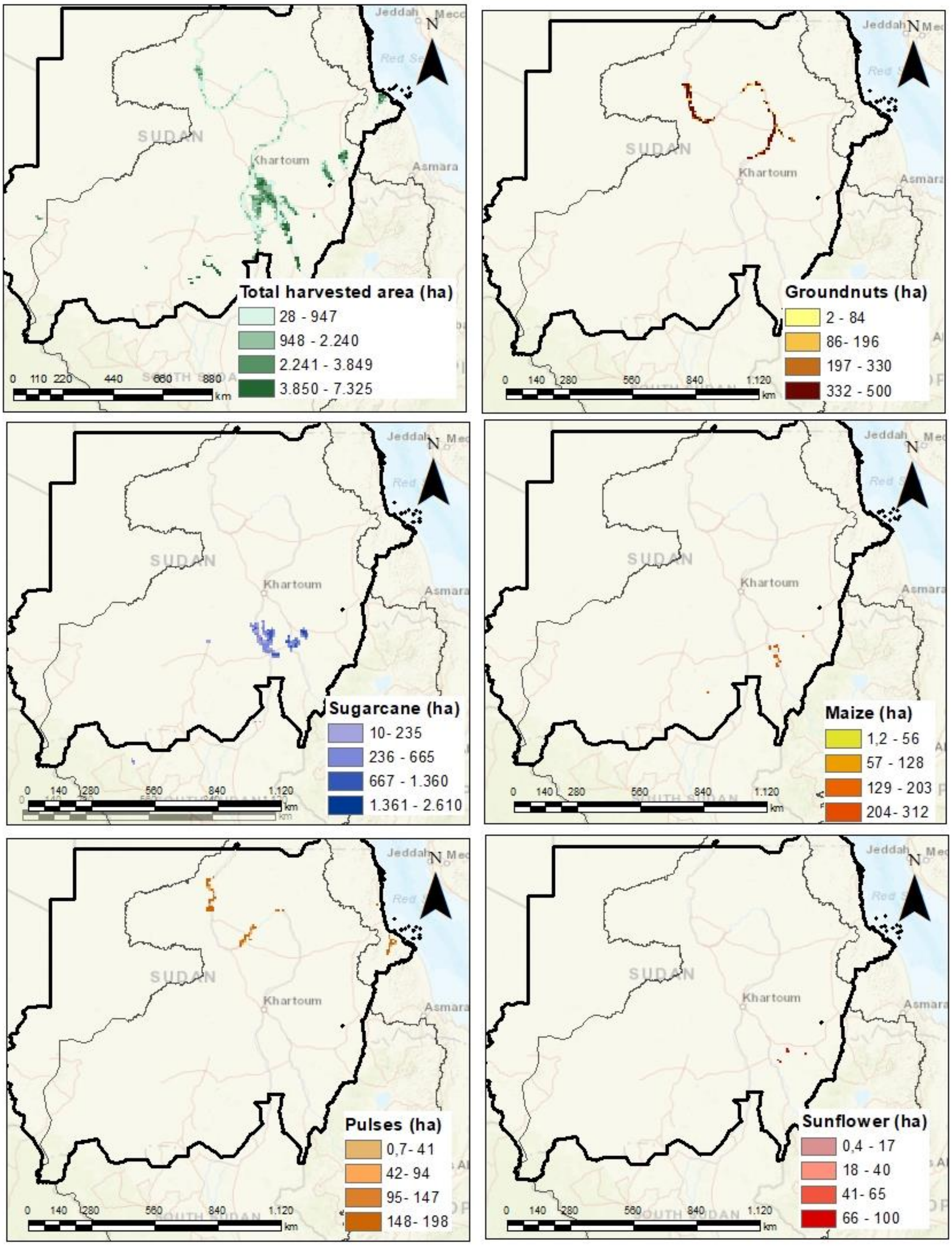

Figure 25 - Total harvested area and single crops' harvested areas (ha) for the five main cultivated crops in Sudan, for the baseline reallocation, D0I0 scenario.

Table 52- New production (tonnes) per crop, after baseline reallocation in Ethiopia. In the scenarios D0I0 and D1I0 (without intensification) the production per crop remains the same of the baseline.

Ethiopia Reallocation Baseline		
Crops	**Production (tonnes)**	
	D0I0-D1I0	**D0I1-D1I1**
Wheat	937,388.66	937,388.66
Maize	2,086,356.87	2,086,356.87
Rice	2,708.75	2,708.75
Sugar beet	0.00	0.00
Soybean	23,111.32	23,111.32
Tropical Fruits	181,309.16	181,309.16
Potato	402,397.65	402,397.65
Vegetables	5,728,246.98	7,440,299.76
Pulses	657,594.30	657,594.30
Sunflower	0.00	0.00
Sugarcane	2,606,001.63	2,606,001.63
Temperate Fruits	5,728,246.98	5,728,246.98
Olives	2,086,356.87	2,086,356.87
Sorghum	1,061,842.09	1,061,842.09
Banana	0.00	0.00
Groundnuts	8,767.07	8,767.07
Fodder grasses	0.00	0.00

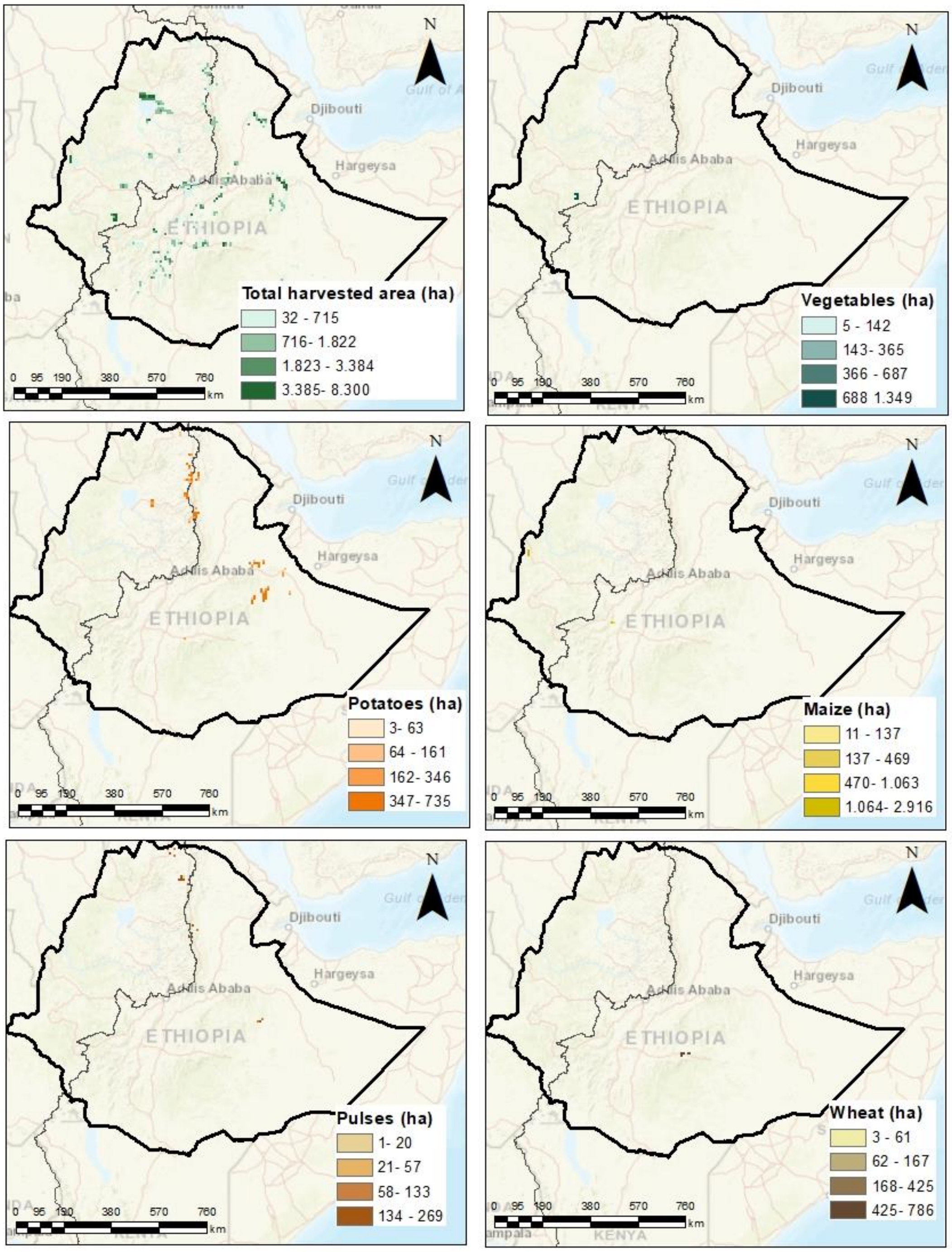

Figure 26- Total harvested area and single crops' harvested areas (ha) for the five main cultivated crops in Ethiopia, for the baseline reallocation, D0I0 scenario.

3.2.3 Crop Reallocation (Present): Hypothetical Irrigation Expansion

In this section, the main results obtained from the present crop reallocation that maximizes *water productivity* over irrigation expansion areas of future plans provided by the ENTRO office[52], are reported for Sudan and Ethiopia. The crop reallocation has been performed with the aim of increasing domestic agricultural production towards the closure of the demand gap, through irrigation expansion. We found that without exceeding the current blue water consumption it is not possible to increase production in Sudan and Ethiopia, being the irrigated cropland very limited. For this reason, we provide a hypothetical expansion scenario that enhances increase in production, with a consequent increase in the consumption of blue water, without exceeding the exploitable water resources of the country. This scenario is explored only as hypothesis of alternative crop reallocation to assess the amount of blue water that would be needed to increase production without exploiting the natural resources of the country. Indeed, increasing the current blue water consumption might be not sustainable environmentally if cumulated effects of performing irrigation expansion in more countries - at the basin scale - are considered. We assess the results in terms of blue water consumption, production and percentage of the demand gap closure and consider four scenarios that include diet shift and agricultural intensification (Section 2). Table 53-Table 56 report results for Sudan, while Table 57-Table 60 report results for Ethiopia. This irrigation expansion scenario gives important benefits in terms of production increase. In Sudan wheat, maize, sunflower and especially bananas production has increase in all four scenarios, while in intensification scenarios also production of potatoes and rice has been privileged (Table 56). In Ethiopia production has increased for wheat and maize in all four scenarios, but the major increase in production can be seen for the crops groundnuts, rice, soybean and potatoes in the scenario when intensification is applied (Table 58). The percentage of satisfaction of the demand increases in average up to 93% in Sudan (D1I1, Table 54), closing the gap for all the main cultivated crops, except for wheat (at 96%). In Ethiopia the best scenario is D1I0, where the average demand satisfaction increases to 73% and demand gap is closed for all the crops except for rice and groundnuts (Table 59). Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link for Sudan and at this link for Ethiopia.

Table 53 – Agricultural blue water consumption (BW) after crop reallocation for baseline (with potential irrigation expansion), in Sudan, in different diet and intensification conditions.

Sudan Reallocation – Irrigation Expansion				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.65	8.01	0.91	9.86
Maize	0.12	0.01	1.07	0.80
Rice	0.15	0.08	2.65	1.09
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.20	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.72	0.00	0.86	0.00
Sunflower	0.01	0.00	0.02	0.01
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.32	0.16	0.33	0.15
Sorghum	6.70	7.18	5.24	2.50
Banana	0.23	0.00	0.00	0.00
Groundnuts	5.35	2.65	5.28	4.12
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.44**	**18.09**	**16.37**	**18.52**

Table 54 - Percentage of demand satisfaction after crop reallocation (with potential irrigation expansion) in the trade scenario of Surplus-Deficit, for the baseline in Sudan, in different diet and intensification conditions.

Sudan Reallocation – Irrigation Expansion				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	5.51	69.75	3.73	96.42
Maize	100	100	54.87	100
Rice	100	100	100	100
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	100	100	100	100
Vegetables	100	100	100	100
Pulses	100	100	100	100
Sunflower	100	100	100	100
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	60.40	100	100	100
Banana	100	100	100	100
Groundnuts	100	100	100	100
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**84.39**	**91.32**	**83.91**	**93.09**

Table 55 - Percentage of demand satisfaction after crop reallocation (with potential irrigation expansion) in the Constant Trade scenario for the baseline in Sudan, in different diet and intensification conditions.

Sudan Reallocation – Irrigation Expansion				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	42.66	100	44.48	100
Maize	100	100	60.50	100
Rice	100	100	100	100
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	100	100	100	100
Vegetables	100	100	100	100
Pulses	100	100	100	100
Sunflower	100	100	100	100
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	62.63	100	100	100
Banana	100	100	100	100
Groundnuts	100	100	100	100
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**87.02**	**93.33**	**87.00**	**93.33**

Table 56 - Production (tonnes) per crop, after reallocation performed considering potential irrigation areas, in Sudan.

Sudan Reallocation - Irrigation Expansion					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	414,789.59	5,250,204.32	256,086.13	6,615,555.52	215,723.29
Maize	216,192.34	216,255.98	594,391.45	1,128,240.50	50,660.82
Rice	58,507.52	58,514.63	908,827.97	908,998.55	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	3.23	3.23	3.23	3.23	1.47
Tropical Fruits	43.33	43.33	43.33	43.33	21.66
Potato	496,600.61	497,510.91	1,040,955.66	1,040,955.66	111,403.68
Vegetables	8,812,369.01	8,867,711.59	6,322,212.02	6,365,761.64	3,226,645.69
Pulses	554,172.34	555,663.43	930,648.97	931,607.59	212,493.51
Sunflower	382,722.53	382,728.98	564,965.37	564,981.78	14,258.69
Sugarcane	7,882,469.83	7,882,469.83	7,882,469.83	7,882,469.83	5,719,621.55
Temperate Fruits	5,444,926.96	5,474,947.68	5,450,691.04	5,471,342.59	3,226,645.69
Olives	95,510.36	95,991.37	95,077.65	95,890.04	50,660.82
Sorghum	4,533,661.65	8,270,593.42	4,231,621.03	5,943,826.28	2,818,841.52
Banana	758,532.67	758,532.67	382,307.22	382,307.22	13.61
Groundnuts	1,542,307.91	1,586,088.00	1,545,898.58	2,057,157.11	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 57 – Agricultural blue water consumption (BW) after crop reallocation for baseline (with potential irrigation expansion), in Ethiopia, in different diet and intensification conditions.

Ethiopia Reallocation– Irrigation Expansion				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	0.76	3.55	0.76	1.02
Maize	0.30	0.02	0.32	0.27
Rice	0.01	0.28	0.01	2.01
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.01	0.00	0.01	0.51
Tropical Fruits	1.64	0.37	1.64	0.66
Potato	0.14	0.00	0.15	0.34
Vegetables	0.54	0.15	0.54	0.21
Pulses	1.03	1.46	1.03	1.83
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	12.65	3.94	12.63	5.47
Olives	2.20	0.63	2.20	0.95
Sorghum	0.07	0.03	0.05	0.01
Banana	0.00	3.95	0.00	0.00
Groundnuts	0.00	0.01	0.00	0.69
Fodder grasses	0.00	0.13	0.00	0.00
Tot	**19.34**	**14.53**	**19.34**	**13.99**

Table 58 - Production (tonnes) per crop, after reallocation performed considering potential irrigation areas, in Ethiopia.

Ethiopia Reallocation – Irrigation Expansion					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	1,800,183.83	5,274,273.99	1,800,414.70	2,104,107.25	937,388.66
Maize	9,453,997.72	10,740,561.61	9,847,189.33	18,845,593.29	2,086,356.87
Rice	3,626.19	27,087.50	3,626.19	29,796.25	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	42,931.40	49,867.68	42,931.25	208,001.91	23,111.32
Tropical Fruits	354,554.21	359,601.11	354,580.33	359,436.61	181,309.16
Potato	3,450,972.17	3,451,638.67	3,494,343.96	3,581,339.12	402,397.65
Vegetables	10,746,672.86	11,351,942.02	10,766,593.10	12,242,635.83	5,728,246.98
Pulses	1,286,234.09	3,028,860.42	1,286,316.46	3,318,187.20	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	2,866,601.79	2,866,601.79	2,866,601.79	2,866,601.79	2,606,001.63
Temperate Fruits	10,292,841.01	11,405,466.17	10,296,330.04	11,348,373.22	5,728,246.98
Olives	3,969,913.41	4,050,595.73	3,971,699.98	4,049,114.04	2,086,356.87
Sorghum	2,792,867.19	4,096,483.00	2,505,723.03	2,553,031.49	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	34,864.83	65,753.00	34,864.83	87,670.67	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 59 - Percentage of demand satisfaction after crop reallocation (with potential irrigation expansion) in Surplus-Deficit Trade scenario, for the baseline in Ethiopia, in different diet and intensification conditions.

Ethiopia Reallocation – Irrigation Expansion				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	43.98	100.00	26.29	30.72
Maize	100.00	100.00	55.81	100.00
Rice	0.94	7.00	0.16	1.31
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100.00	100.00	4.15	20.13
Tropical Fruits	100.00	100.00	100.00	100.00
Potato	100.00	100.00	38.59	39.55
Vegetables	100.00	100.00	100.00	100.00
Pulses	69.52	100.00	62.03	100.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100.00	100.00	100.00	100.00
Temperate Fruits	100.00	100.00	100.00	100.00
Olives	100.00	100.00	100.00	100.00
Sorghum	97.66	100.00	100.00	100.00
Banana	0.00	0.00	0.00	0.00
Groundnuts	36.23	68.33	1.37	3.44
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**65.52**	**73.46**	**49.28**	**55.95**

Table 60 - Percentage of demand satisfaction after crop reallocation (with potential irrigation expansion) in the Constant Trade scenario for the baseline in Ethiopia, in different diet and intensification conditions.

Ethiopia Reallocation – Irrigation Expansion				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	71.14	100	42.53	46.96
Maize	100.00	100.00	55.84	100.00
Rice	61.92	67.99	10.51	11.65
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100.00	100.00	4.15	20.13
Tropical Fruits	100.00	100.00	100.00	100.00
Potato	100.00	100.00	40.06	41.02
Vegetables	100.00	100.00	98.62	100.00
Pulses	51.25	100.00	45.73	100.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100.00	100.00	100.00	100.00
Temperate Fruits	100.00	100.00	100.00	100.00
Olives	100.00	100.00	100.00	100.00
Sorghum	100.00	100.00	100.00	100.00
Banana	0.00	0.00	0.00	0.00
Groundnuts	35.19	67.29	1.33	3.41
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**65.85**	**75.96**	**46.99**	**54.30**

The crop reallocation performed for the baseline scenario in Sudan and Ethiopia, without irrigation expansion, has succeeded in reducing the blue water consumption maintaining constant the agricultural production and, thus, the percentage of satisfaction of the demand (Table 46, Table 50). In Ethiopia the consumption of BW has been reduced of 80% when intensification is applied (scenarios D0I1 and D1I1, Table 49) and of 50% without intensification applied (scenarios D1I0 and D0I0, Table 49). While in Sudan blue water consumption has been reduced of 75% when intensification is applied (scenarios D0I1 and D1I1, Table 45) and of 60% without intensification applied (scenarios D1I0 and D0I0, Table 45). When irrigation expansion is introduced the cropland reallocation succeeds also in increasing the percentage of demand gap closure, thanks to an increase of the agricultural production that enables to reduce the dependency on trade to satisfy the food demand. When irrigation is expanded over potential irrigation areas[52] satisfactory results in terms of production increase have been obtained. In Ethiopia the demand can be totally satisfied (100%) for the 13 main crops cultivated, when intensification is applied (D0I1,Table 59). In Sudan, the best scenario in terms of satisfaction of the demand is D1I1 (Table 54), where the demand gap is closed at 100% for the main cultivated crops, except for wheat, for which the demand is satisfied at 96%. Under the *potential irrigation expansion* scenario in Ethiopia the highest BW consumption is 19.34 km^3 and is reached when intensification is not applied (D0I0 and D1I1, Table 57), in Sudan is 18.52 km^3 for the scenario D1I1 (Table 53). Under this scenario the blue water consumption increases with respect to the baseline, but don't exceed the total current water resources in Ethiopia (122 km^3) and Sudan (37.8 km^3)[12]. However, if irrigation expansion would be performed on larger scale, involving more states contemporary, an increase in blue water consumption might result in an excessive increase in irrigation water withdrawal, putting more pressure on the water resources of the Nile. For this reason, this scenario is provided as useful assessment of the total blue water volumes needed, at the country scale, to perform a reallocation able to increase production in poorly irrigated countries as Sudan and Ethiopia. Results show that, in average, the shift to the balanced diet of Willet et al.[43] enables to satisfy a lower percentage of the demand, and thus, to feed a lower fraction of the population considering the domestic production after crop reallocation for these countries. On the other hand, the diet of Willet et al.[43] promotes an higher intake of cereals, tubers and proteins of vegetable origin (soybeans and groundnuts), with respect to the current diets of Sudan and Ethiopia, which are instead characterized by low energy intake. The shift to a balanced diet would tackle the malnutrition problems in these countries, reducing anemia and malnourishment, but the shift to a balanced diet might also make it more challenging to feed a higher percentage of population with only the domestic crop production. Only when both irrigation expansion over potential irrigation areas and agricultural intensification are applied, a higher percentage of demand can be satisfied in Sudan, when the balanced diet is considered, with a consumption of 18.52 km^3.

3.2.4 Future Crop Reallocation: Hypothetical Irrigation Expansion

In this section the main results obtained from the crop reallocation performed for the future scenarios in Sudan and Ethiopia are reported. Crop reallocation has been performed with the aim of increasing domestic agricultural production and, thus, the country self-sufficiency. With this aim, the crop reallocation for the future scenarios RCP 4.5, 2.6 and 8.5 has been performed considering the scenario of irrigation expansion. Indeed, a crop reallocation performed on the current cropland doesn't succeed in increasing production, but it only preserves the consumption of blue water. On the contrary, an irrigation expansion in the future enhances a reduction in the demand gaps, with an increase in blue water consumption that is proportioned to the cropland expansion. This scenario is explored only as hypothetical expansion scenario to assess the amount of blue water that would be needed to increase production without exploiting the natural resources of the country in the future. In this section we assess the percentage of the demand satisfaction and the consumption of blue water, after crop reallocation with irrigation expansion in the years 2050 and 2100. Four scenarios that include diet shift and agricultural intensification (described in Section 2) have been considered and compared, to evaluate the sustainability of changing diet and intensification in the future. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link for Sudan and at this link for Ethiopia.

3.2.4.1 RCP 4.5

Table 61-Table 68 report the main results for each diet and intensification scenarios for RCP 4.5 in Sudan, and Table 69-Table 76 report the same results for Ethiopia. The demand outcomes satisfied in average up to 55.82%, in 2050, and 47.54%, in 2100, in Sudan for the scenario D1I1 (Table 62 and Table 66, respectively); while in Ethiopia the demand is satisfied up to 77.37%, in 2050, and 71.47%, in 2100, in the scenario D0I1 (Table 70 and Table 74, respectively). The maximum consumption of blue water consumption in Sudan is 18.52 km^3 (both in 2050 and in 2100) in the scenario D1I1, while the minimum consumption is 15.44 km^3 in the scenario D0I0 (Table 61 and Table 65). In Ethiopia, the maximum BW consumption is 11.59 km^3, in 2050, and 11.44 km^3, in 2100, in the scenario D0I1, and the minimum is 7.95 km^3, in 2050, and 6.71 km^3, in 2100, in the scenario D0I0 (Table 69 and Table 73). For RCP 4.5 the potential irrigation expansion scenario gives positive results both in terms of production increase and blue water consumption. The best results in terms of demand

satisfaction are obtained when intensification is applied (D0I1 and D1I1). The production visibly increases for all crops both in Sudan (Table 64 and Table 68) and Ethiopia (Table 72 and Table 76). In Sudan production of bananas, sunflowers, maize and potatoes is privileged in all the four scenarios, while, when intensification is applied, wheat and sugarcane also visibly increase (Table 64 and Table 68). In Ethiopia production of cereals (i.e. sorghum, maize and wheat) increases in all the scenarios, as well as sugarcane and potatoes, when intensification is applied, rice and groundnuts are also privileged (Table 72 and Table 76).

Table 61 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 4.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.01	7.77	0.57	9.17
Maize	0.11	0.01	0.53	0.34
Rice	0.02	0.01	0.73	0.28
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.33	0.17	0.75	0.36
Vegetables	1.12	0.30	0.80	0.06
Pulses	0.67	0.33	1.16	0.58
Sunflower	0.27	0.15	0.45	0.19
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.63	0.59	1.55	0.28
Olives	0.26	0.13	0.26	0.13
Sorghum	5.33	6.32	4.86	3.41
Banana	0.00	0.00	0.00	0.00
Groundnuts	4.69	2.31	4.71	3.72
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.44**	**18.08**	**16.37**	**18.52**

Table 62 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 4.5)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	1.88	23.31	1.29	32.17
Maize	44.68	44.69	18.69	35.09
Rice	36.47	36.47	33.49	33.50
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	36.08	36.10	34.58	34.58
Vegetables	51.13	51.61	60.95	61.36
Pulses	44.34	44.39	42.45	42.50
Sunflower	44.78	44.78	43.13	43.13
Sugarcane	100	100	100	100
Temperate Fruits	81.37	81.62	100	100
Olives	100	100	100	100
Sorghum	23.58	39.69	39.08	53.10
Banana	33.31	33.31	33.31	33.31
Groundnuts	100	100	53.37	68.57
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**53.17**	**55.73**	**50.69**	**55.82**

Table 63 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 4.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	17.35	38.77	18.26	49.13
Maize	59.64	59.64	21.04	37.43
Rice	83.94	83.94	36.35	36.35
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	36.79	36.82	34.91	34.91
Vegetables	51.17	51.65	61.01	61.42
Pulses	54.52	54.58	48.31	48.36
Sunflower	59.66	59.66	52.91	52.91
Sugarcane	100	100	100	100
Temperate Fruits	81.37	81.62	100	100
Olives	100	100	100	100
Sorghum	24.51	40.61	40.74	54.76
Banana	33.31	33.31	33.31	33.31
Groundnuts	100	100	53.37	68.57
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**60.15**	**62.71**	**53.35**	**58.48**

Table 64 - Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 4.5, in the average year 2050.

Sudan 2050 (RCP 4.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	340,431.82	4,214,387.72	212,962.24	5,301,390.23	215,723.29
Maize	182,301.65	182,312.94	486,441.58	912,984.13	50,660.82
Rice	47,635.32	47,638.15	728,003.24	728,029.07	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	38.99	38.99	38.99	21.66
Potato	403,621.71	403,930.43	838,377.51	838,367.20	111,403.68
Vegetables	7,454,878.00	7,525,092.29	5,501,330.04	5,538,299.20	3,226,645.69
Pulses	452,672.27	453,214.20	752,940.89	753,841.48	212,493.51
Sunflower	312,905.72	312,905.72	458,713.11	458,713.11	14,258.69
Sugarcane	11,806,520.02	51,760,419.44	28,413,148.67	46,458,803.97	5,719,621.55
Temperate Fruits	4,839,139.51	4,854,054.56	4,841,964.56	4,841,203.08	3,226,645.69
Olives	85,838.15	86,271.49	85,838.15	86,226.04	50,660.82
Sorghum	4,251,138.51	7,154,797.55	3,928,004.08	5,337,592.55	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,392,112.12	1,425,432.49	1,395,561.78	1,793,187.89	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 65 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 4.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.10	8.20	0.63	10.06
Maize	0.03	0.01	0.21	0.17
Rice	0.03	0.01	0.69	0.25
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.35	0.17	0.75	0.38
Vegetables	2.12	1.05	1.75	0.16
Pulses	0.68	0.34	1.18	0.59
Sunflower	0.20	0.13	0.40	0.18
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.69	0.81	1.66	0.34
Olives	0.27	0.14	0.26	0.13
Sorghum	4.24	4.88	4.06	2.49
Banana	0.00	0.00	0.00	0.00
Groundnuts	4.74	2.35	4.78	3.76
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.44**	**18.08**	**16.37**	**18.52**

Table 66 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 4.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.35	16.69	0.93	23.04
Maize	31.99	32.00	13.39	25.13
Rice	26.12	26.12	23.99	23.99
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	25.81	25.83	24.76	24.75
Vegetables	36.71	37.06	43.83	43.91
Pulses	31.77	31.78	30.41	30.44
Sunflower	32.07	32.07	30.88	30.89
Sugarcane	100	100	100	100
Temperate Fruits	58.28	58.49	100	100
Olives	100	100	100	100
Sorghum	16.69	28.42	28.24	37.86
Banana	23.85	23.85	23.86	23.86
Groundnuts	100	100	38.17	49.31
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**45.64**	**47.49**	**43.90**	**47.54**

Table 67 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 4.5)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	12.42	27.77	13.08	35.19
Maize	42.70	42.70	15.06	26.81
Rice	60.12	60.12	26.03	26.03
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	26.32	26.34	24.99	24.99
Vegetables	36.74	37.09	43.88	43.96
Pulses	39.07	39.08	34.61	34.64
Sunflower	42.73	42.73	37.89	37.89
Sugarcane	100	100	100	100
Temperate Fruits	58.28	58.49	100	100
Olives	100	100	100	100
Sorghum	17.36	29.08	29.43	39.05
Banana	23.85	23.85	23.86	23.86
Groundnuts	100	100	38.17	49.31
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**50.64**	**52.48**	**45.80**	**49.45**

Table 68- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 4.5, in the average year 2100.

Sudan 2100 (RCP 4.5)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	340,434.62	4,214,133.30	212,961.95	5,301,719.19	215,723.29
Maize	182,246.17	182,257.74	486,321.40	912,921.56	50,660.82
Rice	47,635.81	47,638.28	728,007.86	728,040.61	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	38.99	38.99	38.99	21.66
Potato	403,135.45	403,540.30	837,950.01	837,802.76	111,403.68
Vegetables	7,474,330.54	7,545,189.14	5,523,742.69	5,534,292.23	3,226,645.69
Pulses	452,889.95	453,087.68	753,146.78	753,895.96	212,493.51
Sunflower	312,905.72	312,905.72	458,654.93	458,713.11	14,258.69
Sugarcane	22,216,041.59	74,114,651.65	39,536,333.25	61,275,385.91	5,719,621.55
Temperate Fruits	4,839,135.63	4,856,861.57	4,839,126.46	4,835,943.15	3,226,645.69
Olives	85,372.01	85,430.79	85,400.37	85,840.64	50,660.82
Sorghum	4,202,413.59	7,153,194.93	3,963,125.19	5,313,493.46	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,396,705.25	1,429,358.35	1,393,521.80	1,800,304.33	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 69 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 4.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	4.24	9.16	4.27	1.50
Maize	1.31	0.51	1.48	0.25
Rice	0.01	0.56	0.01	1.89
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	1.26	0.48	1.25	0.42
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.07	0.19	0.07	0.00
Sorghum	0.83	0.19	0.68	0.03
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.22	0.50	0.22	7.06
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**7.95**	**11.59**	**7.99**	**11.14**

Table 70 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 4.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	24.30	68.50	14.52	16.59
Maize	53.98	61.40	28.97	55.30
Rice	0.49	51.21	0.08	34.32
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.23	67.47
Tropical Fruits	100	100	100	100
Potato	68.90	69.07	20.20	56.20
Vegetables	100	100	86.68	98.54
Pulses	37.10	85.40	33.11	83.25
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	52.40	76.03	95.97	98.15
Banana	0.00	0.00	0.00	0.00
Groundnuts	19.01	71.53	0.72	38.41
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**61.16**	**77.37**	**48.75**	**67.73**

Table 71 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 4.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 4.5)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	39.72	83.92	23.73	25.81
Maize	54.02	61.44	28.98	55.32
Rice	34.97	85.69	5.96	40.20
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.23	67.47
Tropical Fruits	100	100	100	100
Potato	71.78	71.95	21.04	57.03
Vegetables	100	100	85.41	97.26
Pulses	26.73	75.03	23.86	74.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	54.78	78.41	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	18.42	70.94	0.70	38.39
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**64.32**	**80.53**	**49.42**	**68.25**

Table 72- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Ethiopia, for the RCP 4.5, in the average year 2050.

Ethiopia 2050 (RCP 4.5)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	1,752,184.61	4,939,723.94	1,751,975.20	2,002,144.94	937,388.66
Maize	8,674,589.13	9,866,614.72	9,005,350.93	17,194,327.31	2,086,356.87
Rice	3,355.77	350,544.57	3,355.76	1,379,434.53	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,609.46	46,862.62	40,594.20	1,228,517.90	23,111.32
Tropical Fruits	341,171.39	341,959.15	341,125.27	341,885.89	181,309.16
Potato	3,181,409.09	3,189,544.00	3,223,579.32	8,967,617.56	402,397.65
Vegetables	10,105,592.69	10,702,069.59	10,124,017.16	11,508,758.12	5,728,246.98
Pulses	1,209,530.47	2,784,293.80	1,209,914.91	3,041,947.12	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,764,977.90	10,708,444.49	9,761,148.61	10,709,496.27	5,728,246.98
Olives	3,829,954.51	3,877,352.57	3,830,215.82	3,888,213.86	2,086,356.87
Sorghum	2,640,200.90	3,830,886.90	2,373,111.39	2,427,050.81	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,236.29	121,271.22	32,238.87	1,722,827.65	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 73 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 4.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	4.37	9.54	4.37	1.73
Maize	0.32	0.07	0.40	0.03
Rice	0.01	0.45	0.01	1.53
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	1.14	0.44	1.14	0.39
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.00	0.26	0.00	0.00
Sorghum	0.66	0.19	0.59	0.04
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.21	0.50	0.21	7.08
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**6.71**	**11.44**	**6.72**	**10.80**

Table 74 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 4.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	20.24	56.96	12.10	13.77
Maize	45.09	51.25	24.21	46.14
Rice	0.41	42.58	0.07	28.54
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	1.85	56.10
Tropical Fruits	100	100	100	100
Potato	57.29	57.44	16.80	46.73
Vegetables	100	100	72.35	81.99
Pulses	30.85	71.02	27.54	69.23
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	42.48	61.84	77.82	80.43
Banana	0.00	0.00	0.00	0.00
Groundnuts	15.81	59.49	0.60	31.94
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**58.01**	**71.47**	**45.24**	**61.06**

Table 75 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 4.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 4.5)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	33.06	69.78	19.76	21.43
Maize	45.13	51.28	24.23	46.15
Rice	29.08	71.25	4.95	33.42
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	1.85	56.10
Tropical Fruits	100	100	100	100
Potato	59.68	59.83	17.49	47.43
Vegetables	100	100	71.29	80.93
Pulses	22.23	62.39	19.84	61.54
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	44.46	63.82	81.86	84.47
Banana	0.00	0.00	0.00	0.00
Groundnuts	15.32	59.00	0.58	31.92
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**60.64**	**74.10**	**45.85**	**61.67**

Table 76 - Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 4.5, in the average year 2100.

Ethiopia 2100 (RCP 4.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	1,755,442.29	4,939,810.06	1,755,526.10	1,998,082.93	937,388.66
Maize	8,714,504.21	9,903,419.64	9,051,446.96	17,250,354.07	2,086,356.87
Rice	3,355.75	350,504.90	3,355.75	1,379,416.81	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,609.46	46,862.62	40,594.20	1,228,517.90	23,111.32
Tropical Fruits	341,225.21	342,480.33	341,211.37	342,458.10	181,309.16
Potato	3,181,409.09	3,189,544.00	3,223,579.32	8,967,617.56	402,397.65
Vegetables	10,147,434.02	10,708,444.49	10,162,470.46	11,516,275.30	5,728,246.98
Pulses	1,209,530.47	2,784,293.80	1,209,914.91	3,041,947.12	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,722,563.83	10,702,069.59	9,722,563.83	10,702,069.59	5,728,246.98
Olives	3,826,117.44	3,863,520.89	3,825,020.02	3,888,213.86	2,086,356.87
Sorghum	2,573,870.55	3,747,068.54	2,314,160.85	2,391,848.65	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,234.45	121,296.06	32,234.45	1,722,869.41	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

3.2.4.2 RCP 2.6

Table 77-Table 84 report the main results for each diet and intensification scenarios for the future RCP 2.6 scenario in Sudan, Table 85-Table 92 report results for Ethiopia. The demand results satisfied in average up to 61.20%, in 2050, and 58.09%, in 2100, in Sudan, in the scenario D1I1 (Table 78 and Table 82, respectively); while in Ethiopia the demand is satisfied up to 82.02% in 2050 and 82.72% in 2100 in the scenario D0I1 (Table 86 and Table 90, respectively). The maximum consumption of blue water consumption in Sudan is 18.52 km^3 (both in 2050 and in 2100) in the scenario D1I1, while the minimum consumption is 15.44 km^3 in the scenario D0I0 (Table 77 and Table 81). In Ethiopia, the maximum BW consumption is 11.29 km^3, in 2050, and 10.30 km^3, in 2100, in the scenario D0I1, and the minimum is 7.95 km^3, in 2050, and 6.71 km^3, in 2100, in the scenario D0I0 (Table 85 and Table 89). Similarly, to RCP 4.5, for RCP 2.6 the potential irrigation expansion scenario yields positive outcomes both in terms of production increase and blue water consumption. The best results in terms of demand satisfaction are obtained when intensification is applied (D0I1 and D1I1). The production visibly increases for all crops both in Sudan (Table 80 and Table 84) and Ethiopia (Table 88 and Table 92), with respect to the baseline. This is due to the higher availability of irrigated cropland, that enhanced agricultural production. In Sudan mainly production of bananas, sunflowers, maize, pulses and potatoes is increased in all the four scenarios, while, when intensification is applied, wheat and sugarcane also visibly increase (Table 80 and Table 84). In Ethiopia production of cereals (i.e. sorghum, maize and wheat) increases in all the scenarios, as well as sugarcane and potatoes, when intensification is applied, rice and groundnuts are also privileged (Table 88 and Table 92).

Table 77 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 2.6)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.01	7.60	0.57	9.26
Maize	0.03	0.01	0.22	0.19
Rice	0.02	0.01	0.68	0.28
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.33	0.17	0.72	0.36
Vegetables	2.34	1.55	1.97	0.40
Pulses	0.65	0.32	1.14	0.56
Sunflower	0.29	0.19	0.46	0.22
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.62	0.73	1.62	0.69
Olives	0.25	0.13	0.26	0.12
Sorghum	4.29	5.10	4.09	2.79
Banana	0.00	0.01	0.02	0.00
Groundnuts	4.60	2.27	4.62	3.64
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.44**	**18.08**	**16.37**	**18.52**

Table 78 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 2.6)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	2.23	27.60	1.53	38.09
Maize	52.92	52.92	22.14	41.55
Rice	43.19	43.19	39.66	39.67
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	42.78	42.79	40.96	40.97
Vegetables	60.85	61.48	72.65	72.63
Pulses	52.58	52.60	50.29	50.35
Sunflower	53.03	52.96	51.05	51.07
Sugarcane	100	100	100	100
Temperate Fruits	96.34	96.75	100	100
Olives	100	100	100	100
Sorghum	27.56	47.16	45.84	62.82
Banana	39.44	39.44	39.44	39.44
Groundnuts	100	100	63.25	81.36
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**58.06**	**61.13**	**55.12**	**61.20**

Table 79 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 2.6)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	20.54	45.92	21.62	58.18
Maize	70.62	70.63	24.91	44.32
Rice	99.40	99.40	43.04	43.04
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	43.63	43.63	41.36	41.36
Vegetables	60.90	61.53	72.73	72.71
Pulses	64.64	64.66	57.24	57.30
Sunflower	70.65	70.58	62.63	62.65
Sugarcane	100	100	100	100
Temperate Fruits	96.34	96.75	100	100
Olives	100	100	100	100
Sorghum	28.66	48.26	47.81	64.79
Banana	39.44	39.44	39.44	39.44
Groundnuts	100	100	63.25	81.36
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**66.32**	**69.39**	**58.27**	**64.34**

Table 80- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 2.6, in the average year 2050.

Sudan 2050 (RCP 2.6)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	340,338.25	4,214,523.22	212,925.68	5,301,308.13	215,723.29
Maize	182,303.93	182,314.40	486,390.22	912,945.80	50,660.82
Rice	47,635.82	47,638.33	728,003.30	728,032.03	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	30.33	30.04	38.99	21.66
Potato	404,212.69	404,243.87	838,582.67	838,748.18	111,403.68
Vegetables	7,492,292.77	7,570,248.75	5,537,632.72	5,536,341.98	3,226,645.69
Pulses	453,283.97	453,501.62	753,319.97	754,207.76	212,493.51
Sunflower	312,905.72	312,505.45	458,520.54	458,713.11	14,258.69
Sugarcane	27,254,046.08	88,201,383.29	44,913,181.99	79,675,802.12	5,719,621.55
Temperate Fruits	4,838,128.99	4,858,640.57	4,838,457.06	4,859,309.59	3,226,645.69
Olives	86,435.48	86,033.28	86,102.75	86,627.78	50,660.82
Sorghum	4,195,844.48	7,179,219.20	3,891,285.27	5,332,057.71	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,395,447.30	1,431,041.16	1,396,634.47	1,796,656.86	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 81 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 2.6)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	1.07	8.63	0.70	9.60
Maize	0.10	0.03	0.34	0.33
Rice	0.04	0.02	0.94	0.35
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.33	0.16	0.72	0.36
Vegetables	3.38	1.88	2.46	0.81
Pulses	0.65	0.32	1.13	0.56
Sunflower	0.18	0.01	0.11	0.12
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.60	0.87	1.83	0.81
Olives	0.23	0.12	0.24	0.12
Sorghum	3.01	3.09	2.55	1.82
Banana	0.25	0.67	0.68	0.00
Groundnuts	4.60	2.28	4.66	3.65
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.44**	**18.08**	**16.37**	**18.52**

Table 82 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 2.6)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	2.03	25.18	1.40	34.75
Maize	48.27	48.28	20.19	37.91
Rice	39.40	39.40	36.18	36.19
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	38.97	38.97	37.35	37.36
Vegetables	55.79	56.29	66.33	66.51
Pulses	47.91	47.96	45.89	45.90
Sunflower	48.37	48.37	63.98	46.59
Sugarcane	100	100	100	100
Temperate Fruits	87.77	88.05	100	100
Olives	100	100	100	100
Sorghum	24.59	43.29	41.89	56.10
Banana	35.98	35.98	35.98	35.98
Groundnuts	100	100	56.94	74.06
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**55.27**	**58.12**	**53.74**	**58.09**

Table 83 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 2.6)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	18.74	41.88	19.72	53.08
Maize	64.43	64.43	22.73	40.44
Rice	90.68	90.68	39.27	39.27
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	39.75	39.74	37.71	37.72
Vegetables	55.83	56.34	66.40	66.58
Pulses	58.91	58.96	52.22	52.23
Sunflower	64.45	64.45	74.55	57.16
Sugarcane	100	100	100	100
Temperate Fruits	87.77	88.05	100	100
Olives	100	100	100	100
Sorghum	25.59	44.29	43.68	57.89
Banana	35.98	35.98	35.98	35.98
Groundnuts	100	100	56.94	74.06
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**62.81**	**65.65**	**56.61**	**60.96**

Table 84 - Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 2.6, in the average year 2100.

Sudan 2100 (RCP 2.6)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	340,410.84	4,213,468.53	212,846.53	5,301,495.57	215,723.29
Maize	182,303.28	182,317.51	486,407.40	913,012.93	50,660.82
Rice	47,635.82	47,638.37	728,001.24	728,043.14	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	38.99	38.99	38.99	21.66
Potato	403,631.27	403,604.80	838,170.32	838,387.07	111,403.68
Vegetables	7,529,684.27	7,597,939.77	5,542,200.85	5,557,201.05	3,226,645.69
Pulses	452,769.70	453,233.09	753,401.32	753,640.79	212,493.51
Sunflower	312,867.55	312,905.72	629,929.11	458,713.11	14,258.69
Sugarcane	42,020,000.48	98,895,919.60	50,242,277.84	91,934,813.56	5,719,621.55
Temperate Fruits	4,831,603.11	4,847,216.89	4,819,533.73	4,846,193.67	3,226,645.69
Olives	86,393.77	85,708.96	85,707.81	85,942.19	50,660.82
Sorghum	4,104,173.60	7,223,824.52	3,897,493.76	5,219,515.55	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,389,832.71	1,426,173.75	1,378,345.76	1,792,638.73	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 85 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 2.6)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	3.82	8.41	3.85	1.39
Maize	0.79	0.20	0.96	0.22
Rice	0.01	0.44	0.01	1.79
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	1.08	0.48	1.06	0.42
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.06	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.00	0.98	0.00	0.00
Sorghum	0.84	0.24	0.70	0.07
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.20	0.47	0.20	6.53
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**6.75**	**11.29**	**6.78**	**10.41**

Table 86 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 2.6)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	27.64	77.74	16.52	18.86
Maize	61.46	70.29	32.99	63.07
Rice	0.56	58.30	0.10	39.08
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.54	76.81
Tropical Fruits	100	100	100	100
Potato	78.45	78.64	22.99	63.98
Vegetables	100	100	98.69	100
Pulses	42.32	97.40	37.76	94.71
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	57.94	85.18	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	21.66	81.43	0.82	43.73
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**63.57**	**82.07**	**50.89**	**71.45**

Table 87 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 2.6 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 2.6)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	45.20	95.29	27.01	29.35
Maize	61.50	70.33	33.01	63.09
Rice	39.81	97.55	6.78	45.76
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.54	76.81
Tropical Fruits	100	100	100	100
Potato	81.73	81.92	23.94	64.93
Vegetables	100	100	97.23	100
Pulses	30.52	85.60	27.23	84.18
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	60.65	87.90	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	20.98	80.75	0.79	43.71
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**67.17**	**85.67**	**51.32**	**71.99**

Table 88- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Ethiopia, for the RCP 2.6, in the average year 2050.

Ethiopia 2050 (RCP 2.6)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	1,750,753.15	4,924,048.76	1,750,608.02	1,998,735.32	937,388.66
Maize	8,675,162.21	9,920,760.96	9,009,660.05	17,223,851.34	2,086,356.87
Rice	3,355.76	350,540.82	3,355.77	1,379,393.80	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,618.95	46,862.62	40,600.17	1,228,517.90	23,111.32
Tropical Fruits	341,219.74	341,944.92	341,165.62	341,665.57	181,309.16
Potato	3,181,727.68	3,189,544.00	3,222,777.04	8,967,617.56	402,397.65
Vegetables	10,105,592.69	10,702,069.59	10,124,017.16	11,508,758.12	5,728,246.98
Pulses	1,211,932.89	2,789,154.87	1,211,730.61	3,039,589.61	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,773,758.34	10,708,444.49	9,771,359.53	10,709,496.27	5,728,246.98
Olives	3,783,400.46	3,824,254.65	3,782,516.85	3,895,845.59	2,086,356.87
Sorghum	2,564,177.65	3,769,967.76	2,311,367.01	2,392,728.21	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,247.62	121,251.18	32,254.77	1,722,847.24	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 89 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 2.6)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	3.59	8.27	3.56	1.35
Maize	0.37	0.02	0.42	0.02
Rice	0.01	0.28	0.01	1.13
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	1.01	0.37	1.02	0.38
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.05	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.00	0.79	0.00	0.00
Sorghum	0.12	0.04	0.08	0.01
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.19	0.49	0.19	6.28
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**5.29**	**10.30**	**5.28**	**9.16**

Table 90 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 2.6)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	27.94	78.94	16.65	19.19
Maize	61.80	70.84	33.23	63.90
Rice	0.57	59.28	0.10	39.73
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.58	78.10
Tropical Fruits	100	100	100	100
Potato	79.68	79.70	23.34	64.94
Vegetables	100	100	100	100
Pulses	43.59	99.39	38.89	96.46
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	59.98	87.13	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	22.02	82.80	0.83	44.47
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**63.97**	**82.72**	**51.12**	**71.91**

Table 91 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 2.6 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 2.6)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	45.78	96.79	27.32	29.86
Maize	61.84	70.88	33.25	63.92
Rice	40.48	99.19	6.89	46.53
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.58	78.10
Tropical Fruits	100	100	100	100
Potato	83.02	83.04	24.31	65.90
Vegetables	100	100	99.33	100
Pulses	31.58	87.39	28.18	85.75
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	62.74	89.88	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	21.34	82.12	0.81	44.44
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**67.63**	**86.38**	**51.62**	**72.46**

Table 92 - Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Ethiopia, for the RCP 2.6, in the average year 2100.

Ethiopia 2100 (RCP 2.6)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	1,740,452.86	4,917,998.37	1,736,032.77	2,000,431.54	937,388.66
Maize	8,579,148.49	9,834,270.97	8,924,012.91	17,161,820.80	2,086,356.87
Rice	3,355.77	350,548.37	3,355.76	1,379,372.51	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,612.07	46,858.98	40,621.22	1,228,628.97	23,111.32
Tropical Fruits	340,616.25	342,331.92	340,899.88	342,502.42	181,309.16
Potato	3,178,775.22	3,179,555.29	3,217,977.59	8,951,652.60	402,397.65
Vegetables	10,154,238.51	10,873,804.53	10,171,258.96	11,516,172.88	5,728,246.98
Pulses	1,227,607.24	2,799,384.41	1,227,616.59	3,044,880.70	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,745,430.14	10,814,724.12	9,743,402.67	10,702,613.31	5,728,246.98
Olives	3,805,000.22	3,819,798.14	3,802,394.78	3,895,845.59	2,086,356.87
Sorghum	2,610,850.40	3,792,606.70	2,352,549.60	2,397,970.60	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,255.82	121,277.04	32,255.91	1,722,859.20	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

3.2.4.3 RCP 8.5

Table 93-Table 99 report the main results for each diet and intensification scenarios for the future RCP 8.5 scenario in Sudan, Table 101-Table 107 report the results for Ethiopia. The demand results satisfied in average up to 64.60% in 2050, and 58.33% in 2100 in Sudan in the scenario D1I1 (Table 94 and Table 98, respectively); while in Ethiopia the demand is satisfied up to 82.82% in 2050 and 83.83% in 2100 in the scenario D0I1 (Table 102 and Table 106, respectively). The maximum consumption of blue water consumption in Sudan is 18.50 km^3 (both in 2050 and in 2100), in the scenario D1I1, while the minimum consumption is 15.42 km^3, in the scenario D0I0 (Table 93 and Table 97). In Ethiopia the maximum BW consumption is 7.63 km^3, in 2050 (D0I1), and 7.71 km^3, in 2100 (D1I1), and the minimum is 4.51 km^3, in 2050, and 4.92 km^3, in 2100, in the scenario D0I0 (Table 101 and Table 105). The potential irrigation expansion following the RCP 8.5 gives positive results both in terms of production increase and blue water consumption. The production visibly increases for all crops both in Sudan (Table 96 and Table 100) and Ethiopia (Table 104 and Table 108), with respect to the baseline. This is due to the higher availability of irrigated cropland, that enhanced agricultural production. Similarly to previous RCP scenarios, production of bananas, sunflowers, maize, pulses and potatoes is increased in all the four scenarios in Sudan, while, when intensification is applied, wheat and sugarcane also visibly increase (Table 96 and Table 100). In Ethiopia production of cereals (i.e. sorghum, maize and wheat), sugarcane and potatoes increases mainly and, when intensification is applied, rice and groundnuts are also privileged (Table 104 and Table 108).

Table 93 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 8.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	0.87	9.38	0.74	9.60
Maize	0.00	0.00	0.00	0.06
Rice	0.04	0.06	1.79	0.48
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.32	0.15	0.72	0.36
Vegetables	3.30	2.14	2.63	1.00
Pulses	0.62	0.32	1.14	0.57
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.49	0.94	2.13	0.76
Olives	0.24	0.13	0.24	0.12
Sorghum	2.75	1.59	1.39	1.51
Banana	1.12	1.02	0.88	0.34
Groundnuts	4.66	2.33	4.68	3.70
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.42**	**18.07**	**16.35**	**18.50**

Table 94 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 8.5)				
Trade Surplus-Deficit				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	2.24	27.65	1.53	38.22
Maize	53.08	53.08	22.21	41.70
Rice	43.35	43.35	39.81	39.81
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	42.88	42.88	41.10	41.09
Vegetables	61.25	61.56	72.28	73.57
Pulses	52.75	52.82	50.49	50.53
Sunflower	100	100	100	100
Sugarcane	100	100	100	100
Temperate Fruits	96.64	96.80	100	100
Olives	100	100	100	100
Sorghum	27.32	48.23	47.83	62.26
Banana	39.59	39.59	39.59	39.59
Groundnuts	100	100	63.77	82.18
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**61.27**	**64.40**	**58.57**	**64.60**

Table 95 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Sudan 2050 (RCP 8.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	20.62	46.03	21.70	58.39
Maize	70.85	70.86	25.00	44.49
Rice	99.77	99.77	43.20	43.20
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	43.73	43.73	41.49	41.48
Vegetables	61.30	61.61	72.36	73.64
Pulses	64.85	64.93	57.46	57.49
Sunflower	100	100	100	100
Sugarcane	100	100	100	100
Temperate Fruits	96.64	96.80	100	100
Olives	100	100	100	100
Sorghum	28.42	49.34	49.81	64.23
Banana	39.59	39.59	39.59	39.59
Groundnuts	100	100	63.77	82.18
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**68.38**	**71.51**	**60.96**	**66.98**

Table 96- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 8.5, in the average year 2050.

Sudan 2050 (RCP 8.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	340,416.69	4,205,406.26	212,404.05	5,299,864.30	215,723.29
Maize	182,197.10	182,207.11	486,305.11	912,942.33	50,660.82
Rice	47,637.27	47,639.27	728,001.63	728,051.88	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	38.99	38.99	38.99	21.66
Potato	403,599.13	403,664.45	838,295.59	838,028.83	111,403.68
Vegetables	7,514,002.29	7,552,270.81	5,488,827.32	5,586,717.33	3,226,645.69
Pulses	453,071.43	453,711.45	753,464.20	754,019.96	212,493.51
Sunflower	1,218,156.05	2,025,815.76	1,363,963.44	3,938,306.28	14,258.69
Sugarcane	95,190,046.05	188,806,583.44	95,190,046.05	188,806,583.44	5,719,621.55
Temperate Fruits	4,835,268.29	4,843,481.18	4,809,923.64	4,855,388.53	3,226,645.69
Olives	85,129.81	86,417.61	84,709.25	85,746.83	50,660.82
Sorghum	4,143,508.97	7,315,944.45	4,044,873.24	5,265,089.83	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,409,975.39	1,432,445.83	1,402,937.91	1,808,149.87	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 97 – Agricultural blue water consumption (BW) in Sudan after crop reallocation (with potential irrigation expansion) for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 8.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	0.83	6.28	0.47	8.57
Maize	0.00	0.00	0.03	0.00
Rice	0.02	0.01	0.43	0.24
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	0.33	0.17	0.76	0.38
Vegetables	2.66	1.25	1.59	0.71
Pulses	0.59	0.34	1.06	0.58
Sunflower	0.37	0.15	0.57	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	1.27	0.77	1.62	0.77
Olives	0.27	0.14	0.27	0.13
Sorghum	4.28	5.99	4.17	3.05
Banana	0.00	0.56	0.52	0.28
Groundnuts	4.81	2.42	4.87	3.79
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**15.43**	**18.08**	**16.36**	**18.51**

Table 98 - Percentage of demand satisfaction in Sudan after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 8.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	2.04	25.29	1.40	34.90
Maize	48.46	48.46	20.27	38.05
Rice	39.55	39.56	36.32	36.33
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	39.09	39.15	37.39	37.50
Vegetables	55.28	55.98	65.76	66.40
Pulses	48.15	48.14	46.07	46.10
Sunflower	48.34	48.21	46.62	46.77
Sugarcane	100	100	100	100
Temperate Fruits	87.82	88.63	100	100
Olives	100	100	100	100
Sorghum	26.30	43.56	44.13	57.75
Banana	36.12	36.12	36.12	36.12
Groundnuts	100	100	58.11	75.00
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**55.41**	**58.21**	**52.81**	**58.33**

Table 99 - Percentage of demand satisfaction after crop reallocation in Sudan (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Sudan 2100 (RCP 8.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	18.81	42.06	19.80	53.30
Maize	64.68	64.68	22.81	40.60
Rice	91.03	91.04	39.42	39.42
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	100	100
Tropical Fruits	0.00	0.00	0.00	0.00
Potato	39.87	39.93	37.75	37.85
Vegetables	55.32	56.03	65.83	66.47
Pulses	59.20	59.18	52.43	52.46
Sunflower	64.48	64.35	57.22	57.38
Sugarcane	100	100	100	100
Temperate Fruits	87.82	88.63	100	100
Olives	100	100	100	100
Sorghum	27.30	44.56	45.93	59.56
Banana	36.12	36.12	36.12	36.12
Groundnuts	100	100	58.11	75.00
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**62.98**	**65.77**	**55.69**	**61.21**

Table 100- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Sudan, for the RCP 8.5, in the average year 2100.

Sudan 2100 (RCP 8.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	340,411.88	4,216,023.69	212,951.34	5,302,964.93	215,723.29
Maize	182,304.68	182,314.98	486,379.69	912,984.81	50,660.82
Rice	47,636.19	47,638.36	728,000.21	728,031.06	7,487.79
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	2.88	2.88	2.88	2.88	1.47
Tropical Fruits	38.99	38.99	38.99	38.99	21.66
Potato	403,276.70	403,920.40	835,739.36	838,141.68	111,403.68
Vegetables	7,431,701.40	7,526,744.36	5,472,744.40	5,526,409.13	3,226,645.69
Pulses	453,321.32	453,156.61	753,465.75	754,048.63	212,493.51
Sunflower	311,492.49	310,637.82	457,179.01	458,705.08	14,258.69
Sugarcane	79,832,960.02	188,806,583.44	94,779,875.19	188,806,583.44	5,719,621.55
Temperate Fruits	4,815,435.26	4,859,846.03	4,819,556.91	4,859,667.29	3,226,645.69
Olives	85,556.58	86,323.19	85,556.58	86,371.13	50,660.82
Sorghum	4,371,214.46	7,240,767.67	4,089,872.32	5,352,666.61	2,818,841.52
Banana	606,828.86	606,828.86	305,848.50	305,848.50	13.61
Groundnuts	1,402,622.65	1,440,221.38	1,401,043.91	1,808,358.78	818,386.74
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 101 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 8.5)				
Crops	**BW (km³)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	3.38	6.90	3.40	0.00
Maize	0.06	0.00	0.10	0.00
Rice	0.01	0.25	0.01	0.91
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.72	0.00	0.70	0.00
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.00	0.00	0.00	0.00
Sorghum	0.17	0.04	0.14	0.01
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.17	0.43	0.18	6.02
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**4.51**	**7.63**	**4.52**	**6.93**

Table 102 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 8.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	28.23	79.28	16.86	19.14
Maize	63.10	71.22	33.94	64.20
Rice	0.57	59.31	0.10	39.75
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.58	78.12
Tropical Fruits	100	100	100	100
Potato	79.72	79.54	23.35	65.13
Vegetables	100	100	100	100
Pulses	43.61	99.22	38.91	96.31
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	59.80	88.10	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	22.03	82.82	0.83	44.49
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**64.08**	**82.82**	**51.18**	**71.94**

Table 103 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 8.5 (average year 2050), in different diet and intensification conditions.

Ethiopia 2050 (RCP 8.5)				
Trade Constant				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	46.09	97.13	27.53	29.81
Maize	63.14	71.27	33.96	64.22
Rice	40.49	99.23	6.90	46.55
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.58	78.12
Tropical Fruits	100	100	100	100
Potato	83.05	82.88	24.32	66.10
Vegetables	100	100	99.62	100
Pulses	31.60	87.21	28.20	85.60
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	62.56	90.86	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	21.35	82.14	0.81	44.46
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**67.74**	**86.48**	**51.71**	**72.49**

Table 104- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Ethiopia, for the RCP 8.5, in the average year 2050.

Ethiopia 2050 (RCP 8.5)					
Crops	Production (tonnes)				
	D0I0	D0I1	D1I0	D1I1	BASELINE
Wheat	1,758,066.73	4,936,694.96	1,756,824.15	1,994,637.10	937,388.66
Maize	8,755,962.42	9,883,166.56	9,110,958.46	17,235,065.64	2,086,356.87
Rice	3,350.68	350,548.80	3,344.88	1,379,481.65	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,612.07	46,862.25	40,621.22	1,228,397.94	23,111.32
Tropical Fruits	342,288.00	340,473.75	341,798.50	340,473.75	181,309.16
Potato	3,178,775.22	3,171,822.00	3,217,977.59	8,974,406.53	402,397.65
Vegetables	10,175,122.93	10,828,998.74	10,196,284.51	11,553,195.31	5,728,246.98
Pulses	1,227,607.24	2,793,312.03	1,227,616.59	3,038,624.56	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,745,430.14	10,768,598.21	9,743,402.67	10,735,353.59	5,728,246.98
Olives	3,791,260.72	3,873,810.25	3,792,758.44	3,818,969.91	2,086,356.87
Sorghum	2,601,978.51	3,833,255.96	2,343,175.92	2,421,340.42	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,257.54	121,247.69	32,252.55	1,722,942.15	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

Table 105 – Agricultural blue water consumption (BW) in Ethiopia after crop reallocation (with potential irrigation expansion) for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 8.5)				
Crops	**BW (km^3)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	3.73	6.66	3.73	0.00
Maize	0.02	0.00	0.03	0.00
Rice	0.01	0.31	0.01	1.12
Sugar beet	0.00	0.00	0.00	0.00
Soybean	0.00	0.00	0.00	0.00
Tropical Fruits	0.83	0.00	0.83	0.00
Potato	0.00	0.00	0.00	0.00
Vegetables	0.00	0.00	0.00	0.00
Pulses	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	0.00	0.00	0.00	0.00
Temperate Fruits	0.00	0.00	0.00	0.00
Olives	0.00	0.00	0.00	0.00
Sorghum	0.14	0.06	0.12	0.00
Banana	0.00	0.00	0.00	0.00
Groundnuts	0.19	0.48	0.19	6.59
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**4.92**	**7.51**	**4.92**	**7.71**

Table 106 - Percentage of demand satisfaction in Ethiopia after crop reallocation (with potential irrigation expansion) in the Surplus-Deficit Trade scenario for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 8.5)				
Trade Surplus-Deficit				
Crops	**Demand gap closure (%)**			
	D0I0	**D0I1**	**D1I0**	**D1I1**
Wheat	28.95	81.66	17.30	19.76
Maize	65.33	73.60	35.13	66.10
Rice	0.59	61.20	0.10	41.02
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.67	80.62
Tropical Fruits	100	100	100	100
Potato	82.27	82.43	24.10	67.22
Vegetables	100	100	100	100
Pulses	44.43	100	39.64	99.30
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	61.26	90.14	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	22.72	85.47	0.86	45.91
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**64.68**	**83.89**	**51.41**	**72.85**

Table 107 - Percentage of demand satisfaction after crop reallocation in Ethiopia (with potential irrigation expansion), in the Constant Trade scenario for the future RCP 8.5 (average year 2100), in different diet and intensification conditions.

Ethiopia 2100 (RCP 8.5)				
Trade Constant				
Crops	Demand gap closure (%)			
	D0I0	D0I1	D1I0	D1I1
Wheat	47.38	100	28.31	30.77
Maize	65.38	73.65	35.15	66.12
Rice	41.79	100	7.12	48.04
Sugar beet	0.00	0.00	0.00	0.00
Soybean	100	100	2.67	80.62
Tropical Fruits	100	100	100	100
Potato	85.71	85.87	25.10	68.21
Vegetables	100	100	100	100
Pulses	32.04	89.23	28.58	88.25
Sunflower	0.00	0.00	0.00	0.00
Sugarcane	100	100	100	100
Temperate Fruits	100	100	100	100
Olives	100	100	100	100
Sorghum	64.10	92.99	100	100
Banana	0.00	0.00	0.00	0.00
Groundnuts	22.02	84.77	0.83	45.88
Fodder grasses	0.00	0.00	0.00	0.00
Tot	**68.46**	**87.61**	**51.98**	**73.42**

Table 108- Production (tonnes) per crop, obtained after reallocation (with potential irrigation expansion) in Ethiopia, for the RCP 8.5, in the average year 2100.

Ethiopia 2100 (RCP 8.5)					
Crops	**Production (tonnes)**				
	D0I0	**D0I1**	**D1I0**	**D1I1**	**BASELINE**
Wheat	1,746,919.78	4,927,463.50	1,746,882.28	1,994,637.10	937,388.66
Maize	8,784,817.54	9,896,469.40	9,138,639.15	17,194,934.46	2,086,356.87
Rice	3,350.68	350,548.71	3,350.68	1,379,486.90	2,708.75
Sugar beet	0.00	0.00	0.00	0.00	0.00
Soybean	40,612.07	46,867.45	40,621.22	1,228,397.94	23,111.32
Tropical Fruits	340,632.20	340,473.75	340,632.20	340,473.75	181,309.16
Potato	3,178,775.22	3,185,033.10	3,217,977.59	8,974,406.53	402,397.65
Vegetables	10,171,957.56	10,793,369.69	10,186,678.69	11,524,492.62	5,728,246.98
Pulses	1,212,111.73	2,772,179.39	1,211,848.89	3,035,978.75	657,594.30
Sunflower	0.00	0.00	0.00	0.00	0.00
Sugarcane	111,330,388.33	752,634,130.62	111,330,388.33	220,080,835.05	2,606,001.63
Temperate Fruits	9,726,281.82	10,734,991.97	9,726,639.92	10,702,446.47	5,728,246.98
Olives	3,791,260.72	3,827,862.99	3,792,758.44	3,885,527.72	2,086,356.87
Sorghum	2,582,638.54	3,800,465.07	2,327,438.86	2,408,014.31	1,061,842.09
Banana	0.00	0.00	0.00	0.00	0.00
Groundnuts	32,229.92	121,250.34	32,229.92	1,722,780.15	8,767.07
Fodder grasses	0.00	0.00	0.00	0.00	0.00

The crop reallocation performed for the future scenarios in Sudan and Ethiopia, considering agricultural expansion scenarios, has succeeded in increasing the agricultural production with respect to the baseline (current) scenario. Without expansion, in these countries, it is not possible to guarantee an agricultural production in the future able to satisfy at least the current demand. Low irrigated area, higher consumption of blue water (due to reduced rainfall) and increase in population are the main limitations to reach self-sufficiency in Sudan and Ethiopia in the future scenarios. In the expansion scenarios over potential irrigation expansion areas[52], a satisfactory increase in production with respect to the baseline is obtained. In Sudan the demand satisfaction increases in average of 14% for the RCP 4.5, 27% for the RCP 2.6 and of 34% for the RCP 8.5, with respect to the baseline. In Ethiopia it increases of 79% for the RCP 4.5 and of 90% for the RCPs 2.6 and 8.5, with respect to the baseline. When irrigation expansion is applied over potential irrigated areas, the consumption of blue water increases with respect to baseline, proportionally to the new irrigated harvested hectares. For instance, in the RCP 4.5 blue water consumption in Sudan reaches 18.52 km^3 (both in 2050 and in 2100), and in Ethiopia 11.59 km^3, while in the baseline 8.21 km^3 of blue water are consumed in Sudan and 1.84 km^3 in Ethiopia. Ethiopia has high availability of water, being its total internal renewable water resources around 120 km^3 per year, mainly coming from precipitation and surface water sources[26]. However, Ethiopia provides large amount of water to other countries in the NRB and, thus, the remaining total exploitable water is of 52 km^3. On the contrary, in Sudan has lower water availability, but receives external water sources and its total renewable water resources accounts of around 37.8 km^3 per year. Nevertheless, the blue water consumed at the country scale under the *potential expansion* scenario, results to not exploit the single-country available water resources. However, if the cumulated effects of expanding irrigation at a larger scale are considered, it would result an increase in the pressure on the water resources of the Nile. This hypothetical scenario provides a useful assessment of the total blue water volumes needed, at the country scale, to perform a reallocation able to increase production in poorly irrigated countries as Sudan and Ethiopia. The obtained results suggest that, especially in water scarce countries, such as Sudan (that is characterized by reduced rainfall and is not expected to experience increase in precipitation in future, as in Ethiopia), it is fundamental to perform a sustainable reallocation over the irrigated areas, that consumes a reduced amount of blue water without exploiting the current available resources in the basin.

3.3. THE NILE RIVER BASIN

In this Section, we provide the main results of the reallocation performed over the NRB. We provide an exploratory scenario where all the countries are assumed to share water and land resources. Indeed, the main aim of reallocation over NRB is optimizing the overall agricultural resources within the Basin, showing the possibility of saving water and land consumption at the basin scale, while guaranteeing the current production. The results are provided in terms of harvested area per crop, blue and green water volumes, obtained as outputs of the WATNEEDS[1] model, first considering the current crop distribution and, secondly, the new crop redistribution after performing the crop reallocation.

3.3.1 Baseline

Table 109 reports the results of the current crop distribution for the baseline scenario in the NRB. The total cultivated cropland in the NRB[38,39] is 28,711,513.25 ha, with an irrigated cropland that corresponds to the 27% of the total cropland. The main irrigated crops are vegetables, temperate fruit, sorghum, wheat, maize, sugarcane, groundnuts, and fodder; while cultivated areas of banana, soybean and tropical fruit are mainly rainfed. The total consumption of blue water if 60.5 km^3 and corresponds to around 70% of the current total exploitable water resources of the basin[2]. This means that currently almost the total renewable Nile freshwater resources are already used, with irrigated agriculture in Egypt and Sudan representing the most important water consumer[2,27]. Indeed, the NRB faces a huge challenge in terms of water security, especially considering the future expected increase in population and the conflicts about the water rights and exploitation among the Nile sharing countries. For this reason, it is fundamental to perform a strategic reallocation that might increase production in the basin without exceeding the current already used irrigation water for agriculture. Further results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link.

Table 109 – Harvested areas (ha), provided by MIRCA and IFPRI datasets[38,39], production (tonnes) and crop water requirements (km^3) for the baseline scenario of the Nile River Basin.

NRB Baseline				
Crops	**Area (ha)- MIRCA, IFRPI datasets[38,39]**	**Production (tonnes)**	**GW (km^3)**	**BW (km^3)**
Wheat	1,385,226.92	4,705,196.85	0.42	7.09
Maize	2,736,502.53	5,595,932.50	0.35	5.73
Rice	788,502.24	3,000,736.01	0.1	5.49
Sugar beet	62,764.37	2,967,367.06	0.01	0.50
Soybean	150,483.61	296,048.24	0.00	0.04
Tropical Fruits	431,662.88	311,513.08	0.04	0.01
Potato	275,571.19	2,809,055.81	0.04	0.71
Vegetables	5,749,606.60	32,556,957.19	1.33	24.15
Pulses	2,433,702.10	1,795,846.72	0.02	1.43
Sunflower	53,033.04	68,709.90	0.05	0.17
Sugarcane	339,537.62	25,468,421.93	0.21	2.81
Temperate Fruits	160,429.91	2,043,335.63	0.1	1.78
Olives	5,749,606.60	53,408,853.51	0.46	5.38
Sorghum	5,908,148.25	6,553,792.75	0.95	1.85
Banana	49,880.40	581,102.70	0.00	0.00
Groundnuts	1,624,454.47	1,376,045.99	0.01	0.89
Fodder grasses	812,400.41	21,702,766.79	0.27	2.30
Tot	**28,711,513.25**	**-**	**4.37**	**60.4**

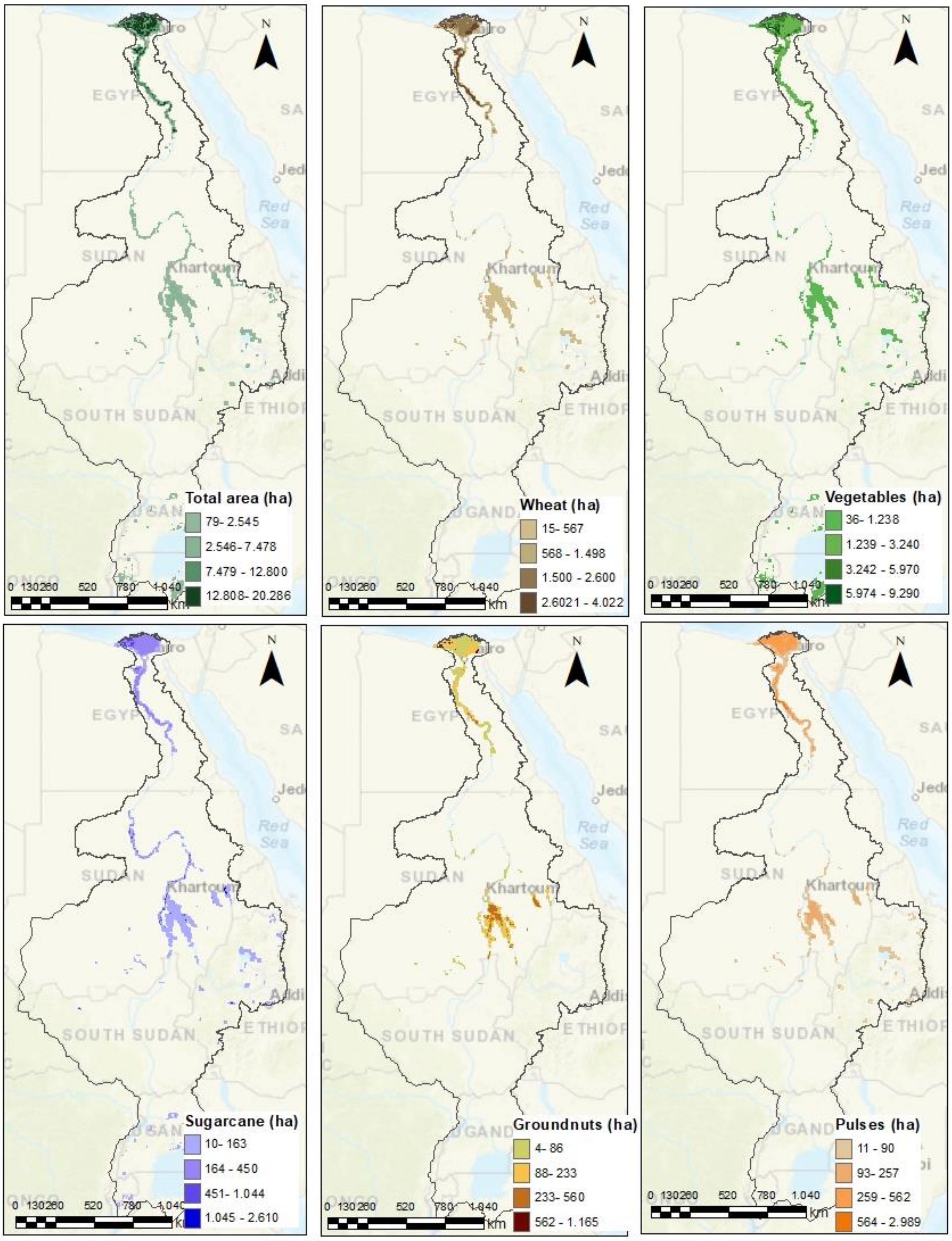

Figure 27 - Current total harvested area and single crops' harvested areas (ha) for the main irrigated crops in the NRB.

3.3.2 Baseline Crop Reallocation (Present):

In this section the main results obtained from the baseline crop reallocation performed over the Nile River Basin are reported. Results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link. The crop reallocation has been performed with the aim of reducing BW consumption and guaranteeing the current production. With this aim crop reallocation over the NRB has been performed considering no agricultural expansion. In this section we report results in term of the new allocated areas per crop and BW consumption after crop reallocation in the NRB for the baseline. Two scenarios of agricultural intensification (Section 2) have been considered and compared. In Table 110 the blue water consumption for the two intensification scenario is reported, while in Table 111 is reported the new harvested area after baseline reallocation. In Figure 28 we also report the spatial distribution of new harvested areas for the main irrigated crops in the NRB, for the scenario I0. When intensification is not applied (I0), the total harvested area remains almost equal to the current crop distribution (28 million ha), on the contrary, when intensification is applied (I1) the total harvested area is reduced of 11% with respect to the baseline distribution, corresponding to around 3 million ha of agricultural land saved. From Figure 28 it is possible to understand how crops are optimally reallocated to reduce blue water consumption. With respect to the baseline (Figure 27), harvested areas of water-consuming crops (e.g. sugarcane and groundnuts) are concentrated in areas characterized by higher water productivity and, thus, lower blue water requirement. Blue water is reduced in total of 6% (I0) and of around 50% (I1) (Table 110). These results show that in case of agricultural intensification (I1) it would be possible to sustainably increase production, proportionally to crop yields, without exceeding the current consumption of blue water.

Table 110 - Blue water consumption (km^3), after baseline cropland reallocation in the Nile River Basin, for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when baseline reallocation is considered.

NRB Reallocation Baseline			
Crops	**BW (km^3)**		**BASELINE**
	I0	**I1**	
Wheat	7.75	3.95	7.09
Maize	3.43	1.03	5.73
Rice	6.93	2.28	5.49
Sugar beet	0.43	0.44	0.50
Soybean	0.03	0.03	0.04
Tropical Fruits	0.07	0.04	0.01
Potato	0.63	0.36	0.71
Vegetables	25.54	13.86	24.15
Pulses	1.16	0.94	1.43
Sunflower	0.30	0.15	0.17
Sugarcane	1.85	1.44	2.81
Temperate Fruits	1.75	1.18	1.78
Olives	4.10	2.27	5.38
Sorghum	1.10	0.45	1.85
Banana	0.00	0.00	0.00
Groundnuts	0.83	0.53	0.89
Fodder grasses	0.27	0.14	2.30
Tot	**56.20**	**29.08**	**60.4**

Table 111 – New irrigated crop harvested areas obtained after baseline cropland reallocation in the Nile River Basin, for the two intensification scenarios considered. The total production per crop for both the scenarios (I0 and I1) is not reported because it remains equal to the baseline.

NRB Reallocation Baseline		
Crops	**Harvested Area (ha)**	
	I0	**I1**
Wheat	1,385,226.92	962,816.99
Maize	2,736,502.53	2,315,596.38
Rice	788,502.25	448,717.72
Sugar beet	62,764.38	62,764.38
Soybean	150,483.61	150,483.61
Tropical Fruits	431,662.89	430,626.37
Potato	275,571.20	229,124.02
Vegetables	5,749,606.60	5,032,317.26
Pulses	2,433,702.10	2,402,244.23
Sunflower	53,033.05	40,041.46
Sugarcane	339,537.63	297,030.05
Temperate Fruits	160,429.92	115,924.93
Olives	5,749,606.60	5,044,938.18
Sorghum	5,908,148.26	5,665,217.99
Banana	49,880.41	49,880.41
Groundnuts	1,624,454.48	1,575,952.80
Fodder grasses	718,919.71	704,044.53
Tot	**28,618,032.54**	**25,527,721.31**

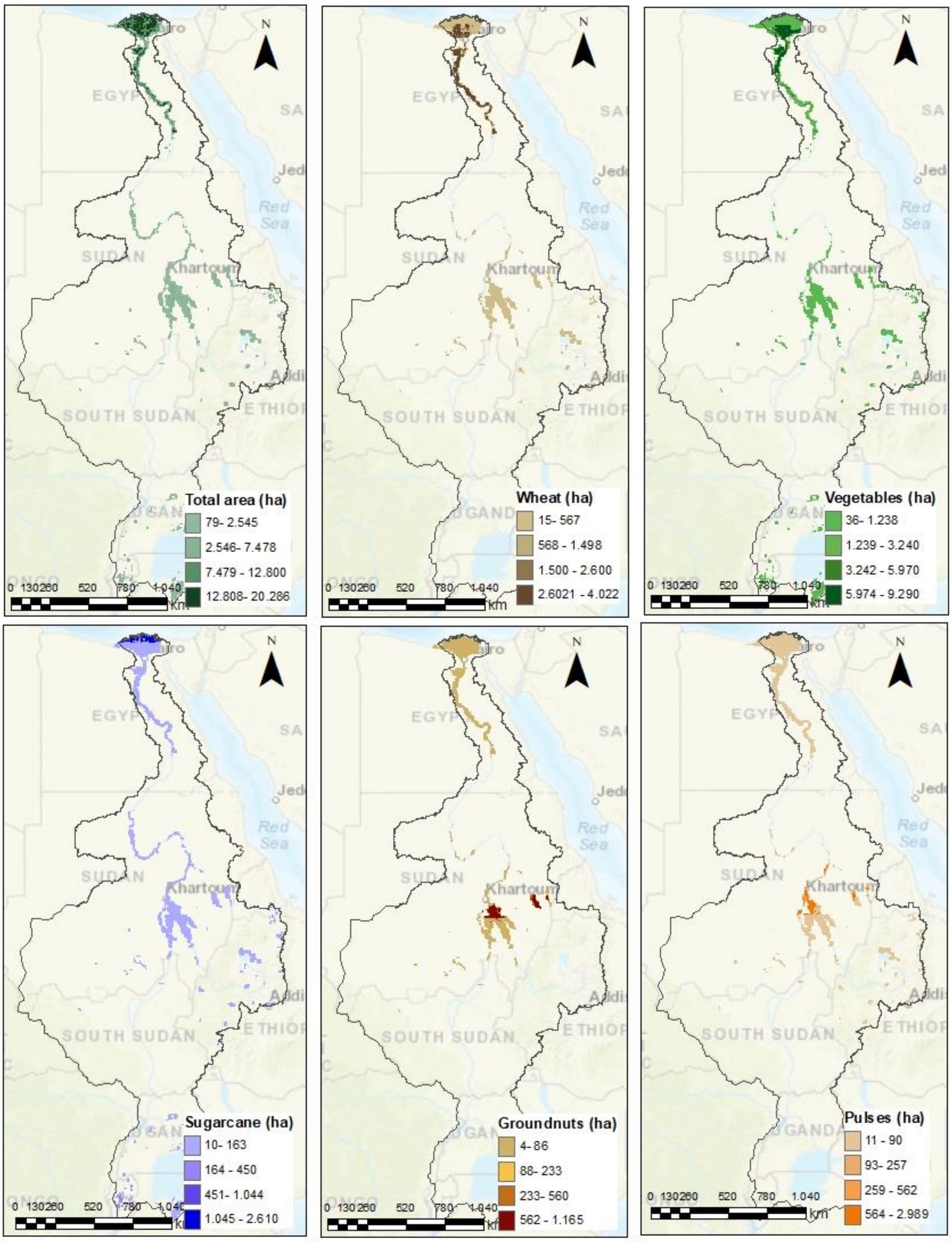

Figure 28 – Total harvested area and single crops' harvested areas (ha) fort eh five main irrigated crops, after baseline reallocation in the NRB.

3.3.3. Baseline Crop Reallocation (Present): Irrigation Expansion

In this section, the main results obtained from the baseline crop reallocation performed over the NRB, considering potential irrigation expansion[52], are reported. Crop reallocation has been performed with the aim of optimizing the current agricultural resources at the basin scale, and this scenario provides an optimal crop distribution that involves future irrigation plans over the NRB. We provide results in terms of blue water consumption, new harvested areas and agricultural land that can be saved. In Figure 29 we also provide the maps of harvested areas for the five main crops irrigated. Table 112 shows the blue water consumption for the two intensification scenario, while Table 113 the new harvested areas per crop. Results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link. In the *potential expansion* scenario, considering a total harvested area of 31.6 million ha (comprehending potential areas of expansion), the reduction in the cropland used is 11% without intensification (I0) – corresponding to 500 thousand ha –, maintaining the same consumption of blue water as the (60.4 km^3), while with intensification (I1) the 21% of land is saved – corresponding to 3.6 million ha – using 40% less of blue water (35.61 km^3). Figure 29 shows the optimal distribution of crops that reduces blue water consumption. With respect to the baseline (Figure 27), the total harvested area results expanded and crops 'areas area reallocated in areas characterized by higher water productivity and, thus, lower blue water requirement. We also provide, in Table 114, a possible crop configuration that increases agricultural production, for this scenario, and that can be obtained only when intensification is applied. Further results and maps are provided as Supplementary Material and at this link. In this case, the crops that result to be cultivated most (and thus with an increase in production) are those with higher water productivity, i.e., maize, sugar beet, potatoes and soybean. Production of potatoes and sugar beet can increase up to 4 times, while maize and soybean increase their production respectively of 10% and 42%, with a total consumption of BW that is 41.84 km^3 – corresponding to 31% less than the baseline.

Table 112 - Blue water consumption (km^3), after baseline cropland reallocation (potential irrigation expansion) in the Nile River Basin, for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when baseline reallocation is considered.

NRB Reallocation - Irrigation Expansion			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	9.01	5.46	7.09
Maize	2.43	0.00	5.73
Rice	5.29	2.84	5.49
Sugar beet	0.45	0.47	0.50
Soybean	0.04	0.03	0.04
Tropical Fruits	0.08	0.07	0.01
Potato	0.75	0.42	0.71
Vegetables	27.99	17.55	24.15
Pulses	1.26	1.02	1.43
Sunflower	0.23	0.01	0.17
Sugarcane	2.54	2.03	2.81
Temperate Fruits	2.02	1.59	1.78
Olives	5.86	3.25	5.38
Sorghum	1.13	0.00	1.85
Banana	0.01	0.02	0.00
Groundnuts	0.98	0.65	0.89
Fodder grasses	0.34	0.20	2.30
Tot	**60.40**	**35.61**	**60.4**

Table 113 – Crop harvested areas obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the two intensification scenarios considered. The total production per crop for both the scenarios (I0 and I1) is not reported because it remains equal to the baseline.

NRB Reallocation - Irrigation Expansion		
Crops	**Harvested Area (ha)**	
	I0	**I1**
Wheat	1,377,615.80	954,168.75
Maize	2,717,335.15	2,293,189.19
Rice	788,458.47	448,668.22
Sugar beet	62,764.38	62,764.38
Soybean	150,462.61	150,462.61
Tropical Fruits	430,611.77	429,139.16
Potato	275,571.20	229,124.02
Vegetables	5,666,387.45	4,941,704.86
Pulses	2,416,275.40	2,384,342.65
Sunflower	53,033.05	40,041.46
Sugarcane	339,537.63	297,030.05
Temperate Fruits	160,429.92	115,924.93
Olives	5,706,426.19	4,978,736.22
Sorghum	5,695,805.95	5,410,764.38
Banana	49,880.41	49,724.95
Groundnuts	1,591,616.31	1,536,614.76
Fodder grasses	718,919.71	704,044.53
Tot	**28,201,131.38**	**25,026,445.10**

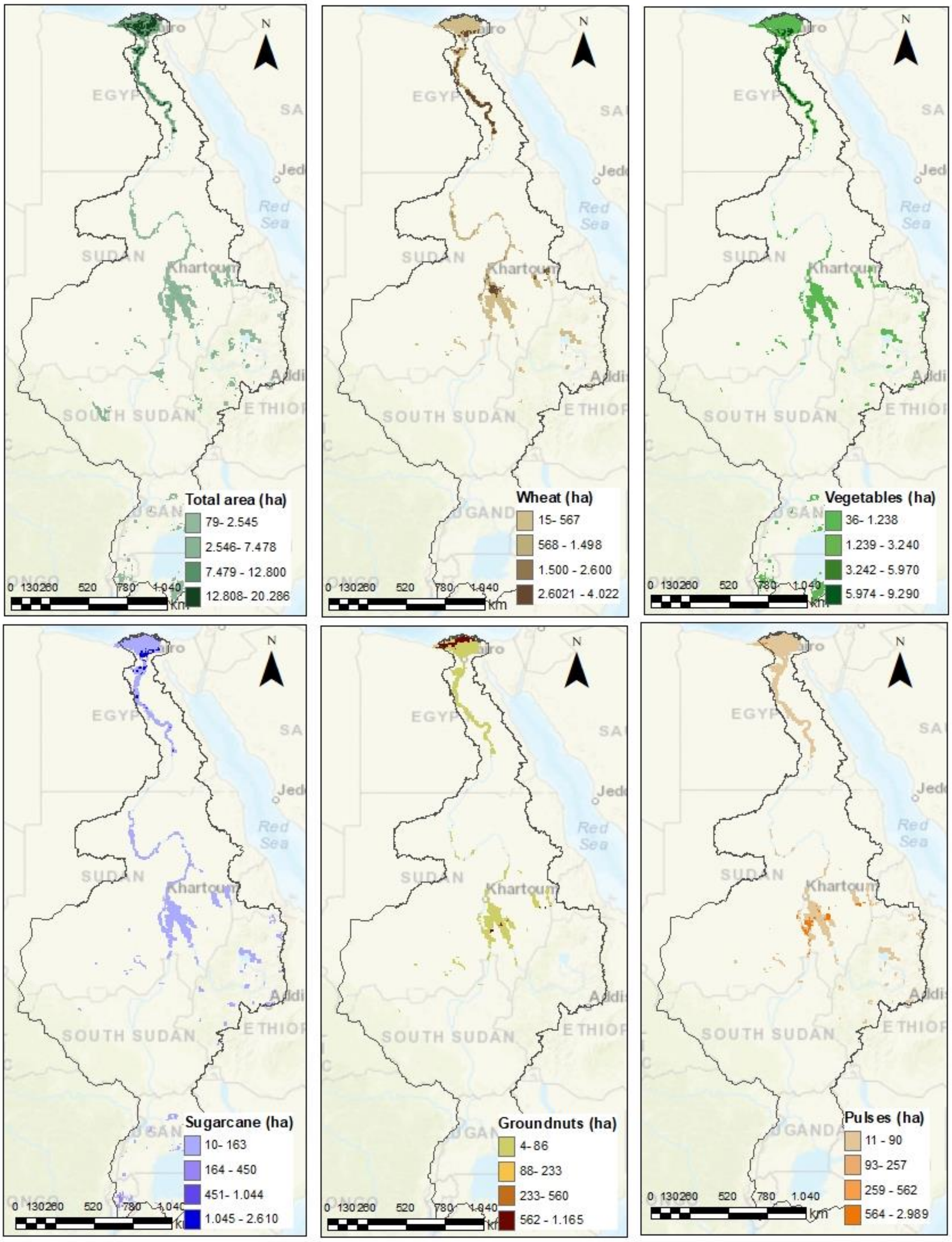

Figure 29 – Total harvested areas and single crops' harvested areas (ha) for the five main irrigated crops in the NRB, after reallocation with potential irrigation expansion at constant production, for the scenario I0.

Table 114 – New crop harvested areas (ha), production (tonnes) and blue water consumption (km^3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the scenario with agricultural intensification, aimed at a potential increase in production.

NRB Reallocation - Irrigation Expansion - Potential Production Increase						
Crops	**I1**			**Baseline**		
	Harvested area (ha)	**Production (tonnes)**	**BW (km^3)**	**Harvested area (ha)**	**Production (tonnes)**	**BW (km^3)**
Wheat	954,168.75	4,705,196.85	5.47	1,385,226.92	4,705,196.85	7.09
Maize	2,371,061.28	6,176,170.42	0.20	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	2.81	788,502.25	3,000,736.01	5.49
Sugar beet	313,821.89	14,836,835.32	2.56	62,764.38	2,967,367.06	0.5
Soybean	181,671.70	420,884.61	0.20	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.07	431,662.89	311,513.08	0.01
Potato	745,290.74	14,866,709.68	3.47	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	17.47	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.09	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.15	53,033.05	68,709.90	0.17
Sugarcane	297,030.05	25,468,421.93	2.22	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.58	160,429.92	2,043,335.63	1.78
Olives	4,978,736.22	53,408,853.51	3.44	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	0.06	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.71	1,624,454.48	1,376,045.99	0.89
Fodder grasses	715,300.25	22,243,041.15	0.30	812,400.42	21,702,766.79	2.3
Tot	**25,914,006.22**	**-**	**41.84**	**28,711,513.25**	**-**	**60.4**

3.3.4 Future Crop Reallocation: Potential Irrigation Expansion

In this section, the main results obtained from the crop reallocation performed for the future scenarios in NRB are reported. The crop reallocation has been performed with the aim of evaluating the possibility of saving agricultural land while not increasing the consumption of blue water, and in the meantime guaranteeing the current production. With this aim crop reallocation on the NRB for the future scenarios RCP 4.5, 2.6 and 8.5 has been performed considering the potential irrigation areas[52]. In this section, we assess the new harvested areas and the portion of cropland saved and calculate the consumption of blue water, after crop reallocation in the years 2050 and 2100. Two scenarios of agricultural intensification have been considered and compared, to evaluate sustainable yield increase in the future. We also provide possible crop configurations that increases agricultural production, that can be obtained only when intensification is applied. Results and maps related to spatial distribution of crops' harvested areas, blue water consumption and production for all the crops of the analysis are provided as Supplementary Materials and can be found at this link, for reallocation that considers constant production, and at this link, for reallocation that enhances agricultural production.

3.3.4.1 RCP 4.5

In this Section results for the future scenario RCP 4.5 with potential irrigation expansion are reported for the years 2050 and 2100. Table 115 and Table 118 the blue water consumption for the two intensification scenario is reported for the years 2050 and 2100, respectively. New harvest areas are reported in Table 116 and Table 120, respectively, for the years 2050 and 2100. The total production per crop, for both the intensification scenarios, remains the same of the baseline, as the algorithm reallocates crops maintaining the same overall production, but reducing water and land use. Under this scenario, it resulted possible to save up to 3.6 Mha of agricultural land both in 2050 and 2100 when intensification is applied (I1, Table 116 and Table 120), corresponding to around 21% of the cropland when irrigation is expanded over potential irrigation areas (31.6 Mha). In the same intensification scenario (I1, Table 115 and Table 118), the consumption of blue water decreases of 41%, being the maximum water saving that is obtained. Without intensification the portion of land saved is around 500 thousand ha, both in 2050 and 2100, corresponding to around 11% of total potential cropland. We also provide, in Table 117 and Table 119, a possible crop configuration that increases agricultural production, for the years 2050 and 2100 respectively, and that can be obtained only when intensification is applied. In 2050, the crops that result an increase in production are potatoes, sugarcane and olives, with a consumption of blue water that is equal to the current (60.4 km^3), while in 2100 only the production of maize is increased, associated to a total blue water consumption of 36.48 km^3.

Table 115 - Blue water consumption (km^3), after cropland reallocation (potential irrigation areas) in the Nile River Basin, in the future scenario 4.5 (average year 2050), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2050 (RCP 4.5)			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	8.02	5.27	7.09
Maize	5.19	1.24	5.73
Rice	5.99	2.99	5.49
Sugar beet	0.49	0.52	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.08	0.07	0.01
Potato	0.67	0.44	0.71
Vegetables	25.84	16.97	24.15
Pulses	1.38	1.16	1.43
Sunflower	0.28	0.19	0.17
Sugarcane	1.91	1.39	2.81
Temperate Fruits	1.90	1.45	1.78
Olives	6.44	3.17	5.38
Sorghum	0.97	0.02	1.85
Banana	0.02	0.02	0
Groundnuts	1.06	0.69	0.89
Fodder grasses	0.13	0.00	2.3
Tot	**60.40**	**35.64**	**60.4**

Table 116 – New harvested obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 4.5 (average year 2050), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2050 (RCP 4.5)			
Crops	**Harvested Area (ha)**		
	I0	**I1**	**BASELINE**
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

Table 117 – New crop harvested areas (ha), production (tonnes) and blue water consumption (km3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 4.5, in the average year 2050. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2050 (RCP 4.5)						
Crops	**I1**			**Baseline**		
	Harvested area (ha)	**Production (tonnes)**	**BW (km3)**	**Harvested area (ha)**	**Production (tonnes)**	**BW (km3)**
Wheat	954,168.75	4,705,196.85	5.81	1,385,226.92	4,705,196.85	7.09
Maize	2,293,189.19	5,595,932.50	2.50	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	2.94	788,502.25	3,000,736.01	5.49
Sugar beet	62,764.38	2,967,367.06	0.52	62,764.38	2,967,367.06	0.5
Soybean	150,462.61	296,048.24	0.04	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.07	431,662.89	311,513.08	0.01
Potato	753,355.49	15,055,102.27	3.96	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	17.25	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.21	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.16	53,033.05	68,709.90	0.17
Sugarcane	837,995.13	88,858,714.03	9.06	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.52	160,429.92	2,043,335.63	1.78
Olives	8,079,069.25	120,528,602.56	14.61	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	0.02	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.72	1,624,454.48	1,376,045.99	0.89
Fodder grasses	704,044.53	21,702,766.79	0.00	812,400.42	21,702,766.79	2.3
Tot	**29,191,974.68**	**-**	**60.40**	**28,711,513.25**	**-**	**60.4**

Table 118 - Blue water consumption (km^3), after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 4.5 (average year 2100), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2100 (RCP 4.5)			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	7.70	5.07	7.09
Maize	2.08	0.00	5.73
Rice	6.15	3.04	5.49
Sugar beet	0.52	0.56	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.09	0.08	0.01
Potato	0.82	0.50	0.71
Vegetables	27.07	16.97	24.15
Pulses	1.43	1.20	1.43
Sunflower	0.26	0.17	0.17
Sugarcane	2.15	1.60	2.81
Temperate Fruits	1.93	1.50	1.78
Olives	7.00	3.99	5.38
Sorghum	1.86	0.37	1.85
Banana	0.02	0.02	0
Groundnuts	1.10	0.74	0.89
Fodder grasses	0.18	0.01	2.3
Tot	**60.39**	**35.86**	**60.4**

Table 119 – New crop harvested areas (ha), production (tonnes) and blue water consumption (km3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 4.5, in the average year 2100. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2100 (RCP 4.5)						
Crops	**I1**			**Baseline**		
	Harvested area (ha)	**Production (tonnes)**	**BW (km3)**	**Harvested area (ha)**	**Production (tonnes)**	**BW (km3)**
Wheat	954,168.75	4,705,196.85	5.05	1,385,226.92	4,705,196.85	7.09
Maize	2,486,097.48	7,033,324.39	0.00	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	3.04	788,502.25	3,000,736.01	5.49
Sugar beet	62,764.38	2,967,367.06	0.56	62,764.38	2,967,367.06	0.5
Soybean	150,462.61	296,048.24	0.04	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.08	431,662.89	311,513.08	0.01
Potato	229,124.02	2,809,055.81	0.51	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	16.95	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.20	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.17	53,033.05	68,709.90	0.17
Sugarcane	297,030.05	25,468,421.93	1.62	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.50	160,429.92	2,043,335.63	1.78
Olives	4,978,736.22	53,408,853.51	3.98	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	1.05	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.72	1,624,454.48	1,376,045.99	0.89
Fodder grasses	704,044.53	21,702,766.79	0.01	812,400.42	21,702,766.79	2.3
Tot	**25,219,353.39**	**-**	**36.48**	**28,711,513.25**	**-**	**60.4**

Table 120 – New harvested areas obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 4.5 (average year 2100), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2100 (RCP 4.5)			
Crops	**Harvested Area (ha)**		
	I0	**I1**	**BASELINE**
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

3.3.4.2 RCP 2.6

In this section, the results for the future scenario RCP 2.6 with potential irrigation expansion are reported for the years 2050 and 2100. Table 121 and Table 123 report the blue water consumption for the two intensification scenario for the years 2050 and 2100, respectively. In Table 122 and Table 125 we report new harvested areas, respectively for the years 2050 and 2100. The total production per crop, for both the intensification scenarios, remains the same of the baseline, as the algorithm reallocates crops maintaining the same overall production, but reducing water and land use. Similarly to RCP 4.5, under this scenario, it resulted possible to save around 11% of cropland – corresponding to 500 thousand ha – when intensification is not applied (I0) both in 2050 and 2100 (Table 122 and Table 125). When intensification is considered (I1), agricultural land can be saved up to 41%– corresponding to 3.6 Mha – both in 2050 and 2100 (Table 122 and Table 125). The highest blue water consumption for RCP 2.6 is obtained in 2100, in I1 (Table 123), corresponding to a reduction of 41% with respect to the baseline consumption (35.36 km^3), while in 2050 the total blue water consumption resulted of 36.38 km^3. We provide, in Table 124 and Table 126, a possible crop configuration that increases agricultural production, for the years 2050 and 2100 respectively, and that is obtained only when intensification is applied. In 2050, the crops that result an increase in production are maize, sugar beet, soybean, potatoes, sugarcane, olives and fodder grasses, with a consumption of blue water that is equal to the current (60.4 km^3), while in 2100 the production of maize, sugarcane, fodder grasses is increased, associated to a total blue water consumption of 42,05 km^3.

Table 121 - Blue water consumption (km^3), after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 2.6 (average year 2050), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2050 (RCP 2.6)			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	7.93	5.15	7.09
Maize	1.74	0.00	5.73
Rice	6.15	3.17	5.49
Sugar beet	0.54	0.56	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.08	0.06	0.01
Potato	0.82	0.45	0.71
Vegetables	27.08	16.95	24.15
Pulses	1.39	1.41	1.43
Sunflower	0.26	0.16	0.17
Sugarcane	2.57	2.07	2.81
Temperate Fruits	1.90	1.42	1.78
Olives	6.55	3.51	5.38
Sorghum	1.88	0.40	1.85
Banana	0.02	0.02	0
Groundnuts	1.07	0.77	0.89
Fodder grasses	0.35	0.22	2.3
Tot	**60.40**	**36.38**	**60.4**

Table 122 – New harvested areas obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 2.6 (average year 2050), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2050 (RCP 2.6)			
Crops	Harvested Area (ha)		
	I0	I1	BASELINE
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

Table 123 - Blue water consumption (km³), after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 2.6 (average year 2100), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2100 (RCP 2.6)			
Crops	**BW (km³)**		
	I0	**I1**	**BASELINE**
Wheat	7.93	5.09	7.09
Maize	1.77	0.00	5.73
Rice	5.91	2.87	5.49
Sugar beet	0.52	0.53	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.09	0.06	0.01
Potato	0.82	0.45	0.71
Vegetables	26.64	16.25	24.15
Pulses	1.38	1.36	1.43
Sunflower	0.25	0.16	0.17
Sugarcane	2.71	2.15	2.81
Temperate Fruits	1.97	1.50	1.78
Olives	6.43	3.68	5.38
Sorghum	1.73	0.23	1.85
Banana	0.02	0.02	0
Groundnuts	1.07	0.76	0.89
Fodder grasses	0.34	0.21	2.3
Tot	**59.61**	**35.36**	**60.4**

Table 124– New crop harvested areas (ha), production (tonnes) and blue water consumption (km^3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 2.6, in the average year 2050. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2050 (RCP 2.6)						
Crops	**I1**				**Baseline**	
	Harvested area (ha)	**Production (tonnes)**	**BW (km3)**	**Harvested area (ha)**	**Production (tonnes)**	**BW (km3)**
Wheat	954,168.75	4,705,196.85	5.23	1,385,226.92	4,705,196.85	7.09
Maize	2,493,708.36	7,090,034.33	0.00	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	3.04	788,502.25	3,000,736.01	5.49
Sugar beet	92,328.18	4,365,080.96	0.81	62,764.38	2,967,367.06	0.5
Soybean	384,857.53	1,233,627.94	1.40	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.06	431,662.89	311,513.08	0.01
Potato	315,954.17	4,837,408.11	1.06	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	16.87	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.34	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.16	53,033.05	68,709.90	0.17
Sugarcane	737,129.56	77,039,285.50	8.68	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.39	160,429.92	2,043,335.63	1.78
Olives	5,129,909.27	56,681,630.00	3.99	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	1.16	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.79	1,624,454.48	1,376,045.99	0.89
Fodder grasses	772,688.89	24,997,696.07	0.88	812,400.42	21,702,766.79	2.3
Tot	**26,237,670.06**	**-**	**46.86**	**28,711,513.25**	**-**	**60.4**

Table 125 – New harvested areas obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 2.6 (average year 2100), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2100 (RCP 2.6)			
Crops	**Harvested Area (ha)**		
	I0	**I1**	**BASELINE**
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

Table 126– New crop harvested areas (ha), production (tonnes) and blue water consumption (km^3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 2.6, in the average year 2100. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2100 (RCP 2.6)						
Crops	I1			Baseline		
	Harvested area (ha)	Production (tonnes)	BW (km3)	Harvested area (ha)	Production (tonnes)	BW (km3)
Wheat	954,168.75	4,705,196.85	5.08	1,385,226.92	4,705,196.85	7.09
Maize	2,596,819.07	7,858,329.46	0.71	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	2.83	788,502.25	3,000,736.01	5.49
Sugar beet	313,821.89	14,836,835.32	2.68	62,764.38	2,967,367.06	0.5
Soybean	150,462.61	296,048.24	0.04	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.06	431,662.89	311,513.08	0.01
Potato	229,124.02	2,809,055.81	0.45	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	16.25	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.36	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.16	53,033.05	68,709.90	0.17
Sugarcane	522,141.52	51,846,985.74	5.43	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.47	160,429.92	2,043,335.63	1.78
Olives	4,978,736.22	53,408,853.51	3.66	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	0.88	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.76	1,624,454.48	1,376,045.99	0.89
Fodder grasses	706,490.67	21,820,181.60	0.23	812,400.42	21,702,766.79	2.3
Tot	**25,808,690.10**	**-**	**42.05**	**28,711,513.25**	**-**	**60.4**

3.3.4.4 RCP 8.5

In this section, the results for the future scenario RCP 8.5 with potential irrigation expansion are reported for the years 2050 and 2100. Table 127 and Table 130 report the blue water consumption for the two intensification scenarios for the years 2050 and 2100, respectively. Table 128 and Table 131 report new harvested areas, respectively for the years 2050 and 2100. The total production per crop, for both the intensification scenarios, remains the same of the baseline, as the algorithm reallocates crops maintaining the same overall production, but reducing water and land use. Similarly to the previous scenarios under this scenario, it is possible to save around 11% of cropland – corresponding to 500 thousand ha –, when intensification is not applied (I0), both in 2050 and 2100, and 41%– corresponding to 3.6 Mha –, when intensification is applied, both in 2050 and 2100 (Table 128 and Table 131). RCP 8.5 is the scenarios with highest potential savings in blue water consumption, reaching 31.51 km^3, in 2050, and 32.49 km^3, in 2100, when intensification is applied (Table 127 and Table 130). For this scenario, we provide, in Table 129 and Table 132, a possible crop configuration that increases agricultural production, for the years 2050 and 2100 respectively, and that is obtained only when intensification is applied. In 2050, the crops that result an increase in production are maize, sugarcane and fodder grasses, with a consumption of blue water that is equal to 34.64 km^3, while in 2100 also the production of sugar beet is increased, associated to a total blue water consumption of 37.87 km^3.

Table 127 - Blue water consumption (km^3), after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 8.5 (average year 2050), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2050 (RCP 8.5)			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	8.06	5.30	7.09
Maize	1.03	0.00	5.73
Rice	6.03	2.62	5.49
Sugar beet	0.00	0.00	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.10	0.07	0.01
Potato	0.48	0.00	0.71
Vegetables	27.68	16.46	24.15
Pulses	1.34	1.26	1.43
Sunflower	0.25	0.00	0.17
Sugarcane	0.00	0.00	2.81
Temperate Fruits	2.07	1.54	1.78
Olives	5.88	3.40	5.38
Sorghum	1.77	0.00	1.85
Banana	0.02	0.02	0
Groundnuts	1.12	0.80	0.89
Fodder grasses	0.00	0.00	2.3
Tot	**55.87**	**31.51**	**60.4**

Table 128 – New harvested areas obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future RCP 8.5 (average year 2050), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2050 (RCP 8.5)			
Crops	**Harvested Area (ha)**		
	I0	**I1**	**BASELINE**
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

Table 129– New crop harvested areas (ha), production (tonnes) and blue water consumption (km^3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 8.5, in the average year 2050. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2050 (RCP 8.5)						
Crops	**I1**				**Baseline**	
	Harvested area (ha)	**Production (tonnes)**	**BW (km3)**	**Harvested area (ha)**	**Production (tonnes)**	**BW (km3)**
Wheat	954,168.75	4,705,196.85	5.30	1,385,226.92	4,705,196.85	7.09
Maize	2,688,411.71	8,540,801.51	0.00	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	3.06	788,502.25	3,000,736.01	5.49
Sugar beet	62,764.38	2,967,367.06	0.51	62,764.38	2,967,367.06	0.5
Soybean	150,462.61	296,048.24	0.04	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.06	431,662.89	311,513.08	0.01
Potato	229,124.02	2,809,055.81	0.48	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	16.62	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.28	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.17	53,033.05	68,709.90	0.17
Sugarcane	417,157.99	39,545,014.79	0.00	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.51	160,429.92	2,043,335.63	1.78
Olives	4,978,736.22	53,408,853.51	3.80	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	1.00	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.78	1,624,454.48	1,376,045.99	0.89
Fodder grasses	747,910.65	23,808,340.32	0.00	812,400.42	21,702,766.79	2.3
Tot	**25,585,661.67**	**-**	**34.64**	**28,711,513.25**	**-**	**60.4**

Table 130 - Blue water consumption (km^3), after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 8.5 (average year 2100), for the two intensification scenarios considered. As production remains the same, results can be compared to the baseline blue water consumption, to understand the reduction of irrigation water use when reallocation is considered.

NRB Reallocation - Year 2100 (RCP 8.5)			
Crops	**BW (km^3)**		
	I0	**I1**	**BASELINE**
Wheat	8.22	5.11	7.09
Maize	0.90	0.00	5.73
Rice	6.36	3.11	5.49
Sugar beet	0.00	0.00	0.5
Soybean	0.04	0.04	0.04
Tropical Fruits	0.09	0.07	0.01
Potato	0.48	0.00	0.71
Vegetables	29.82	16.83	24.15
Pulses	1.49	1.46	1.43
Sunflower	0.27	0.00	0.17
Sugarcane	0.00	0.00	2.81
Temperate Fruits	2.21	1.52	1.78
Olives	6.03	3.47	5.38
Sorghum	1.89	0.00	1.85
Banana	0.02	0.02	0
Groundnuts	1.17	0.87	0.89
Fodder grasses	0.00	0.00	2.3
Tot	**59.00**	**32.49**	**60.4**

Table 131 – New harvested areas obtained after cropland reallocation (potential irrigation expansion) in the Nile River Basin, in the future scenario 8.5 (average year 2100), for the two intensification scenarios considered. The total production per crop, for both the intensification scenarios, is not reported as it remains the same of the baseline.

NRB Reallocation - Year 2100 (RCP 8.5)			
Crops	**Harvested Area (ha)**		
	I0	**I1**	**BASELINE**
Wheat	1,377,615.80	954,168.75	1,385,226.92
Maize	2,717,335.15	2,293,189.19	2,736,502.53
Rice	788,458.47	448,668.22	788,502.25
Sugar beet	62,764.38	62,764.38	62,764.38
Soybean	150,462.61	150,462.61	150,483.61
Tropical Fruits	430,611.77	429,139.16	431,662.89
Potato	275,571.20	229,124.02	275,571.20
Vegetables	5,666,387.45	4,941,704.86	5,749,606.60
Pulses	2,416,275.40	2,384,342.65	2,433,702.10
Sunflower	53,033.05	40,041.46	53,033.05
Sugarcane	339,537.63	297,030.05	339,537.63
Temperate Fruits	160,429.92	115,924.93	160,429.92
Olives	5,706,426.19	4,978,736.22	5,749,606.60
Sorghum	5,695,805.95	5,410,764.38	5,908,148.26
Banana	49,880.41	49,724.95	49,880.41
Groundnuts	1,591,616.31	1,536,614.76	1,624,454.48
Fodder grasses	718,919.71	704,044.53	812,400.42
Tot	**28,201,131.38**	**25,026,445.10**	**28,711,513.25**

Table 132– New crop harvested areas (ha), production (tonnes) and blue water consumption (km^3) obtained after cropland reallocation (with potential irrigation expansion) in the Nile River Basin, for the RCP 8.5, in the average year 2100. Only the scenario with agricultural intensification enhances a potential increase in production.

NRB Reallocation - Year 2100 (RCP 8.5)						
Crops	I1			Baseline		
	Harvested area (ha)	Production (tonnes)	BW (km^3)	Harvested area (ha)	Production (tonnes)	BW (km^3)
Wheat	954,168.75	4,705,196.85	5.35	1,385,226.92	4,705,196.85	7.09
Maize	2,750,429.89	9,002,909.37	0.80	2,736,502.53	5,595,932.50	5.73
Rice	448,668.22	3,000,736.01	3.10	788,502.25	3,000,736.01	5.49
Sugar beet	102,878.84	4,863,894.16	0.87	62,764.38	2,967,367.06	0.5
Soybean	150,462.61	296,048.24	0.04	150,483.61	296,048.24	0.04
Tropical Fruits	429,139.16	311,513.08	0.07	431,662.89	311,513.08	0.01
Potato	229,124.02	2,809,055.81	0.53	275,571.20	2,809,055.81	0.71
Vegetables	4,941,704.86	32,556,957.19	18.00	5,749,606.60	32,556,957.19	24.15
Pulses	2,384,342.65	1,795,846.72	1.45	2,433,702.10	1,795,846.72	1.43
Sunflower	40,041.46	68,709.90	0.18	53,033.05	68,709.90	0.17
Sugarcane	422,431.29	40,162,939.87	0.00	339,537.63	25,468,421.93	2.81
Temperate Fruits	115,924.93	2,043,335.63	1.61	160,429.92	2,043,335.63	1.78
Olives	4,978,736.22	53,408,853.51	3.92	5,749,606.60	53,408,853.51	5.38
Sorghum	5,410,764.38	6,553,792.75	1.12	5,908,148.26	6,553,792.75	1.85
Banana	49,724.95	581,102.70	0.02	49,880.41	581,102.70	0
Groundnuts	1,536,614.76	1,376,045.99	0.81	1,624,454.48	1,376,045.99	0.89
Fodder grasses	747,910.65	23,808,340.32	0.00	812,400.42	21,702,766.79	2.3
Tot	**25,693,067.62**	**-**	**37.87**	**28,711,513.25**	**-**	**60.4**

Different scenarios of crop reallocation performed over the entire NRB gave different interesting results in terms of agricultural land savings and consumption of irrigation water at the meso-scale. The baseline reallocation (Section 3.3.2) over the current irrigated cropland in NRB succeeds in reducing the amount of blue water consumed of 6% (I0) and of 50% (I1) in average (Table 110), with respect to the current scenario (Table 109). However, the results show that, only when reallocation is expanded over the whole cropland and over potential irrigation areas, it is possible to gain the highest benefit in terms of savings in agricultural land, that can potentially lead to an increase in agricultural production. The best results are obtained when agricultural intensification is applied (I1). In the present, it has been possible to reduce land use of 11%, in the baseline reallocation scenario and 21%, in the *potential expansion* scenario (Table 113). Concerning the consumption of blue water in the present scenario, the *potential irrigation expansion* scenario resulted in around up to 31% reduction of blue water when intensification is applied. Results related to future scenarios, show that also in the future analysed RCPs it is possible to obtain high savings of blue water and agricultural land. Especially, in RCP 8.5 it is possible to reduce BW of 48%, in the *potential expansion* scenario in 2050 and 46% in 2100 (Table 127 and Table 130). Savings in agricultural land are possible up to 21% in all three future RCPs.

4 Conclusion

Reaching self-sufficiency while preserving local water resources and ensuring a balanced nutritious intake and economic benefits represents a great challenge for the present and future socio-climatic condition of Egypt, Sudan and Ethiopia, and for the entire Nile River Basin. The analysis conducted within T2.3 of WP2 of the AWESOME project aims at combining efficient crop reallocation that maximizes water productivity, while considering a shift toward a balanced diet and yield intensification for both present and future projections. The main limitation of the analysis is the country-scale availability of data concerning the diet, that precluded to perform a reallocation with the assessment of the satisfaction of the demand and the diet shift on the entire Nile River Basin. Another limitation is the availability of spatially distributed data regarding harvested areas and yields for the main cultivated crops in the study area. To include some major cultivated crops, we combined data from two different datasets[38,39].

Our analysis provides a broad framework of the current agricultural resources, the satisfaction of the diet demand and the associated consumption of irrigation water, for the main countries of the Nile River Basin. Moreover, our analysis proposes different possible scenarios of strategic cropland reallocation that optimizes the natural resources through a maximization of the water productivity in the present and in the future scenarios, considering the change in the demand, which is due to population increase, diet shift, and increase in production efficiency linked to agricultural intensification. Overall, results show that the *water productivity* strategy, aimed at maximizing the production and the preservation of the freshwater resources, generates a positive impact in the main countries of the Nile River Basin, preserving the consumption of blue water and guaranteeing at least the current production. The main constraints on increasing food production and, thus, reaching food self-sufficiency, are the limited cropland and the current low irrigation, especially in Sudan and Ethiopia. In Egypt - being the 98% of the current cropland irrigated – it has been possible to increase production towards the satisfaction the diet – current and balanced[43] – not exceeding the current blue water consumption, or, in the worst scenarios, consuming at maximum the 5% more. On the contrary, in Sudan and Ethiopia an increase in production has resulted impossible without the expansion of the current irrigated cropland. When irrigation is expanded over potential irrigation areas[52] in Sudan and Ethiopia, production is increased towards the satisfaction of the diet; the consumption of blue water has increased proportionally to the new harvested area, without exceeding the exploitable water resources of the country, accounting also for the environmental flows[53]. Results show that reallocation perfumed at the basin scale is more useful in suggesting hypothetical sustainable reallocation of resources without exceeding the total available water in the NRB. Indeed, reallocation performed over the entire NRB gave satisfactory results showing that it is possible to obtain optimized crop distribution with higher productivity and lower blue water consumption at the basin scale with respect to the country scale. Our modelling outcomes prove that an agricultural intensification is fundamental to achieve food self-sufficiency in study area in the future. Moreover, the promotion of a balanced diet is necessary to reduce malnutrition problems (i.e., overnutrition due to overconsumption of cereals and sugars items in Egypt, undernourishment due to reduced energy intake in Sudan and Ethiopia, and anemia due to lack of protein and iron intake, common to all the countries). Its application generates benefits in producing adequate quantities of kcal and proteins, but might also be challenging, due to the arid climatic condition and the low harvested areas for some existent crops in the diet (e.g., soybean, groundnuts, rice in Sudan and Ethiopia and soybean and sunflower in Egypt). The coupling of multiple water-saving options resulted the most convenient solution to enhance sustainably productivity in the NRB. Thus, agricultural management measures like the expansion of irrigated agriculture implementing water conservation techniques for the rainfed systems (e.g. rainwater harvesting) and improved scheme management in the irrigated areas might promote a sustainable increase productivity in the Nile Basin[55]. Our results provide data regarding water consumption, crop production, crop water value and satisfaction of crop demand, under different scenarios, that will be used, at a later stage, by WP3 and WP4 and the respective upcoming deliverables, to explore the WEF nexus under a macro-economic point of view and evaluate different innovative technological solutions both at the micro- and meso-scales.

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