Model Documentation

Modelling software: Stella 1.5

Start Time: 1961. Many data sets from international organizations are only available from 1961, which limited the time horizon for this project to that year.

Stop Time: 2006. The year of the peace agreement in Darfur. After that year, strong continuous international intervention happened, which the model does not capture well, although running it for stop times after 2006 shows interesting amplification of the conflicts (and consequent international reactions) until the space for herds is completely depleted and the model collapses.

Timestep: 1/64

Method: Euler

Modules:

AOI – No International Intervention: contains a non-realistic scenario that ignores any international intervention on Sudan's wars and famines.

BAU – Business As Usual: contains a structure that roughly models the international reaction as happened in Sudan, but with technical limits, as such interventions have not yet finished until the present moment and cannot be fully understood yet.

Policy Model: contains simple structures for the proposed policies, set to half effectiveness by standard, and a lower delay before international intervention occurs (1.5 year instead of 3 years).

Converters

Variable name	Value [unit]	Explanation/Source
Absence of gov services	1-Relative_presence_of_gov_services	Variable created only for analysis purposes.
Adjustment for Sorghum	0.9707/1.33	Sorghum productivity in tonnes per hectare is different than maize (from Gerber, 2016). We did a correction based on FAO (2017) and also applied this multiplier to the efficiency of fertilizer, so that fertilizer had approximately the same cost-benefit relationship as in maize.
annual growth in herd size	Table function [1/year]	Real data from Sudan. UNEP (2007, p. 184).
Annual change rate in precipitation	-0.004	Although UNEP (2007, p. 60) pictures a much more important decrease (-0.008), there is a huge discrepancy with other sources such as the World Bank (2017), that points to -0.001. In the context of low data quality, we adopted a more conservative value.
Annual deforestation rate	0.0084 [1/year]	UNEP (2007, p. 204)
Avg time to death at malnutrition	5 [years]	A rough simplification based on WHO (2017). People who suffer from severe malnutrition most commonly suffer it during the first five years of life.
Avg time to death at climate war	16 [years]	Based on Welzer (2012, p. 69), who describes a life expectancy of 42 years (average death time to death of 21 years assuming even age distribution) in constant conflict zones in Sudan. It turns out that the age distribution tends to youth and this conflict tends to be more deadly than other conflicts, so we believe that values between 10 and 21 are acceptable, 16 being a middle point.
Avg time to generate group identitarianism	4 [years]	The time that people take to adopt the preservation and development of ethnic and cultural identity as their central ideological principle in life, when in contact to pastoral conflict or organized conflict.
CALORIC DENSITY PLANT PRODUCTS	3290000 [KCAL/TON]	FAO (2017)

eff of family planning on fractional growth rate	SWITCH_FAMILY_PLANNING* outreach_of_family_planning	We assumed a simple linear relationship limited to half effectiveness of the family planning policy on avoiding population growth.
eff of food deficit on severe malnutrition	MAX(0; food_deficit-share_of_population_depending_on_food_aid)*(0,05/0,85)	Based on UNICEF (2017) data, we extracted the rate of people who reach severe malnutrition among those in contact with some form of malnutrition in Sudan.
Eff of herd density on annual desertification	Table function [1/year]	UNEP (2007) points out that desertification, although observed in Sudan since the 1950s, reached a new level somewhere in the late twentieth century, when herds started growing a lot. Based on that, the logic we adopted is that this relationship between herd density and desertification was linear until reference levels and exponential after that. We used 1983 levels of herd density as a reference, as explained in 'Ref herd density'.
eff of international intervention on insurgency	Table function	This function describes how strongly the international intervention is able to demobilize insurgency. Based on ACLED (2017).
eff of land zoning on pastoral conflict	Table function	We simplified this relationship as linear.
Eff of precipitation on produced biomass	Table function	Muna Elhag, M. (2012)
eff of severe malnutrition on death rate	prevalence_of_severe_malnutrition*0,40	Based on WHO (2017).
eff of technical assistance on herd size	Table function	A linear simplification of the impact technical assistance would have on herd growth. UNEP (2007, p. 86) explains that farmers tend to increase herd growth when productivity goes down, and suggests this policy to change this reality.
fraction of GDP coming from agriculture	0.4	UNEP (2007, p. 161)
Government revenue	("Taxation /GDP"*far	As agriculture only represented a fraction of the total income, we divided the revenue from taxes on

	m_income)/fraction_of_GDP_coming_from_agriculture [USD/year]	agriculture by its fraction on total revenue to get the total revenue.
Harvested yield	produced_biomass*(1-SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS)*Adjustment_for_Sorghum [TON/HA/YEAR]	Modified the original equation (Gerber, 2016) to incorporate a correction due to the fact that Sorghum has a different productivity than maize.
Herd density	Herd_size/Potential_Arable_Land [animals/ha]	A typical density function.
Initial arable land	1843005 [ha]	Value for 1961 from FAO (2017)
INITIAL FARM INCOME	170*1440000 [USD/YEAR]	Price for the first year of simulation multiplied by quantity on that same year (at standard parameters). This parameter must be updated if SHARE OF PRODUCTION SOLD or REFERENCE FOOD PRICE suffer a major change.
Initial herd size	28600000 [animals]	Real data from Sudan. UNEP (2007, p. 184).
Initial potential arable land	0.7*total area [ha]	A rough estimate based on several parts of UNEP (2007), especially pages 46 and 62, among others.
International food aid reaction time	1 [year]	Based on recent famines crises in the region, especially the recent South Sudan famine, when the international organizations took about a year to solve the problem, although alleged less than a year (BBC, 2017).

Non-productive annual deforestation rate	MAX(0; (Annual_deforestation_rate-(conversion_rate/Potential_Arable_Land)))	We assumed that all deforestation/degradation that does not generate arable land ends up as desert or degraded land.
outreach of technical assistance	0.5	The extent that the technical assistance policy reaches herd owners in Sudan.
outreach of land zoning policy	0.5	The extent to which the land zoning policy is applied in Sudan.
outreach of family planning	0.5	To what extent the family planning policy reaches population.
Per ha mineral fertilizer application	total_fertilizer_expenditure/(FERTILIZER_PRICE*Adjustment_for_Sorghum)/Arable_Land [ton/ha/year]	Modified the original equation (Gerber, 2016) to incorporate a correction due to the fact that Sorghum has a different productivity (and an assumed proportional cost structure) than maize.
Perceived death rate	SMTH3(Death_rate_at_war; time_for_international_community_to_perceive_war)	The international community does not perceive a conflict in Africa immediately. It depends on how lethal the conflicts are, and it takes some time for the information to flow and for political processes to happen.
POPULATION SCENARIO FRACTIONAL GROWTH RATE	0.0312569 [1/year]	World Bank (2017b)
prevalence of severe malnutrition	SMTH3(eff_of_food_deficit_on_severe_malnutrition; 1)	We assumed food deficit has its effect on severe malnutrition delayed by a year.

Prevalence of pastoral conflict	IF(Herd_density>Ref_herd_density) THEN MIN("Share_of_nomadic-pastoral_population"*2; ((Herd_density-Ref_herd_density)/Ref_herd_density)*"Share_of_nomadic-pastoral_population")*eff_of_land_zoning_on_pastoral_conflict ELSE 0	Translating UNEP's (2007) rationale to this formulation, pastoral conflict only happens if herd density is beyond normality, and cannot go beyond a certain level due to the fact that only a part of the Sudanese population is composed by traditional pastoralist people. We limited it to double of the pastoralist population, because conflicts will seldom be happening between 3 or more parties, but are often limited to two.
Ref gov revenue	("Taxation/GDP"*INITIAL_FARM_INCOME)/fraction_of_GDP_coming_from_agriculture [USD/year]	As agriculture only represented a fraction of the total income, we divided the revenue from taxes on agriculture by its fraction on total revenue to get the total revenue. We used the initial (1961) income to get the reference value.
Ref herd density	0.56 [animals/ha]	This is the herd density from 1983 levels, to be used as a comparison parameter for desertification and prevalence of pastoral conflict. UNEP (2007) points that these two phenomena gained a new importance in the late twentieth century, but does not state a clear year. Decent data on desertification is only available from 1990 on. We chose 1983 because UNEP (2007) shows a change in the pattern of herd growth from that year

		on, and herd growth is strongly associated to both phenomena.
REFERENCE FOOD PRICE	212.2 [USD/TON]	World Bank (2017c)
Reference precipitation	450 [mm/year]	UNEP (2007, p. 38-41) and World Bank (2017a)
Relative presence of gov services	DELAY3(((1-Prevalence_of_organized_climate_conflict)*(Government_revenue/population))/(Ref_gov_revenue/INITIAL_POPULATION); 4)	We assumed it takes 4 years for the government services to worsen or leave certain territories uncovered by basic services when facing declining revenues relative to population size.
SHARE OF PRODUCTION SOLD	0.7863	Based on UNEP (2017, p. 163), and assuming that traditional farmers are 5 times less productive than irrigated farmers. This means that half of the production comes from very productive commercial agriculture that sells 100% of their output and the other 28.63% come from farmers that sell 45% of their production and are 5 times less productive in average.
Share of nomadic-pastoral population	0.10	UNDP (2006, p. 3)
SHARE OF PLANTS IN TOTAL KCAL REQUIREMENTS	0.7486	FAO (2017)
share of population depending on food aid	SMTH3(food_deficit; International_food_aid_reaction_time)	UNEP (2007, p. 160) briefly describes the mechanism of food aid in Sudan. The simulated values coincide with reality.
Susceptibility to war	0.1	We assumed that 10% of the identitarian population is prone to either join insurgence or be a direct victim of the conflict.
SWITCH FAMILY PLANNING	0	A switch for the family planning policy.

SWITCH INTERNATIONAL INTERVENTION	1	This is a switch for the international intervention policy. It is turned on even in the explanatory model to describe the interventions that happened in reality.
SWITCH LAND ZONING AND DEMARCATION	0	A switch for the land zoning policy.
SWITCH TECHNICAL ASSISTANCE	0	This is a policy switch for technical assistance.
Taxation/GDP	0.0064	World Bank (2017b)
time for international community to perceive war	3 [years]	Based on real ACLED (2017) data. The conflicts started to rise in 2000 but they were only recognized by the international community as conflicts in 2003.
Time to organize insurgency	1.5 [year]	Through ACLED (2017) and UNEP (2007) we know this is >1 and <2, but have no clear exact value.
Tolerated death rate	5581 [people/year]	The average death rate until international community responded, according to ACLED (2017) data.
Total area	188600000 [ha]	The area of Sudan.

Stocks (initial values)

Variable name	Initial value [unit]	Explanation
Annual precipitation	Reference_precipitation	Initial precipitation from UNEP (2007).
Arable land	Initial_arable_land	See 'Initial_arable_land'
climate war-related deaths	0 [person]	Initialized as zero to see the full effect.
Desertified or degraded land	0 [ha]	No data available, and no major impact on the model as this value is relativized. We assumed 1961 to be pre-industrial level. This leads the 2006 value to the actual level.
famine-related deaths	0 [person]	Initialized as zero to see the full effect.
Herd size	Initial_herd_size	Initial herd size from UNEP (2007).
Potential Arable Land	Initial_potential_arable_land	See 'Initial_potential_arable_land'
Prevalence of organized climate conflict	0	Although resource-related conflict has always existed at some level, we understand, based on UNEP (2007) and Welzer (2012) the modern climate conflicts are a new form of conflict.
Prevalence of group identitarianism	0	Although group identitarianism has always existed at some level, we understand, based on UNEP (2007) and Welzer (2012) the modern pastoral conflicts and climate conditions generated the emergence of a new form of identitarianism.

Flow equations

Variable/explanation	Equation [unit]
Change in precipitation	Annual_change_rate_in_precipitation*Annual_precipitation [mm/year/year]
Precipitation is changing every year.	
Change in herd size	Herd_size*annual_growth_in_herd_size*eff_of_technical_assistance_on_herd_size [animals/year]
Herd size is changing every year and might be affected by technical assistance	
Desertification of potential arable land	((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification)))) [ha/year]
Desertification is affected, at the same time, by change in precipitation, deforestation and herd density. The multiplication here ensures that the weight of the three factors is decently adjusted when one of them becomes more prevalent, although further research is needed to determine this relationship.	
Desertification of arable land	(Arable_Land*(-Annual_change_rate_in_precipitation)) [ha/year]
Desertification of arable land is a less important phenomenon when compared to desertification of potential arable land, but it is also happening due to variations in precipitation. Further research is needed to determine this relationship.	
Change in group identitarianism	IF Prevalence_of_group_identitarianism >=1 THEN 0 ELSE ((Prevalence_of_Pastoral_conflict+Prevalence_of_organized_conflict)-Prevalence_of_group_identitarianism)/Avg_time_to_generate_group_identitarianism [1/year]
An attempt to determine the relationship described by UNEP (2007) and Welzer (2012). The logic here is that people are forced to choose a side when facing pastoral conflict OR organized conflict. When both are present, this force is doubled. If they are already identitarian, they are not susceptible anymore. It takes some time for this socio-cultural process to happen.	
Death rate by famines	(population*eff_of_severe_malnutrition_on_death_rate)/Avg_time_to_death_at_malnutrition [people/year]
A typical death rate formulation.	
Death rate at climate war	(Prevalence_of_organized_conflict*population)/Avg_time_to_death_at_war_zones [people/year]
A typical death rate formulation.	
Change in organized conflict	IF (SWITCH_INTERNATIONAL_INTERVENTION*eff_of_international_intervention_on_insurgency)<0 THEN (SWITCH_INTERNATIONAL_INTERVENTION*

	eff_of_international_intervention_on_insurgency)/Time_to_organize_insurgency ELSE ((((1-Relative_presence_of_gov_services)*Prevalence_of_group_identitarianism)*Susceptibility_to_war)/Time_to_organize_insurgency) [1/year]
Organized conflict is dependent on both the quality/presence of governmental services AND group identitarianism (weighted by susceptibility). The multiplication here ensures that the weight of the three factors is decently adjusted when one of them becomes more prevalent, although further research is needed to determine this relationship. International intervention might affect this variable abruptly.	
Population scenario growth rate	(Population_Scenario*POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE*eff_of_family_planning_on_fractonal_growth_rate)-Death_rate_at_climate_war-Death_rate_by_famines [people/year]
What we did here was to take the growth rate by World Bank (2017b) and increase it a bit so that population growth would be as in reality even when subtracting deaths from climate war and famines, which are usually not modelled in populational studies (although gradual malnutrition is).	

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Parameter Sensitivity Tests

BAU

Parameter	***Effect of a 10% increase on the final value of 'climate war-related deaths'***	***Effect of a 10% decrease on the final value of 'climate war-related deaths'***	***Analysis***
Annual change rate in precipitation	0.2% lower	No significant change	The annual change rate in precipitation is certainly not constant as modelled here, but there is no trustworthy data about it. World Bank (2017) and UNEP (2007) diverge enormously. The parameter value adopted here is simply an average of the general trends displayed by each institution.
Annual deforestation rate	No significant change	0.2% lower	Although this is well defined by data, it is interesting to look at the impact of this variable, as it could be avoided by policy. Overall, it seems not be sensitive in this context.
Annual growth in herd size	0.36% higher	**6.3% lower**	**Potential for policy intervention.**
Avg time to death at climate war	**Deaths are counterintuitively 1.45% higher**	**Deaths are counterintuitively 1.82% lower**	**Due to different international reaction when the conflict escalates earlier or later.**

Avg time to generate group identitarianism	**Deaths are counterintuitively 0.2% higher**	No significant change	**Due to different international reaction when conflict escalates earlier or later.**
Avg time to organize insurgency	**Deaths are counterintuitively 0.45% higher**	**Deaths are counterintuitively 2% lower**	**Due to different international reaction when the conflict escalates earlier or later.**
Time for international community to perceive war	6.5% higher	**6.5% lower**	**Potential for policy intervention.**
Tolerated death rate	**11.45% higher**	**11.8% lower**	**Potential for policy intervention**

AOI

Parameter	Effect of a 10% increase on deaths	Effect of a 10% decrease on deaths
Annual change rate in precipitation (the values are usually negative in the context of Sudan)	(an increase on the negative value means less change, therefore more rain) 4.4% less deaths	4.5% more deaths
Annual deforestation rate	7.8% higher	6.7% lower
Annual growth in herd size	29.53% higher	Deaths are 26.8% lower
Avg time to death at climate war	Deaths are 9.1% lower	Deaths are 11.1% higher
Avg time to generate group identitarianism	4.5% lower	4.8% higher
Avg time to organize insurgency	9.3% lower	11.4% higher
Time for international community to perceive war	NA	NA

Stella equations

Top-Level Model:

"AOI_-_No_international_intervention":

Annual_precipitation(t) = Annual_precipitation(t - dt) + (Change_in_precipitation) * dt

INIT Annual_precipitation = Reference_precipitation

UNITS: mm/year

INFLOWS:

Change_in_precipitation = Annual_change_rate_in_precipitation*Annual_precipitation

UNITS: mm/year/years

Arable_Land(t) = Arable_Land(t - dt) + (conversion_rate - Desertification_of_arable_land) * dt

INIT Arable_Land = Initial_arable_land

UNITS: ha

INFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

OUTFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

"climate_war-related_deaths"(t) = "climate_war-related_deaths"(t - dt) + (Death_rate_at_climate_war) * dt

INIT "climate_war-related_deaths" = 0

UNITS: people

INFLOWS:

Death_rate_at_climate_war = (Prevalence_of_organized_climate_conflict*population)/Avg_time_to_death_at_climate_war

UNITS: people/years

Desertified_or_degraded_land(t) = Desertified_or_degraded_land(t - dt) + (Desertification_of_arable_land + Desertification_of_potential_arable_land) * dt

INIT Desertified_or_degraded_land = 0

UNITS: ha

INFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

"famine-related_deaths"(t) = "famine-related_deaths"(t - dt) + (Death_rate_by_famines) * dt

INIT "famine-related_deaths" = 0

UNITS: People

INFLOWS:

Death_rate_by_famines = (population*eff_of_severe_malnutrition_on_death_rate)/Avg_time_to_death_at_malnutrition

UNITS: people/years

Flexible_Fertilizer_Subsidies(t) = Flexible_Fertilizer_Subsidies(t - dt) + (change_rate_fertillizer_subsidies) * dt

INIT Flexible_Fertilizer_Subsidies = CONSTANT_FERTILIZER_SUBSIDIES

UNITS: USD/year

INFLOWS:

change_rate_fertillizer_subsidies = Flexible_Fertilizer_Subsidies*ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES

UNITS: USD/year/years

Herd_size(t) = Herd_size(t - dt) + (Change_in_herd_size) * dt

INIT Herd_size = Initial_herd_size

UNITS: animals

INFLOWS:

Change_in_herd_size = Herd_size*annual_growth_in_herd_size

UNITS: animals/years

Population_Scenario(t) = Population_Scenario(t - dt) + (population_scenario_growth_rate) * dt

INIT Population_Scenario = INITIAL_POPULATION

UNITS: people

INFLOWS:

population_scenario_growth_rate = (Population_Scenario*POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE)-Death_rate_at_climate_war-Death_rate_by_famines

UNITS: people/years

Potential_Arable_Land(t) = Potential_Arable_Land(t - dt) + (- conversion_rate - Desertification_of_potential_arable_land) * dt

INIT Potential_Arable_Land = Initial_potential_arable_land

UNITS: ha

OUTFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

Prevalence_of_group_identitarianism(t) = Prevalence_of_group_identitarianism(t - dt) + (Change_in_group_identitarianism) * dt

INIT Prevalence_of_group_identitarianism = 0

UNITS: 1

INFLOWS:

Change_in_group_identitarianism = IF Prevalence_of_group_identitarianism >=1 THEN 0 ELSE ((Prevalence_of_Pastoral_conflict+Prevalence_of_organized_climate_conflict)-Prevalence_of_group_identitarianism)/Avg_time_to_generate_group_identitarianism

UNITS: 1/year

Prevalence_of_organized_climate_conflict(t) = Prevalence_of_organized_climate_conflict(t - dt) + (Change_in_organized_conflict) * dt

INIT Prevalence_of_organized_climate_conflict = 0

UNITS: 1

INFLOWS:

Change_in_organized_conflict = ((((1-Relative_presence_of_gov_services)*Prevalence_of_group_identitarianism)*Susceptibility_to_war)/Time_to_organize_insurgency)

UNITS: 1/year

Soil_Organic_Matter(t) = Soil_Organic_Matter(t - dt) + (SOM_addition - SOM_mineralization) * dt

INIT Soil_Organic_Matter = 60

UNITS: ton/ha

INFLOWS:

SOM_addition = plant_residues*SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD+SOM_FROM_ANIMALS+(SOM_FROM_LEGUMES*SWITCH_LEGUMES)

UNITS: ton/ha/year

OUTFLOWS:

SOM_mineralization = Soil_Organic_Matter/SOM_MINERALIZATION_TIME

UNITS: ton/ha/year

Absence_of_gov_services = 1-Relative_presence_of_gov_services

UNITS: 1

Adjustment_for_Sorghum = 0,9707/1,33

UNITS: 1

Annual_change_rate_in_precipitation = -0,004

UNITS: 1/year

Annual_deforestation_rate = 0,0084

UNITS: 1/year

annual_food_requirements =
annual_kcal_requirements_plants/CALORIC_DENSITY_PLANT_PRODUCTS

UNITS: TON/YEAR

annual_growth_in_herd_size = GRAPH(TIME)

(1961,00, 0,029838), (1962,00, 0,025404), (1963,00, 0,025404), (1964,00, 0,025404), (1965,00, 0,025404), (1966,00, 0,025404), (1967,00, 0,025404), (1968,00, 0,025404), (1969,00, 0,025404), (1970,00, 0,025404), (1971,00, 0,025404), (1972,00, 0,025404), (1973,00, 0,023575269), (1974,00, 0,023575269), (1975,00, 0,023575269), (1976,00, 0,023575269), (1977,00, 0,023575269), (1978,00, 0,023575269), (1979,00, 0,023575269), (1980,00, 0,023575269), (1981,00, 0,023575269), (1982,00, 0,023575269), (1983,00, 0,023575269), (1984,00, 0,023575269), (1985,00, 0,023575269), (1986,00, 0,0508715551), (1987,00, 0,0508715551), (1988,00, 0,0508715551), (1989,00, 0,0508715551), (1990,00, 0,0508715551), (1991,00, 0,0508715551), (1992,00, 0,0508715551), (1993,00, 0,0508715551), (1994,00, 0,0508715551), (1995,00, 0,0508715551), (1996,00, 0,0508715551), (1997,00, 0,0508715551), (1998,00, 0,0508715551), (1999,00, 0,0508715551), (2000,00, 0,0508715551), (2001,00, 0,0508715551), (2002,00, 0,0508715551), (2003,00, 0,0508715551), (2004,00, 0,0508715551), (2005,00, 0,0508715551), (2006,00, 0,0508715551)

UNITS: 1/year

ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES = 0,025

UNITS: 1/year

annual_kcal_requirements_plants =
total_daily_kcal_requirements_plants*DAYS_PER_YEAR

UNITS: Kilocalories/Years

Avg_time_to_death_at_climate_war = 16

UNITS: year

Avg_time_to_death_at_malnutrition = 5

UNITS: years

Avg_time_to_generate_group_identitarianism = 4

UNITS: years

CALORIC_DENSITY_PLANT_PRODUCTS = 3290000

UNITS: KCAL/TON

CONSTANT_FERTILIZER_SUBSIDIES = 251100000

UNITS: USD/year

DAYS_PER_YEAR = 365

UNITS: DAY/YEAR

demand_supply_ratio = food_demand/food_production

UNITS: 1

eff_of_food_deficit_on_severe_malnutrition = MAX(0; food_deficit)*(0,05/0,85)

UNITS: 1

Eff_of_herd_density_on_annual_desertification = GRAPH(Herd_density/Ref_herd_density)

(0,000, 0), (0,200, 0,0002), (0,400, 0,0004), (0,600, 0,0006), (0,800, 0,0008), (1,000, 0,001), (1,200, 0,00144), (1,400, 0,00196), (1,600, 0,00256), (1,800, 0,00324), (2,000, 0,004)

UNITS: 1/year

Eff_of_precipitation_on_produced_biomass = GRAPH(((Reference_precipitation-Annual_precipitation)/Reference_precipitation))

(0,000, 1,000), (0,100, 0,900), (0,200, 0,750), (0,300, 0,600), (0,400, 0,400), (0,500, 0,150), (0,600, 0,000), (0,700, 0,000), (0,800, 0,000), (0,900, 0,000), (1,000, 0,000)

UNITS: 1

eff_of_severe_malnutrition_on_death_rate = prevalence_of_severe_malnutrition*0,40

UNITS: 1

farm_income = SMTH1(food_sold*food_price;
INCOME_PERCEPTION_ADJUSTMENT_TIME; INITIAL_FARM_INCOME)

UNITS: USD/year

FERTILIZER_PRICE = 30000

UNITS: USD/ton

fertilizer_subsidies =
Flexible_Fertilizer_Subsidies*SWITCH_FERTILIZER_SUBSIDIES+CONSTANT_FERTILIZER_
SUBSIDIES*(1-SWITCH_FERTILIZER_SUBSIDIES)

UNITS: USD/year

food_deficit = MAX(demand_supply_ratio; 1)-1

UNITS: 1

food_demand = annual_food_requirements

UNITS: TON/YEAR

food_price =
REFERENCE_FOOD_PRICE*(demand_supply_ratio^SENSITIVITY_OF_PRICE_TO_DEMAN
D_SUPPLY_IMBALANCE)

UNITS: USD/TON

food_production = Harvested_yield*Arable_Land

UNITS: ton/Years

food_sold = food_production*SHARE_OF_PRODUCTION_SOLD

UNITS: ton/Years

fraction_of_GDP_coming_from_agriculture = 0,4

UNITS: 1

Government_revenue =
("Taxation/GDP"*farm_income)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Harvested_yield = produced_biomass*(1-
SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS)*Adjustment_for_Sorghum

UNITS: TON/ha/year

Herd_density = Herd_size/Potential_Arable_Land

UNITS: animals/ha

INCOME_PERCEPTION_ADJUSTMENT_TIME = 1

UNITS: year

Initial_arable_land = 1843005

UNITS: ha

INITIAL_FARM_INCOME = 170*1440000

UNITS: USD/year

Initial_herd_size = 28600000

UNITS: animals

INITIAL_POPULATION = 7769482

UNITS: PEOPLE

Initial_potential_arable_land = 0,7*total_area

UNITS: ha

LAND_CONVERSION_TIME = 4

UNITS: year

mineralized_nutrients_from_SOM = SOM_mineralization*NUTRIENT_CONTENT_IN_SOM

UNITS: ton/ha/year

"Non-productive_annual_deforestation_rate" = MAX(0; (Annual_deforestation_rate-(conversion_rate/Potential_Arable_Land)))

UNITS: 1/year

NUTRIENT_CONTENT_IN_SOM = 0,015

UNITS: 1

nutrient_uptake = per_ha_mineral_fertilizer_application+mineralized_nutrients_from_SOM

UNITS: ton/ha/year

PER_CAPITA_DAILY_KCAL_REQUIREMENTS = 2200

UNITS: kcal/person/day

per_capita_daily_kcal_requirements_plants = PER_CAPITA_DAILY_KCAL_REQUIREMENTS*SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS

UNITS: kcal/person/day

per_ha_mineral_fertilizer_application = total_fertilizer_expenditure/(FERTILIZER_PRICE*Adjustment_for_Sorghum)/Arable_Land

UNITS: ton/ha/year

plant_residues = produced_biomass*SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS

UNITS: ton/ha/year

population = Population_Scenario*SWITCH_POPULATION_SCENARIO+INITIAL_POPULATION*(1-SWITCH_POPULATION_SCENARIO)

UNITS: PEOPLE

POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE = 0,0312569

UNITS: 1/year

Prevalence_of_Pastoral_conflict = IF(Herd_density>Ref_herd_density) THEN MIN("Share_of_nomadic-pastoral_population"*2; ((Herd_density-Ref_herd_density)/Ref_herd_density)*"Share_of_nomadic-pastoral_population") ELSE 0

UNITS: 1

prevalence_of_severe_malnutrition = SMTH3(eff_of_food_deficit_on_severe_malnutrition; 1)

UNITS: 1

private_fertilizer_expenditure = farm_income*SHARE_OF_INCOME_SPENT_ON_FERTILIZER

UNITS: USD/year

produced_biomass = (YIELD_PLATEAU*(1-10^(-YIELD_RESPONSE_COEFFICIENT*nutrient_uptake)))*Eff_of_precipitation_on_produced_biomass

UNITS: TON/HA/YEAR

productive_land_demand = Arable_Land*(1+food_deficit)

UNITS: ha

Ref_gov_revenue = ("Taxation/GDP"*INITIAL_FARM_INCOME)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Ref_herd_density = 0,56

UNITS: animals/ha

REFERENCE_FOOD_PRICE = 212,2

UNITS: USD/TON

Reference_precipitation = 450

UNITS: mm/year

Relative_presence_of_gov_services = DELAY3(((1-Prevalence_of_organized_climate_conflict)*(Government_revenue/population))/(Ref_gov_revenue/INITIAL_POPULATION); 4)

UNITS: 1

SENSITIVITY_OF_PRICE_TO_DEMAND_SUPPLY_IMBALANCE = 0,86

UNITS: 1

SHARE_OF_INCOME_SPENT_ON_FERTILIZER = 0,1

UNITS: 1

"Share_of_nomadic-pastoral_population" = 0,10

UNITS: 1

SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS = 0,5

UNITS: 1

SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD = 0,75

UNITS: 1

SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS = 0,7486

UNITS: 1

SHARE_OF_PRODUCTION_SOLD = 0,7863

UNITS: 1

SOM_FROM_ANIMALS = 0,5

UNITS: ton/ha/year

SOM_FROM_LEGUMES = 0,28

UNITS: TON/HA/YEAR

SOM_MINERALIZATION_TIME = 30

UNITS: year

Susceptibility_to_war = 0,1

UNITS: 1

SWITCH_FERTILIZER_SUBSIDIES = 0

UNITS: 1

SWITCH_LEGUMES = 0

UNITS: 1

SWITCH_POPULATION_SCENARIO = 1

UNITS: 1

"Taxation/GDP" = 0,064

UNITS: 1

Time_to_organize_insurgency = 1,5

UNITS: year

total_area = 188600000

UNITS: ha

total_daily_kcal_requirements_plants =
population*per_capita_daily_kcal_requirements_plants

UNITS: Kilocalories/Days

total_fertilizer_expenditure = fertilizer_subsidies+private_fertilizer_expenditure

UNITS: USD/year

YIELD_PLATEAU = 14

UNITS: TON/ha/year

YIELD_RESPONSE_COEFFICIENT = 2,55

UNITS: ha*year/ton

"BAU_-_Business_As_Usual":

Annual_precipitation(t) = Annual_precipitation(t - dt) + (Change_in_precipitation) * dt

INIT Annual_precipitation = Reference_precipitation

UNITS: mm/year

INFLOWS:

Change_in_precipitation = Annual_change_rate_in_precipitation*Annual_precipitation

UNITS: mm/year/years

Arable_Land(t) = Arable_Land(t - dt) + (conversion_rate - Desertification_of_arable_land) * dt

INIT Arable_Land = Initial_arable_land

UNITS: ha

INFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

OUTFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

"climate_war-related_deaths"(t) = "climate_war-related_deaths"(t - dt) + (Death_rate_at_climate_war) * dt

INIT "climate_war-related_deaths" = 0

UNITS: people

INFLOWS:

Death_rate_at_climate_war = (Prevalence_of_organized_climate_conflict*population)/Avg_time_to_death_at_climate_war

UNITS: people/years

Desertified_or_degraded_land(t) = Desertified_or_degraded_land(t - dt) + (Desertification_of_arable_land + Desertification_of_potential_arable_land) * dt

INIT Desertified_or_degraded_land = 0

UNITS: ha

INFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

"famine-related_deaths"(t) = "famine-related_deaths"(t - dt) + (Death_rate_by_famines) * dt

INIT "famine-related_deaths" = 0

UNITS: People

INFLOWS:

Death_rate_by_famines = (population*eff_of_severe_malnutrition_on_death_rate)/Avg_time_to_death_at_malnutrition

UNITS: people/years

Flexible_Fertilizer_Subsidies(t) = Flexible_Fertilizer_Subsidies(t - dt) + (change_rate_fertillizer_subsidies) * dt

INIT Flexible_Fertilizer_Subsidies = CONSTANT_FERTILIZER_SUBSIDIES

UNITS: USD/year

INFLOWS:

change_rate_fertillizer_subsidies = Flexible_Fertilizer_Subsidies*ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES

UNITS: USD/year/years

Herd_size(t) = Herd_size(t - dt) + (Change_in_herd_size) * dt

INIT Herd_size = Initial_herd_size

UNITS: animals

INFLOWS:

Change_in_herd_size = Herd_size*annual_growth_in_herd_size

UNITS: animals/years

Population_Scenario(t) = Population_Scenario(t - dt) + (population_scenario_growth_rate) * dt

INIT Population_Scenario = INITIAL_POPULATION

UNITS: people

INFLOWS:

population_scenario_growth_rate = (Population_Scenario*POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE)-Death_rate_at_climate_war-Death_rate_by_famines

UNITS: people/years

Potential_Arable_Land(t) = Potential_Arable_Land(t - dt) + (- conversion_rate - Desertification_of_potential_arable_land) * dt

INIT Potential_Arable_Land = Initial_potential_arable_land

UNITS: ha

OUTFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

Prevalence_of_group_identitarianism(t) = Prevalence_of_group_identitarianism(t - dt) + (Change_in_group_identitarianism) * dt

INIT Prevalence_of_group_identitarianism = 0

UNITS: 1

INFLOWS:

Change_in_group_identitarianism = IF Prevalence_of_group_identitarianism >=1 THEN 0 ELSE ((Prevalence_of_Pastoral_conflict+Prevalence_of_organized_climate_conflict)-Prevalence_of_group_identitarianism)/Avg_time_to_generate_group_identitarianism

UNITS: 1/year

Prevalence_of_organized_climate_conflict(t) = Prevalence_of_organized_climate_conflict(t - dt) + (Change_in_organized_conflict) * dt

INIT Prevalence_of_organized_climate_conflict = 0

UNITS: 1

INFLOWS:

Change_in_organized_conflict = IF (SWITCH_INTERNATIONAL_INTERVENTION*eff_of_international_intervention_on_insurgency)<0 THEN (SWITCH_INTERNATIONAL_INTERVENTION* eff_of_international_intervention_on_insurgency)/Time_to_organize_insurgency ELSE ((((1-Relative_presence_of_gov_services)*Prevalence_of_group_identitarianism)*Susceptibility_to_war)/Time_to_organize_insurgency)

UNITS: 1/year

Soil_Organic_Matter(t) = Soil_Organic_Matter(t - dt) + (SOM_addition - SOM_mineralization) * dt

INIT Soil_Organic_Matter = 60

UNITS: ton/ha

INFLOWS:

SOM_addition = plant_residues*SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD+SOM_FROM_ANIMALS+(SOM_FROM_LEGUMES*SWITCH_LEGUMES)

UNITS: ton/ha/year

OUTFLOWS:

SOM_mineralization = Soil_Organic_Matter/SOM_MINERALIZATION_TIME

UNITS: ton/ha/year

Absence_of_gov_services = 1-Relative_presence_of_gov_services

UNITS: 1

Adjustment_for_Sorghum = 0,9707/1,33

UNITS: 1

Annual_change_rate_in_precipitation = -0,004

UNITS: 1/year

Annual_deforestation_rate = 0,0084

UNITS: 1/year

annual_food_requirements =
annual_kcal_requirements_plants/CALORIC_DENSITY_PLANT_PRODUCTS

UNITS: TON/YEAR

annual_growth_in_herd_size = GRAPH(TIME)

(1961,00, 0,029838), (1962,00, 0,025404), (1963,00, 0,025404), (1964,00, 0,025404), (1965,00, 0,025404), (1966,00, 0,025404), (1967,00, 0,025404), (1968,00, 0,025404), (1969,00, 0,025404), (1970,00, 0,025404), (1971,00, 0,025404), (1972,00, 0,025404), (1973,00, 0,023575269), (1974,00, 0,023575269), (1975,00, 0,023575269), (1976,00, 0,023575269), (1977,00, 0,023575269), (1978,00, 0,023575269), (1979,00, 0,023575269), (1980,00, 0,023575269), (1981,00, 0,023575269), (1982,00, 0,023575269), (1983,00, 0,023575269), (1984,00, 0,023575269), (1985,00, 0,023575269), (1986,00, 0,0508715551), (1987,00, 0,0508715551), (1988,00, 0,0508715551), (1989,00, 0,0508715551), (1990,00, 0,0508715551), (1991,00, 0,0508715551), (1992,00, 0,0508715551), (1993,00, 0,0508715551), (1994,00, 0,0508715551), (1995,00, 0,0508715551), (1996,00, 0,0508715551), (1997,00, 0,0508715551), (1998,00, 0,0508715551), (1999,00, 0,0508715551), (2000,00, 0,0508715551), (2001,00, 0,0508715551), (2002,00, 0,0508715551), (2003,00, 0,0508715551), (2004,00, 0,0508715551), (2005,00, 0,0508715551), (2006,00, 0,0508715551)

UNITS: 1/year

ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES = 0,025

UNITS: 1/year

annual_kcal_requirements_plants =
total_daily_kcal_requirements_plants*DAYS_PER_YEAR

UNITS: Kilocalories/Years

Avg_time_to_death_at_climate_war = 16

UNITS: year

Avg_time_to_death_at_malnutrition = 5

UNITS: years

Avg_time_to_generate_group_identitarianism = 4

UNITS: years

CALORIC_DENSITY_PLANT_PRODUCTS = 3290000

UNITS: KCAL/TON

CONSTANT_FERTILIZER_SUBSIDIES = 251100000

UNITS: USD/year

DAYS_PER_YEAR = 365

UNITS: DAY/YEAR

demand_supply_ratio = food_demand/food_production

UNITS: 1

eff_of_food_deficit_on_severe_malnutrition = MAX(0; food_deficit-food_aid_dependence)*(0,05/0,85)

UNITS: 1

Eff_of_herd_density_on_annual_desertification = GRAPH(Herd_density/Ref_herd_density)

(0,000, 0), (0,200, 0,0002), (0,400, 0,0004), (0,600, 0,0006), (0,800, 0,0008), (1,000, 0,001), (1,200, 0,00144), (1,400, 0,00196), (1,600, 0,00256), (1,800, 0,00324), (2,000, 0,004)

UNITS: 1/year

eff_of_international_intervention_on_insurgency = GRAPH((perceived_death_rate-tolerated_death_rate)/tolerated_death_rate)

(0,000, 1,000), (0,100, -0,005), (0,200, -0,005), (0,300, -0,005), (0,400, -0,005), (0,500, -0,005), (0,600, -0,005), (0,700, -0,005), (0,800, -0,005), (0,900, -0,005), (1,000, -0,005)

UNITS: 1

Eff_of_precipitation_on_produced_biomass = GRAPH(((Reference_precipitation-Annual_precipitation)/Reference_precipitation))

(0,000, 1,000), (0,100, 0,900), (0,200, 0,750), (0,300, 0,600), (0,400, 0,400), (0,500, 0,150), (0,600, 0,000), (0,700, 0,000), (0,800, 0,000), (0,900, 0,000), (1,000, 0,000)

UNITS: 1

eff_of_severe_malnutrition_on_death_rate = prevalence_of_severe_malnutrition*0,40

UNITS: 1

farm_income = SMTH1(food_sold*food_price; INCOME_PERCEPTION_ADJUSTMENT_TIME; INITIAL_FARM_INCOME)

UNITS: USD/year

FERTILIZER_PRICE = 30000

UNITS: USD/ton

fertilizer_subsidies = Flexible_Fertilizer_Subsidies*SWITCH_FERTILIZER_SUBSIDIES+CONSTANT_FERTILIZER_SUBSIDIES*(1-SWITCH_FERTILIZER_SUBSIDIES)

UNITS: USD/year

food_aid_dependence = SMTH3(food_deficit; International_food_aid_reaction_time)

UNITS: 1

food_deficit = MAX(demand_supply_ratio; 1)-1

UNITS: 1

food_demand = annual_food_requirements

UNITS: TON/YEAR

food_price = REFERENCE_FOOD_PRICE*(demand_supply_ratio^SENSITIVITY_OF_PRICE_TO_DEMAND_SUPPLY_IMBALANCE)

UNITS: USD/TON

food_production = Harvested_yield*Arable_Land

UNITS: ton/Years

food_sold = food_production*SHARE_OF_PRODUCTION_SOLD

UNITS: ton/Years

fraction_of_GDP_coming_from_agriculture = 0,4

UNITS: 1

Government_revenue = ("Taxation/GDP"*farm_income)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Harvested_yield = produced_biomass*(1-SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS)*Adjustment_for_Sorghum

UNITS: TON/ha/year

Herd_density = Herd_size/Potential_Arable_Land

UNITS: animals/ha

INCOME_PERCEPTION_ADJUSTMENT_TIME = 1

UNITS: year

Initial_arable_land = 1843005

UNITS: ha

INITIAL_FARM_INCOME = 170*1440000

UNITS: USD/year

Initial_herd_size = 28600000

UNITS: animals

INITIAL_POPULATION = 7769482

UNITS: PEOPLE

Initial_potential_arable_land = 0,7*total_area

UNITS: ha

International_food_aid_reaction_time = 1

UNITS: Years

LAND_CONVERSION_TIME = 4

UNITS: year

mineralized_nutrients_from_SOM = SOM_mineralization*NUTRIENT_CONTENT_IN_SOM

UNITS: ton/ha/year

"Non-productive_annual_deforestation_rate" = MAX(0; (Annual_deforestation_rate-(conversion_rate/Potential_Arable_Land)))

UNITS: 1/year

NUTRIENT_CONTENT_IN_SOM = 0,015

UNITS: 1

nutrient_uptake = per_ha_mineral_fertilizer_application+mineralized_nutrients_from_SOM

UNITS: ton/ha/year

PER_CAPITA_DAILY_KCAL_REQUIREMENTS = 2200

UNITS: kcal/person/day

per_capita_daily_kcal_requirements_plants = PER_CAPITA_DAILY_KCAL_REQUIREMENTS*SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS

UNITS: kcal/person/day

per_ha_mineral_fertilizer_application = total_fertilizer_expenditure/(FERTILIZER_PRICE*Adjustment_for_Sorghum)/Arable_Land

UNITS: ton/ha/year

perceived_death_rate = SMTH3(Death_rate_at_climate_war; time_for_international_community_to_perceive_war)

UNITS: people/year

plant_residues = produced_biomass*SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS

UNITS: ton/ha/year

population = Population_Scenario*SWITCH_POPULATION_SCENARIO+INITIAL_POPULATION*(1-SWITCH_POPULATION_SCENARIO)

UNITS: PEOPLE

POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE = 0,0312569

UNITS: 1/year

Prevalence_of_Pastoral_conflict = IF(Herd_density>Ref_herd_density) THEN MIN("Share_of_nomadic-pastoral_population"*2; ((Herd_density-Ref_herd_density)/Ref_herd_density)*"Share_of_nomadic-pastoral_population") ELSE 0

UNITS: 1

prevalence_of_severe_malnutrition = SMTH3(eff_of_food_deficit_on_severe_malnutrition; 1)

UNITS: 1

private_fertilizer_expenditure = farm_income*SHARE_OF_INCOME_SPENT_ON_FERTILIZER

UNITS: USD/year

produced_biomass = (YIELD_PLATEAU*(1-10^(-YIELD_RESPONSE_COEFFICIENT*nutrient_uptake)))*Eff_of_precipitation_on_produced_biomass

UNITS: TON/HA/YEAR

productive_land_demand = Arable_Land*(1+food_deficit)

UNITS: ha

Ref_gov_revenue = ("Taxation/GDP"*INITIAL_FARM_INCOME)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Ref_herd_density = 0,56

UNITS: animals/ha

REFERENCE_FOOD_PRICE = 212,2

UNITS: USD/TON

Reference_precipitation = 450

UNITS: mm/year

Relative_presence_of_gov_services = DELAY3(((1-Prevalence_of_organized_climate_conflict)*(Government_revenue/population))/(Ref_gov_revenue/INITIAL_POPULATION); 4)

UNITS: 1

SENSITIVITY_OF_PRICE_TO_DEMAND_SUPPLY_IMBALANCE = 0,86

UNITS: 1

SHARE_OF_INCOME_SPENT_ON_FERTILIZER = 0,1

UNITS: 1

"Share_of_nomadic-pastoral_population" = 0,10

UNITS: 1

SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS = 0,5

UNITS: 1

SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD = 0,75

UNITS: 1

SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS = 0,7486

UNITS: 1

SHARE_OF_PRODUCTION_SOLD = 0,7863

UNITS: 1

SOM_FROM_ANIMALS = 0,5

UNITS: ton/ha/year

SOM_FROM_LEGUMES = 0,28

UNITS: TON/HA/YEAR

SOM_MINERALIZATION_TIME = 30

UNITS: year

Susceptibility_to_war = 0,1

UNITS: 1

SWITCH_FERTILIZER_SUBSIDIES = 0

UNITS: 1

SWITCH_INTERNATIONAL_INTERVENTION = 1

UNITS: 1

SWITCH_LEGUMES = 0

UNITS: 1

SWITCH_POPULATION_SCENARIO = 1

UNITS: 1

"Taxation/GDP" = 0,064

UNITS: 1

time_for_international_community_to_perceive_war = 3

UNITS: year

Time_to_organize_insurgency = 1,5

UNITS: year

tolerated_death_rate = 5581

UNITS: people/year

total_area = 188600000

UNITS: ha

total_daily_kcal_requirements_plants = population*per_capita_daily_kcal_requirements_plants

UNITS: Kilocalories/Days

total_fertilizer_expenditure = fertilizer_subsidies+private_fertilizer_expenditure

UNITS: USD/year

YIELD_PLATEAU = 14

UNITS: TON/ha/year

YIELD_RESPONSE_COEFFICIENT = 2,55

UNITS: ha*year/ton

BAU_CLD:

Policy_Model:

Annual_precipitation(t) = Annual_precipitation(t - dt) + (Change_in_precipitation) * dt

INIT Annual_precipitation = Reference_precipitation

UNITS: mm/year

INFLOWS:

Change_in_precipitation = Annual_change_rate_in_precipitation*Annual_precipitation

UNITS: mm/year/years

Arable_Land(t) = Arable_Land(t - dt) + (conversion_rate - Desertification_of_arable_land) * dt

INIT Arable_Land = Initial_arable_land

UNITS: ha

INFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

OUTFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

"climate_war-related_deaths"(t) = "climate_war-related_deaths"(t - dt) + (Death_rate_at_climate_war) * dt

INIT "climate_war-related_deaths" = 0

UNITS: people

INFLOWS:

Death_rate_at_climate_war = (Prevalence_of_organized_climate_conflict*population)/Avg_time_to_death_at_climate_war

UNITS: people/years

Desertified_or_degraded_land(t) = Desertified_or_degraded_land(t - dt) + (Desertification_of_arable_land + Desertification_of_potential_arable_land) * dt

INIT Desertified_or_degraded_land = 0

UNITS: ha

INFLOWS:

Desertification_of_arable_land = (Arable_Land*(-Annual_change_rate_in_precipitation))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-

productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

"famine-related_deaths"(t) = "famine-related_deaths"(t - dt) + (Death_rate_by_famines) * dt

INIT "famine-related_deaths" = 0

UNITS: People

INFLOWS:

Death_rate_by_famines = (population*eff_of_severe_malnutrition_on_death_rate)/Avg_time_to_death_at_malnutrition

UNITS: people/years

Flexible_Fertilizer_Subsidies(t) = Flexible_Fertilizer_Subsidies(t - dt) + (change_rate_fertillizer_subsidies) * dt

INIT Flexible_Fertilizer_Subsidies = CONSTANT_FERTILIZER_SUBSIDIES

UNITS: USD/year

INFLOWS:

change_rate_fertillizer_subsidies = Flexible_Fertilizer_Subsidies*ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES

UNITS: USD/year/years

Herd_size(t) = Herd_size(t - dt) + (Change_in_herd_size) * dt

INIT Herd_size = Initial_herd_size

UNITS: animals

INFLOWS:

Change_in_herd_size = Herd_size*annual_growth_in_herd_size*eff_of_technical_assistance_on_herd_size

UNITS: animals/years

Population_Scenario(t) = Population_Scenario(t - dt) + (population_scenario_growth_rate) * dt

INIT Population_Scenario = INITIAL_POPULATION

UNITS: people

INFLOWS:

population_scenario_growth_rate = (Population_Scenario*POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE*eff_of_family_planning_on_fractional_growth_rate)-Death_rate_at_climate_war-Death_rate_by_famines

UNITS: people/years

Potential_Arable_Land(t) = Potential_Arable_Land(t - dt) + (- conversion_rate - Desertification_of_potential_arable_land) * dt

INIT Potential_Arable_Land = Initial_potential_arable_land

UNITS: ha

OUTFLOWS:

conversion_rate = MAX(0,00001; ((productive_land_demand-Arable_Land)/LAND_CONVERSION_TIME))

UNITS: ha/years

Desertification_of_potential_arable_land = ((Potential_Arable_Land*(-Annual_change_rate_in_precipitation+("Non-productive_annual_deforestation_rate"+Eff_of_herd_density_on_annual_desertification))))

UNITS: ha/years

Prevalence_of_group_identitarianism(t) = Prevalence_of_group_identitarianism(t - dt) + (Change_in_group_identitarianism) * dt

INIT Prevalence_of_group_identitarianism = 0

UNITS: 1

INFLOWS:

Change_in_group_identitarianism = IF Prevalence_of_group_identitarianism >=1 THEN 0 ELSE ((Prevalence_of_Pastoral_conflict+Prevalence_of_organized_climate_conflict)-Prevalence_of_group_identitarianism)/Avg_time_to_generate_group_identitarianism

UNITS: 1/year

Prevalence_of_organized_climate_conflict(t) = Prevalence_of_organized_climate_conflict(t - dt) + (Change_in_organized_conflict) * dt

INIT Prevalence_of_organized_climate_conflict = 0

UNITS: 1

INFLOWS:

Change_in_organized_conflict = IF (SWITCH_INTERNATIONAL_INTERVENTION*eff_of_international_intervention_on_insurgency)<0 THEN (SWITCH_INTERNATIONAL_INTERVENTION* eff_of_international_intervention_on_insurgency)/Time_to_organize_insurgency ELSE ((((1-Relative_presence_of_gov_services)*Prevalence_of_group_identitarianism)*Susceptibility_to_war)/Time_to_organize_insurgency)

UNITS: 1/year

Soil_Organic_Matter(t) = Soil_Organic_Matter(t - dt) + (SOM_addition - SOM_mineralization) * dt

INIT Soil_Organic_Matter = 60

UNITS: ton/ha

INFLOWS:

SOM_addition = plant_residues*SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD+SOM_FROM_ANIMALS+(SOM_FROM_LEGUMES*SWITCH_LEGUMES)

UNITS: ton/ha/year

OUTFLOWS:

SOM_mineralization = Soil_Organic_Matter/SOM_MINERALIZATION_TIME

UNITS: ton/ha/year

Absence_of_gov_services = 1-Relative_presence_of_gov_services

UNITS: 1

Adjustment_for_Sorghum = 0,9707/1,33

UNITS: 1

Annual_change_rate_in_precipitation = -0,004

UNITS: 1/year

Annual_deforestation_rate = 0,0084

UNITS: 1/year

annual_food_requirements = annual_kcal_requirements_plants/CALORIC_DENSITY_PLANT_PRODUCTS

UNITS: TON/YEAR

annual_growth_in_herd_size = GRAPH(TIME)

(1961,00, 0,029838), (1962,00, 0,025404), (1963,00, 0,025404), (1964,00, 0,025404), (1965,00, 0,025404), (1966,00, 0,025404), (1967,00, 0,025404), (1968,00, 0,025404), (1969,00, 0,025404), (1970,00, 0,025404), (1971,00, 0,025404), (1972,00, 0,025404), (1973,00, 0,023575269), (1974,00, 0,023575269), (1975,00, 0,023575269), (1976,00, 0,023575269), (1977,00, 0,023575269), (1978,00, 0,023575269), (1979,00, 0,023575269), (1980,00, 0,023575269), (1981,00, 0,023575269), (1982,00, 0,023575269), (1983,00, 0,023575269), (1984,00, 0,023575269), (1985,00, 0,023575269), (1986,00, 0,0508715551), (1987,00, 0,0508715551), (1988,00, 0,0508715551), (1989,00, 0,0508715551), (1990,00, 0,0508715551), (1991,00, 0,0508715551), (1992,00, 0,0508715551), (1993,00, 0,0508715551), (1994,00, 0,0508715551), (1995,00, 0,0508715551), (1996,00, 0,0508715551), (1997,00, 0,0508715551), (1998,00, 0,0508715551), (1999,00, 0,0508715551), (2000,00, 0,0508715551), (2001,00, 0,0508715551), (2002,00, 0,0508715551), (2003,00, 0,0508715551), (2004,00, 0,0508715551), (2005,00, 0,0508715551), (2006,00, 0,0508715551)

UNITS: 1/year

ANNUAL_GROWTH_RATE_FERTILIZER_SUBSIDIES = 0,025

UNITS: 1/year

annual_kcal_requirements_plants = total_daily_kcal_requirements_plants*DAYS_PER_YEAR

UNITS: Kilocalories/Years

Avg_time_to_death_at_climate_war = 16

UNITS: year

Avg_time_to_death_at_malnutrition = 5

UNITS: years

Avg_time_to_generate_group_identitarianism = 4

UNITS: years

CALORIC_DENSITY_PLANT_PRODUCTS = 3290000

UNITS: KCAL/TON

CONSTANT_FERTILIZER_SUBSIDIES = 251100000

UNITS: USD/year

DAYS_PER_YEAR = 365

UNITS: DAY/YEAR

demand_supply_ratio = food_demand/food_production

UNITS: 1

eff_of_family_planning_on_fractional_growth_rate = GRAPH(SWITCH_FAMILY_PLANNING*outreach_of_family_planning)

(0,000, 1,000), (0,100, 0,950), (0,200, 0,900), (0,300, 0,850), (0,400, 0,800), (0,500, 0,750), (0,600, 0,700), (0,700, 0,650), (0,800, 0,600), (0,900, 0,550), (1,000, 0,500)

UNITS: 1

eff_of_food_deficit_on_severe_malnutrition = MAX(0; food_deficit-food_aid_dependence)*(0,05/0,85)

UNITS: 1

Eff_of_herd_density_on_annual_desertification = GRAPH(Herd_density/Ref_herd_density)

(0,000, 0), (0,200, 0,0002), (0,400, 0,0004), (0,600, 0,0006), (0,800, 0,0008), (1,000, 0,001), (1,200, 0,00144), (1,400, 0,00196), (1,600, 0,00256), (1,800, 0,00324), (2,000, 0,004)

UNITS: 1/year

eff_of_international_intervention_on_insurgency = GRAPH((perceived_death_rate-tolerated_death_rate)/tolerated_death_rate)

(0,000, 1,000), (0,100, -0,005), (0,200, -0,005), (0,300, -0,005), (0,400, -0,005), (0,500, -0,005), (0,600, -0,005), (0,700, -0,005), (0,800, -0,005), (0,900, -0,005), (1,000, -0,005)

UNITS: 1

eff_of_land_zoning_on_pastoral_conflict = GRAPH(SWITCH_LAND_ZONING_AND_DEMARCATION*outreach_of_land_zoning_policy)

(0,000, 1,000), (0,100, 0,900), (0,200, 0,800), (0,300, 0,700), (0,400, 0,600), (0,500, 0,500), (0,600, 0,400), (0,700, 0,300), (0,800, 0,200), (0,900, 0,100), (1,000, 0,000)

UNITS: 1

Eff_of_precipitation_on_produced_biomass = GRAPH(((Reference_precipitation-Annual_precipitation)/Reference_precipitation))

(0,000, 1,000), (0,100, 0,900), (0,200, 0,750), (0,300, 0,600), (0,400, 0,400), (0,500, 0,150), (0,600, 0,000), (0,700, 0,000), (0,800, 0,000), (0,900, 0,000), (1,000, 0,000)

UNITS: 1

eff_of_severe_malnutrition_on_death_rate = prevalence_of_severe_malnutrition*0,40

UNITS: 1

eff_of_technical_assistance_on_herd_size = GRAPH(SWITCH_TECHNICAL_ASSISTANCE*outreach_of_technical_assistance)

(0,000, 1,000), (0,100, 0,900), (0,200, 0,800), (0,300, 0,700), (0,400, 0,600), (0,500, 0,500), (0,600, 0,400), (0,700, 0,300), (0,800, 0,200), (0,900, 0,100), (1,000, 0,000)

UNITS: 1

farm_income = SMTH1(food_sold*food_price; INCOME_PERCEPTION_ADJUSTMENT_TIME; INITIAL_FARM_INCOME)

UNITS: USD/year

FERTILIZER_PRICE = 30000

UNITS: USD/ton

fertilizer_subsidies = Flexible_Fertilizer_Subsidies*SWITCH_FERTILIZER_SUBSIDIES+CONSTANT_FERTILIZER_SUBSIDIES*(1-SWITCH_FERTILIZER_SUBSIDIES)

UNITS: USD/year

food_aid_dependence = SMTH3(food_deficit; International_food_aid_reaction_time)

UNITS: 1

food_deficit = MAX(demand_supply_ratio; 1)-1

UNITS: 1

food_demand = annual_food_requirements

UNITS: TON/YEAR

food_price = REFERENCE_FOOD_PRICE*(demand_supply_ratio^SENSITIVITY_OF_PRICE_TO_DEMAND_SUPPLY_IMBALANCE)

UNITS: USD/TON

food_production = Harvested_yield*Arable_Land

UNITS: ton/Years

food_sold = food_production*SHARE_OF_PRODUCTION_SOLD

UNITS: ton/Years

fraction_of_GDP_coming_from_agriculture = 0,4

UNITS: 1

Government_revenue = ("Taxation/GDP"*farm_income)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Harvested_yield = produced_biomass*(1-SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS)*Adjustment_for_Sorghum

UNITS: TON/ha/year

Herd_density = Herd_size/Potential_Arable_Land

UNITS: animals/ha

INCOME_PERCEPTION_ADJUSTMENT_TIME = 1

UNITS: year

Initial_arable_land = 1843005

UNITS: ha

INITIAL_FARM_INCOME = 170*1440000

UNITS: USD/year

Initial_herd_size = 28600000

UNITS: animals

INITIAL_POPULATION = 7769482

UNITS: PEOPLE

Initial_potential_arable_land = 0,7*total_area

UNITS: ha

International_food_aid_reaction_time = 1

UNITS: Years

LAND_CONVERSION_TIME = 4

UNITS: year

mineralized_nutrients_from_SOM = SOM_mineralization*NUTRIENT_CONTENT_IN_SOM

UNITS: ton/ha/year

"Non-productive_annual_deforestation_rate" = MAX(0; (Annual_deforestation_rate-(conversion_rate/Potential_Arable_Land)))

UNITS: 1/year

NUTRIENT_CONTENT_IN_SOM = 0,015

UNITS: 1

nutrient_uptake = per_ha_mineral_fertilizer_application+mineralized_nutrients_from_SOM

UNITS: ton/ha/year

outreach_of_family_planning = 0,5

UNITS: 1

outreach_of_land_zoning_policy = 0,5

UNITS: 1

outreach_of_technical_assistance = 0,5

UNITS: 1

PER_CAPITA_DAILY_KCAL_REQUIREMENTS = 2200

UNITS: kcal/person/day

per_capita_daily_kcal_requirements_plants = PER_CAPITA_DAILY_KCAL_REQUIREMENTS*SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS

UNITS: kcal/person/day

per_ha_mineral_fertilizer_application = total_fertilizer_expenditure/(FERTILIZER_PRICE*Adjustment_for_Sorghum)/Arable_Land

UNITS: ton/ha/year

perceived_death_rate = SMTH3(Death_rate_at_climate_war; time_for_international_community_to_perceive_war)

UNITS: people/year

plant_residues = produced_biomass*SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS

UNITS: ton/ha/year

population = Population_Scenario*SWITCH_POPULATION_SCENARIO+INITIAL_POPULATION*(1-SWITCH_POPULATION_SCENARIO)

UNITS: PEOPLE

POPULATION_SCENARIO_FRACTIONAL_GROWTH_RATE = 0,0312569

UNITS: 1/year

Prevalence_of_Pastoral_conflict = IF(Herd_density>Ref_herd_density) THEN MIN("Share_of_nomadic-pastoral_population"*2; ((Herd_density-Ref_herd_density)/Ref_herd_density)*"Share_of_nomadic-pastoral_population")*eff_of_land_zoning_on_pastoral_conflict ELSE 0

UNITS: 1

prevalence_of_severe_malnutrition = SMTH3(eff_of_food_deficit_on_severe_malnutrition; 1)

UNITS: 1

private_fertilizer_expenditure = farm_income*SHARE_OF_INCOME_SPENT_ON_FERTILIZER

UNITS: USD/year

produced_biomass = (YIELD_PLATEAU*(1-10^(-YIELD_RESPONSE_COEFFICIENT*nutrient_uptake)))*Eff_of_precipitation_on_produced_biomass

UNITS: TON/HA/YEAR

productive_land_demand = Arable_Land*(1+food_deficit)

UNITS: ha

Ref_gov_revenue = ("Taxation/GDP"*INITIAL_FARM_INCOME)/fraction_of_GDP_coming_from_agriculture

UNITS: USD/year

Ref_herd_density = 0,56

UNITS: animals/ha

REFERENCE_FOOD_PRICE = 212,2

UNITS: USD/TON

Reference_precipitation = 450

UNITS: mm/year

Relative_presence_of_gov_services = DELAY3(((1-Prevalence_of_organized_climate_conflict)*(Government_revenue/population))/(Ref_gov_revenue/INITIAL_POPULATION); 4)

UNITS: 1

SENSITIVITY_OF_PRICE_TO_DEMAND_SUPPLY_IMBALANCE = 0,86

UNITS: 1

SHARE_OF_INCOME_SPENT_ON_FERTILIZER = 0,1

UNITS: 1

"Share_of_nomadic-pastoral_population" = 0,10

UNITS: 1

SHARE_OF_PLANT_RESIDUES_IN_PRODUCED_BIOMASS = 0,5

UNITS: 1

SHARE_OF_PLANT_RESIDUES_REMAINING_ON_THE_FIELD = 0,75

UNITS: 1

SHARE_OF_PLANTS_IN_TOTAL_KCAL_REQUIREMENTS = 0,7486

UNITS: 1

SHARE_OF_PRODUCTION_SOLD = 0,7863

UNITS: 1

SOM_FROM_ANIMALS = 0,5

UNITS: ton/ha/year

SOM_FROM_LEGUMES = 0,28

UNITS: TON/HA/YEAR

SOM_MINERALIZATION_TIME = 30

UNITS: year

Susceptibility_to_war = 0,1

UNITS: 1

SWITCH_FAMILY_PLANNING = 1

UNITS: 1

SWITCH_FERTILIZER_SUBSIDIES = 0

UNITS: 1

SWITCH_INTERNATIONAL_INTERVENTION = 1

UNITS: 1

SWITCH_LAND_ZONING_AND_DEMARCATION = 1

UNITS: 1

SWITCH_LEGUMES = 0

UNITS: 1

SWITCH_POPULATION_SCENARIO = 1

UNITS: 1

SWITCH_TECHNICAL_ASSISTANCE = 1

UNITS: 1

"Taxation/GDP" = 0,064

UNITS: 1

time_for_international_community_to_perceive_war = 1,5

UNITS: year

Time_to_organize_insurgency = 1,5

UNITS: year

tolerated_death_rate = 5581

UNITS: people/year

total_area = 188600000

UNITS: ha

total_daily_kcal_requirements_plants = population*per_capita_daily_kcal_requirements_plants

UNITS: Kilocalories/Days

total_fertilizer_expenditure = fertilizer_subsidies+private_fertilizer_expenditure

UNITS: USD/year

YIELD_PLATEAU = 14

UNITS: TON/ha/year

YIELD_RESPONSE_COEFFICIENT = 2,55

UNITS: ha*year/ton

{ The model has 335 (335) variables (array expansion in parens).

In root model and 4 additional modules with 0 sectors.

Stocks: 36 (36) Flows: 39 (39) Converters: 260 (260)

Constants: 143 (143) Equations: 156 (156) Graphicals: 14 (14)

There are also 118 expanded macro variables.

}