Running a first baseline

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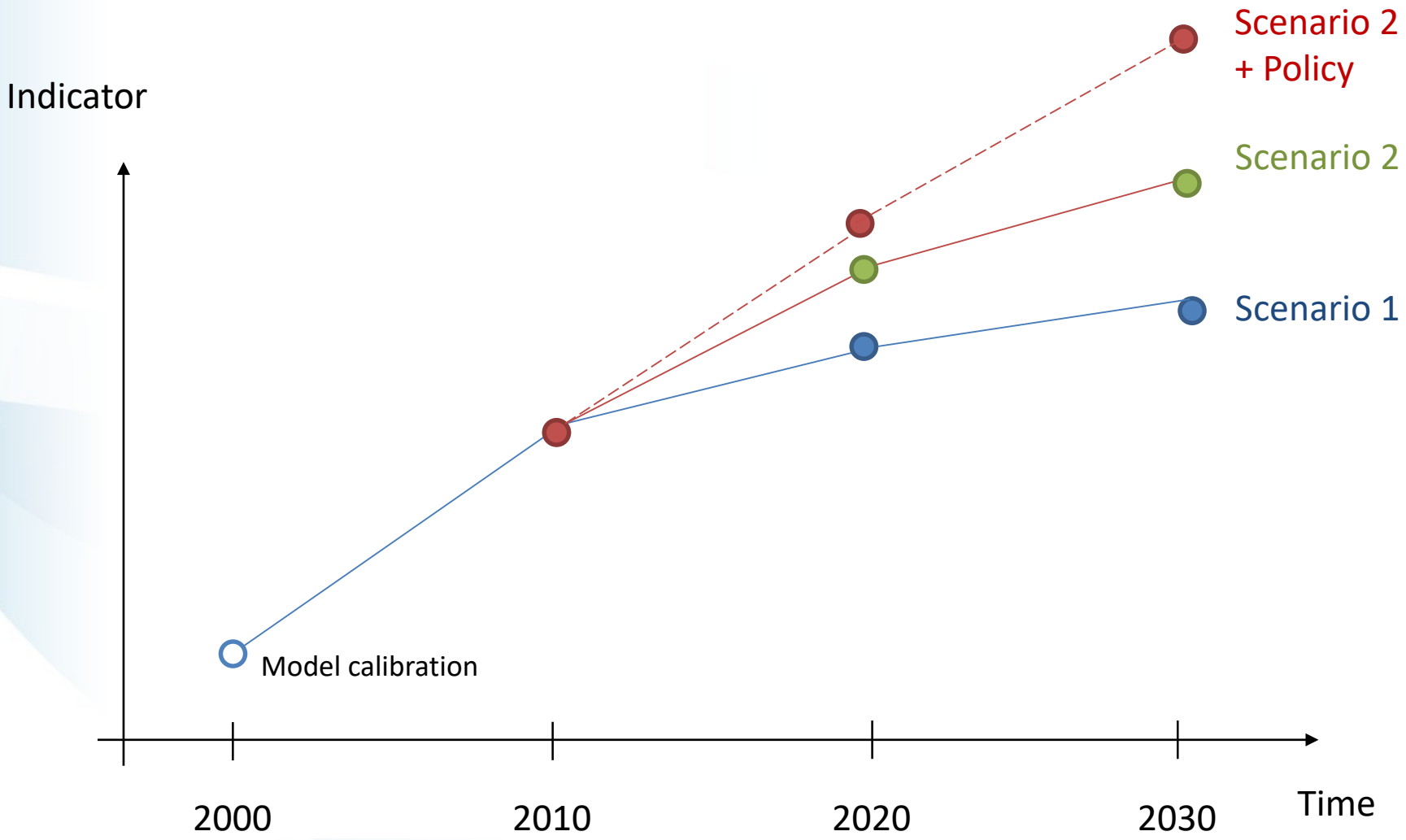
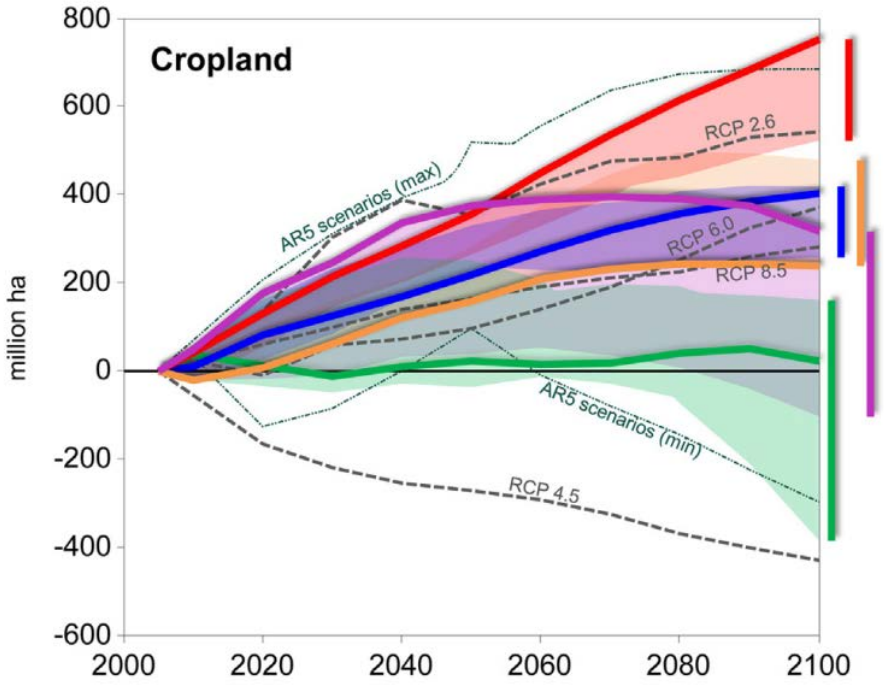
Baseline and scenarios with GLOBIOM



Some GLOBIOM baseline repositories



Source: Riahi et al. 2017

- SSP database

https://tntcat.iiasa.ac.at/SspDb/

- AgMIP/AgCLIM50

https://datam.jrc.ec.europa.eu/

Digging into the baseline / scenario code

```
***
* ======================
* GLOBIOM EXECUTION FILE
* ======================
* Top-level script of the GLOBIOM model. It executes the numbered stages of
* the model in-sequence, passing the output of a stage as input to the
* next stage via the filesystem (``.g00`` files in the ``Model/t`` directory).
*
* This allows the model to be re-run quickly after modifying a stage by
* commenting out the execute statements of prior stages: since these will not
* produce modified output, their existing output files can be re-used.
*
* After running this script, check that all files compiled and executed
* without error by opening ``0_executebatch.log`` and searching for occurrences
* of "error" and "infeasible". These should be absent.
****

$set env ide=%gams.ide% lo=%gams.lo% errorlog=%gams.errorlog% errmsg=1 pw=130 cerr=5

$setLocal X %system.dirSep%
execute "gams 1_loaddata.gms          %env%                          -s .%X%t%X%a1_v1                          ";
execute "gams 2_activesets.gms        %env% -r .%X%t%X%a1_v1         -s .%X%t%X%a2_v1  gdx=.%X%gdx%X%a2_v1 ";
execute "gams 3_precompute.gms        %env% -r .%X%t%X%a2_v1         -s .%X%t%X%a3_v1  gdx=.%X%gdx%X%a3_v1 ";
execute "gams 3b_calibtrade.gms       %env% -r .%X%t%X%a3_v1         -s .%X%t%X%a3b_v1 gdx=.%X%gdx%X%a3b_v1";
execute "gams 4_model.gms             %env% -r .%X%t%X%a3b_v1        -s .%X%t%X%a4_v1  gdx=.%X%gdx%X%a4_v1 ";

*execute "gams 5_precompute_scen.gms  %env% -r .%X%t%X%a4_v1         -s .%X%t%X%a5_v1  gdx=.%X%gdx%X%a5_v1";

* Identifier of the output file
$set output_name Baseline_may18_adj

execute "gams 6_scenarios.gms         %env% -r .%X%t%X%a4_v1         -s .%X%t%X%a6_v1_test  gdx=.%X%gdx%X%a6_v1_test";

*execute "gams 7_output.gms  %env%  -r .%X%t%X%a6_v1  //CSV=1 //lab=%output_name%";

***
* Arguments for ``7_output.gms``:
*   - ``//CSV=1`` for production of a CSV file using GDXVIEWER.

* Use this command to convert a .g00 into .gdx
*execute "gams blank.gms               %env% -r .%X%t%X%a6_v1 gdx=.%X%gdx%X%a6_v1  FW=1"
```

What is the 6_scenarios.gms file doing?

- Defines the **baseline** projection framework
- Initialise the projection values for the baseline
- Defines the options to be used for the baseline (switches on equations)

- Declares the **scenario** definitions
- Introduces new equations for the scenarios
  - Constraints
  - Extra terms in the objective function
- Defines the parameter changes corresponding to the scenarios

- Runs the model for the different scenarios

Running the 6_scenario.gms

- Let's immediately launch the simulation in background
  - Baseline to 2030 (takes approx. 25 min to run)

- execute "gams 6_scenarios.gms"
  with arguments
  - -r .%X%t%X%a4_v1
  - -s .%X%t%X%a6_v1
  - gdx=.%X%gdx%X%a6_v1";

- GAMS should start loading the model like in 4_model.gms and launch a number of simulations

Structure of the 6_scenarios.gms file

- Header:
  - defines some high level control parameters
  - determines the model default setup parameters
    - model_scen_defaultsetup.gms
- Scenario definition block
  - Scenario names, scenario selection, time period
- Main scenario assumptions block
  - Scenario features and parameters
- Scenario listing: automatic listing of scenarios
- Model initialization
    - define_base.gms
    - model_scen.gms
- Model execution
    - define_scenario.gms

Model default parameters

- Header:
  - T_run
  - Nsim
  - writescen_only
  - ARTVAR_ACTIVE = 1

- model_scen_defaultsetup.gms
  - EXG_FOOD_DEMAND
  - EXG_WOOD_DEMAND
  - etc…

Scenario definitions

- All sets in this section are declared by 2
  - One general set with all possible elements
  - One dynamic subset with the selected elemets

- Key sets for identification of scenario variables:
  - AllScenYear / ScenYear: periods of simulation
  - AllMacroScen / MacroScen: macroeconomic scenario dimension
  - AllBioenScen / BioenScen: first scenario dimension
  - AllIEA_SCEN / IEA_SCEN: second scenario dimension

- For our baseline: SSP2 – scenBase – 0_Ref

Scenario switches

- Main scenario assumptions block relies on switches ‘Qxxx’
- Scenario names can be mapped to different switches position
  - Two mappings
    - ALL_SCENMAP(QTRD,QAFR,QBIO,QCHG,G4MS): fixed switches
    - IEA_SCENMAP(ALLIEA_SCEN,QRCP,QGCM,QCRM)

    ➔ IEA_SCEN switches (scenario dependent)
- Current version: 8 switches
- Switches are a convenient but not the only way to define alternative scenarios

Scenario listing

- Scenarios can be run in GLOBIOM with two methods:
  - All scenarios the ones after the other (can take some time)
  - Scenarios can be run separately with an argument to the 6_scenario.gms file (nsim) → Allow for parallelized computing

- Scenario listing can be used to generate a listing of scenario names in case of large number of scenarios and to know their identifier

- Listing can be generated alone using the header command writescen_only

Model scenario assumptions

- Three key files:
  - Additional equations/constraints definition:
    - model_scen.gms
  - Modification of model parameters for a given time period
    - define_scenario.gms
  - **Initialisation** of parameters for define_scenario.gms
    - define_base.gms

Additional model equations

- Model_scen.gms

```
EQUATIONS
OBJECTIVE_EQU2 Updated objective function to be used for scenarios

EXG_FOOD_DEMAND2_EQU(ANYREGION,NUTR_SOURCE) Exogenous food demand constraint equation (aggregated constraint)
EXG_FOOD_DEMDET_EQU(ANYREGION,ALLPRODUCT)   Exogenous food demand constraint equation (product level constraint)
EXG_WOOD_DEMAND_EQU(ANYREGION,PRODUCT)      Exogeneous wood demand constraint in 1000 m3
AFFORG4M_REG_EQU(ANYREGION)                 Afforestation equation
LUC_GHG_EQU(ANYREGION,ACCOUNT)              Land use change emissions
MSG_ENGSCEN_EQU(ANYREGION,MSG_AGGENG)       MESSAGE model biomass demand equation constraint (aggregated constraint)
FUELWOOD_EQU(GGIREGION)                     Fuel wood demand for bioenergy constraint
MSG_SOLIDBIODET_EQU(GGIREGION,ALLPRODUCT)   MESSAGE model biomass demand equation constraint (product level constraint)
;
```

Initialisation of parameters

- define_base.gms
  - Initialisation file for the scenarios definition
  - Contains the following section for parameter initialisation
    1) Technologies crops and livestock
    2) Food scenarios
    3) Wood demand and forestry sector
    4) Land use initialisation
    5) Afforestation
    6) Bioenergy and solid biomass demand
    7) Trade assumptions

Scenario parameter updates

- define_scenario.gms
  - This file sets up the scenario dynamic sets and parameters value depending on the scenario assumptions
  - Large part of the scenarios are derived from the SSP assumptions used for GLOBIOM
    0) Population
    1) Technical progress for crops and livestock sector
    2) Losses and waste scenarios
    3) Food demand scenarioss
    4) Land use change scenario
    5) Afforestation scenario
    6) Wood sector scenarios
    7) Biofuels and bioenergy scenarios
    8) Trade policy scenarios
    9) Climate policy scenarios

Scenario elements in GLOBIOM

- **Demographics:**

Population growth, Fertility, Mortality, Migration, Level and type of urbanization, Education

- **Economy and lifestyles:**

Growth, Structure, Inequality, International trade, Globalization, Consumption, Diets

- **Policies and institutions:**

International cooperation, Environmental policy, Institutions

- **Technology:**

Development, Transfer, Carbon intensity, Energy Intensity

- **Environment and natural resources:**

Fossil constraints, Environment, Agriculture

Shared Socio-economic Pathways (SSPs)

SSP2: Middle of the Road

General

- medium economic growth overall
- slow convergence between LIC and HIC
- **inequality remains high**
- population growth moderate – high in some LICs
- **reducing resource intensity** (slower than SSP1)
- **reducing fossil fuel dependency** (slower than SSP1)
- **uneven planned urbanization in LIC**
- world economy fragmented – **reduced flows of trade and technologies**
- **rapid technological change in HIC** but not shared with LIC

Agriculture

- **trade barriers in agricultural markets remain**

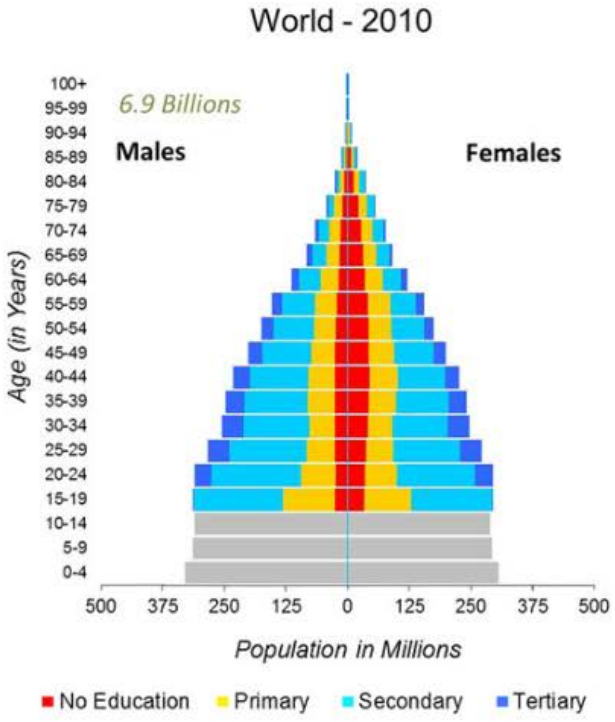
GLOBIOM SSP scenario elements

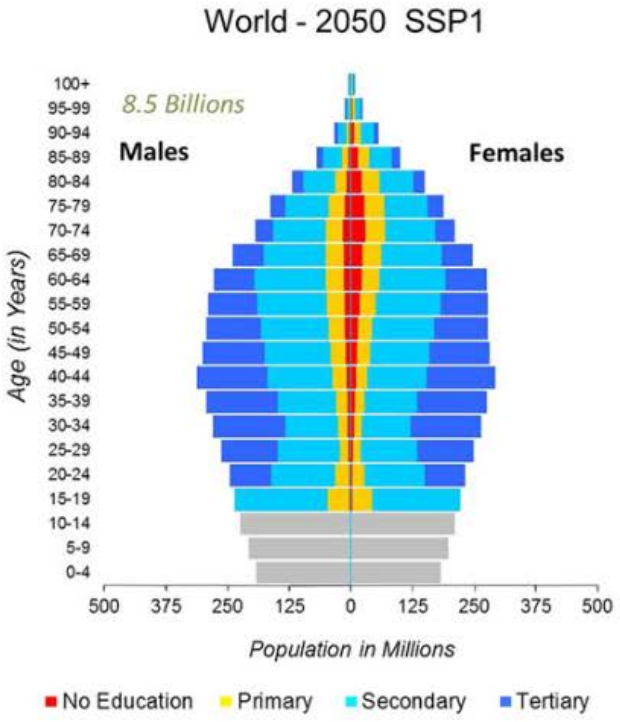
Agriculture and land use			
	SSP1	**SSP2**	**SSP3**
Net deforestation	Afforestation (*No net deforestation by 2050, +3% forest area by 2100 compared to 2010*)	Deforestation/Afforestation (Forest loss of 1% by 2050, back to 2010 area by 2100)	Deforestation (*Net forest loss of 3% by 2050 and 6% by 2100 compared to 2010*)
Land productivity growth			
Crops: Yields	High yield growth (*Annual yield growth from 0.51% p.a. in the North to 0.66% in the South*)	Moderate yield growth (*Annual yield growth from 0.46% p.a. in the North to 0.60% in the South*)	Slow yield growth (*Annual yield growth from 0.35% p.a. in the North to 0.35% in the South*)
Crops: Input intensity	Low intensity (*Elasticity of variable inputs incl. fertilizer use wrt technological change: 0.75*)	Medium intensity (*Elasticity of variable inputs incl. fertilizer use wrt technological change: 1.00*)	High intensity (*Elasticity of variable inputs incl. fertilizer use wrt technological change: 1.25*)
Livestock: Feed conversion efficiency	Enhanced efficiency growth (*Annual feed conversion efficiency change from 0.10% in the North to 0.26% in the South*)	Moderate efficiency growth (*Annual feed conversion efficiency change from 0.10% in the North to 0.24% in the South*)	Slow efficiency growth (*Annual feed conversion efficiency change from 0.07% in the North to 0.14% in the South*)
Livestock: Endogenous productivity growth	High livestock systems transition (*Annually, up to 5% of livestock production systems can be converted to an alternative system or the activity can be abandoned*)	Medium livestock systems transition (*Annually, up to 2.5% of livestock production systems can be converted to an alternative system or the activity can be abandoned*)	Low livestock systems transition (*No adjustment in the ruminant production system structure*)
Environmental impact of food consumption			
Food demand	Slow consumption growth and more sustainable and healthy diets (*Calorie consumption per capita growing – North : 1%, South: 16%. Livestock product share decreases in North by one third but increases in South, leading to a stable share of 15% globally*)	Moderate consumption growth and increasing share of livestock products in the diet (*Calorie consumption per capita growing by 11% in the North and 22% in the South. Livestock product share in the diet growing from 15% to 18%.*)	Substantial consumption growth but lagging demand for animal proteins in diet in the South (*Calorie consumption per capita growing by 5% in the North and 15% in the South. Livestock product share stays at 15%.*)
Losses & Wastes	Fast reduction of losses & wastes (L&W) (*L&W in the processing chains reduced from 12% to 7% in the Oilseed and Pulses sector and from 7% to 2.5% in the dairy sector over 2000 and 2050*)	Medium reduction of losses & wastes (L&W) (*L&W in the processing chains reduced from 12% to 7.5% in the Oilseed and Pulses sector and from 7% to 3% in the dairy sector over 2000 and 2050*)	Slow reduction of losses & wastes (L&W) (*L&W in the processing chains reduced from 12% to 9% in the Oilseed and Pulses sector and from 7% to 4.5% in the dairy sector over 2000 and 2050*)

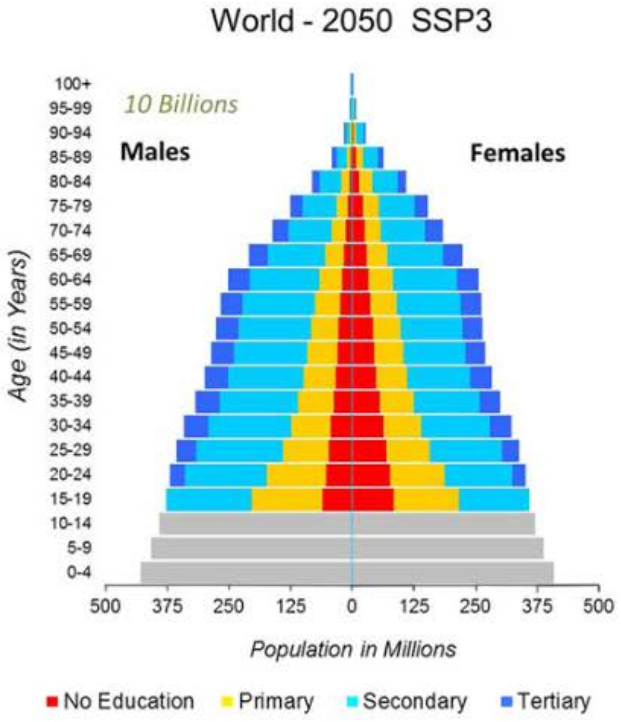
SSPs: Quantitative elements

- MACROSCEN_DATA

Population

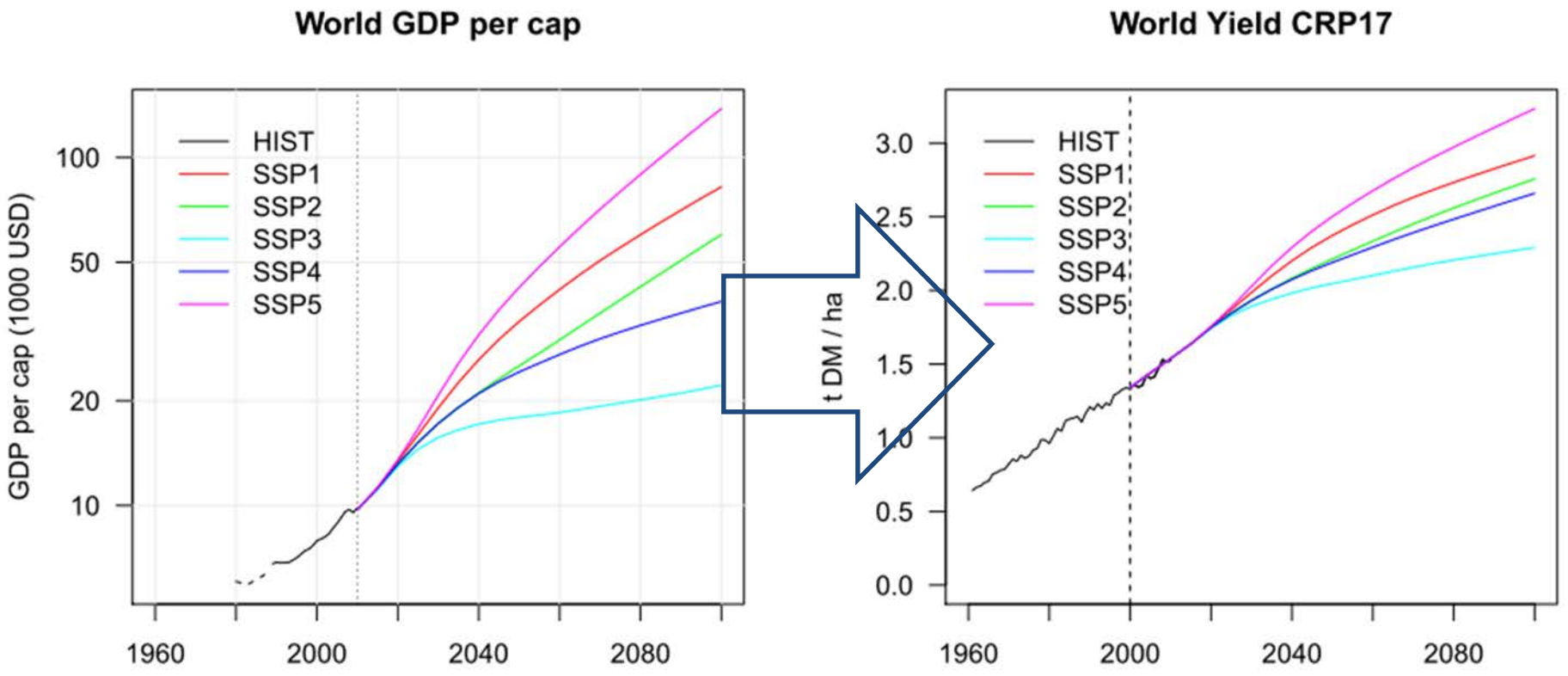






(KC & Lutz, 2014)

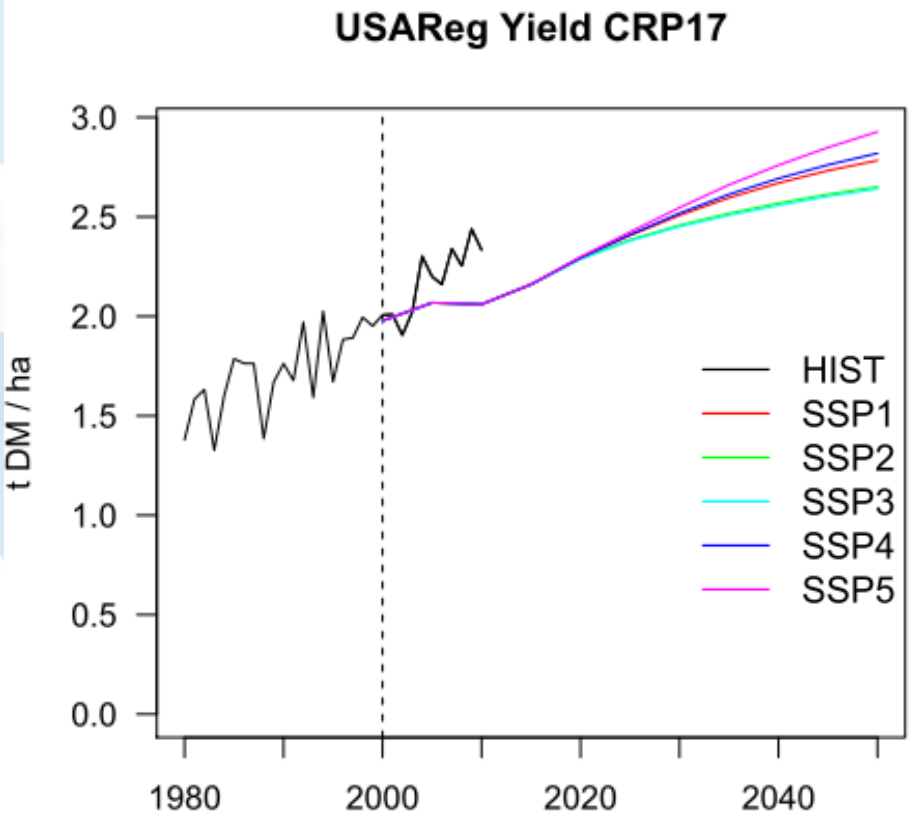
Crop yield development in GLOBIOM

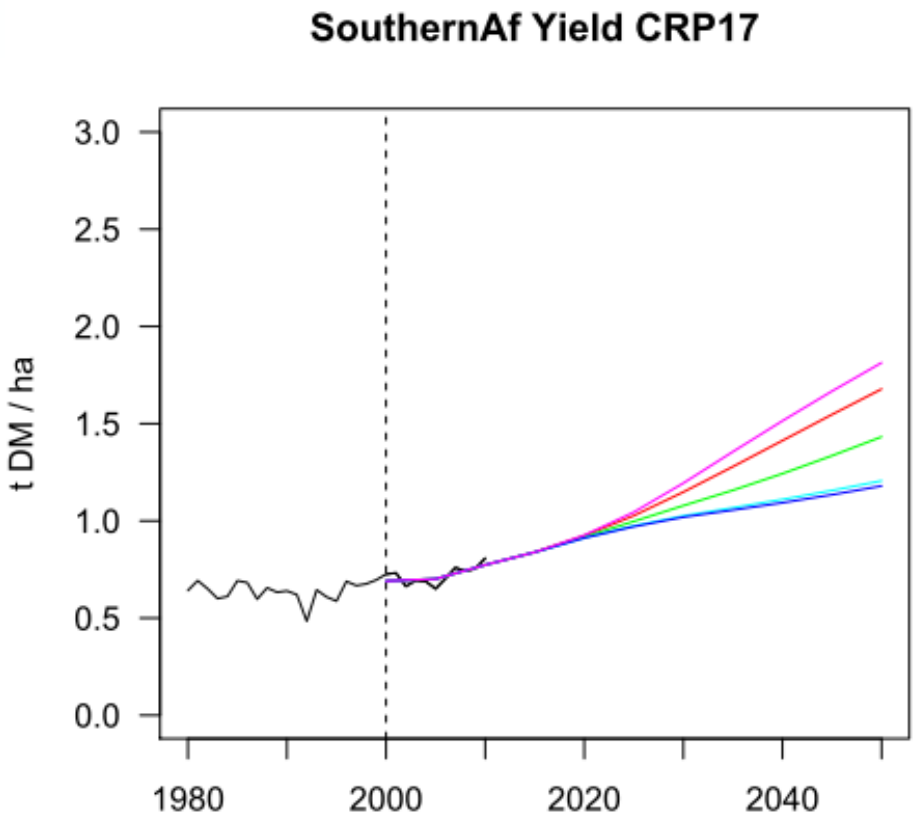


Crop yield developments projected as a function of GDP per capita
based on econometric estimation on 1980-2010, and 4 income group clusters.

Crop yield development in GLOBIOM

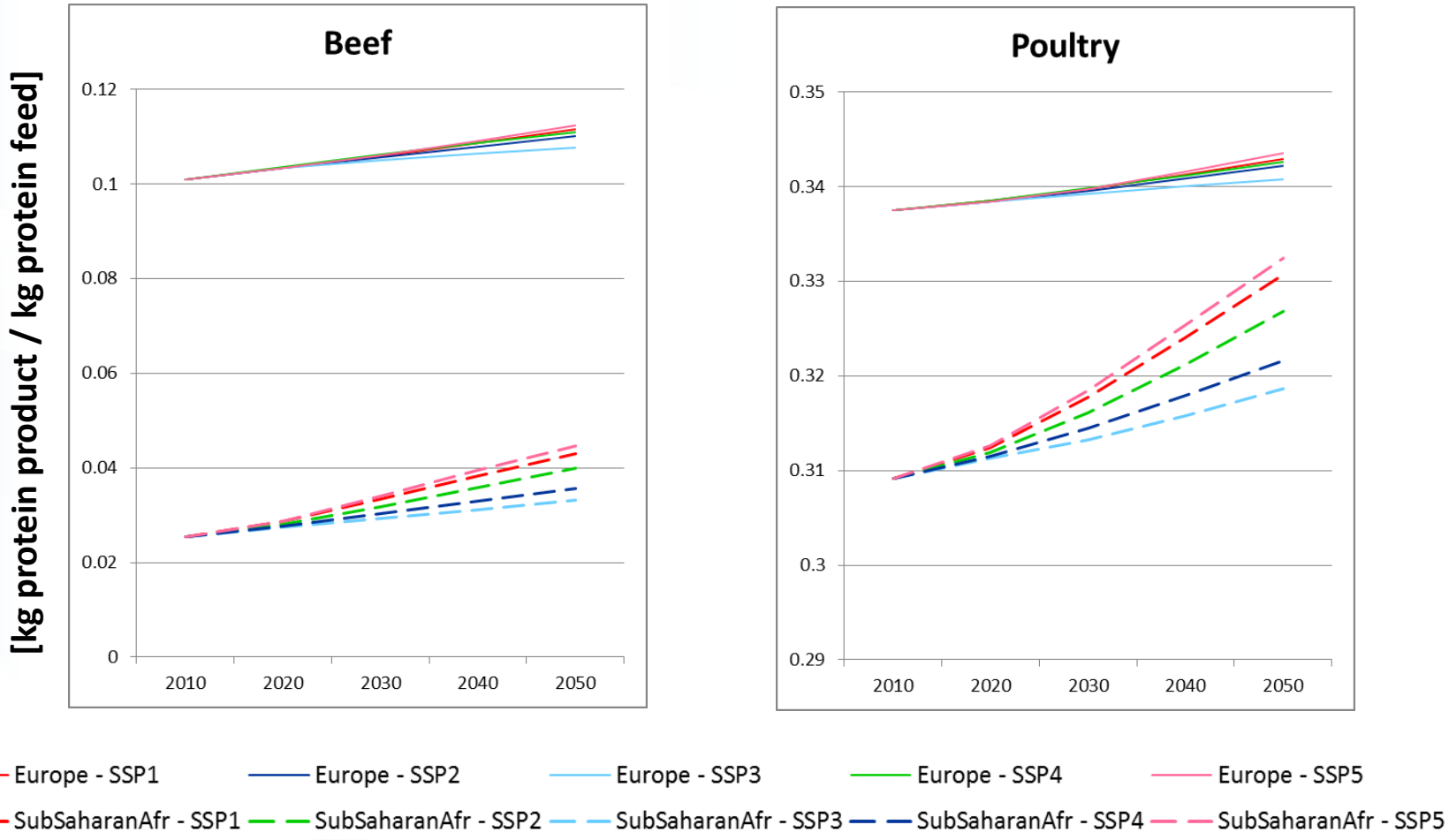
- YLD_SSP_STAT and YIELD_X_ELA





Feed conversion efficiencies across SSPs

- GrowthRel2000_AnimalChange_Data

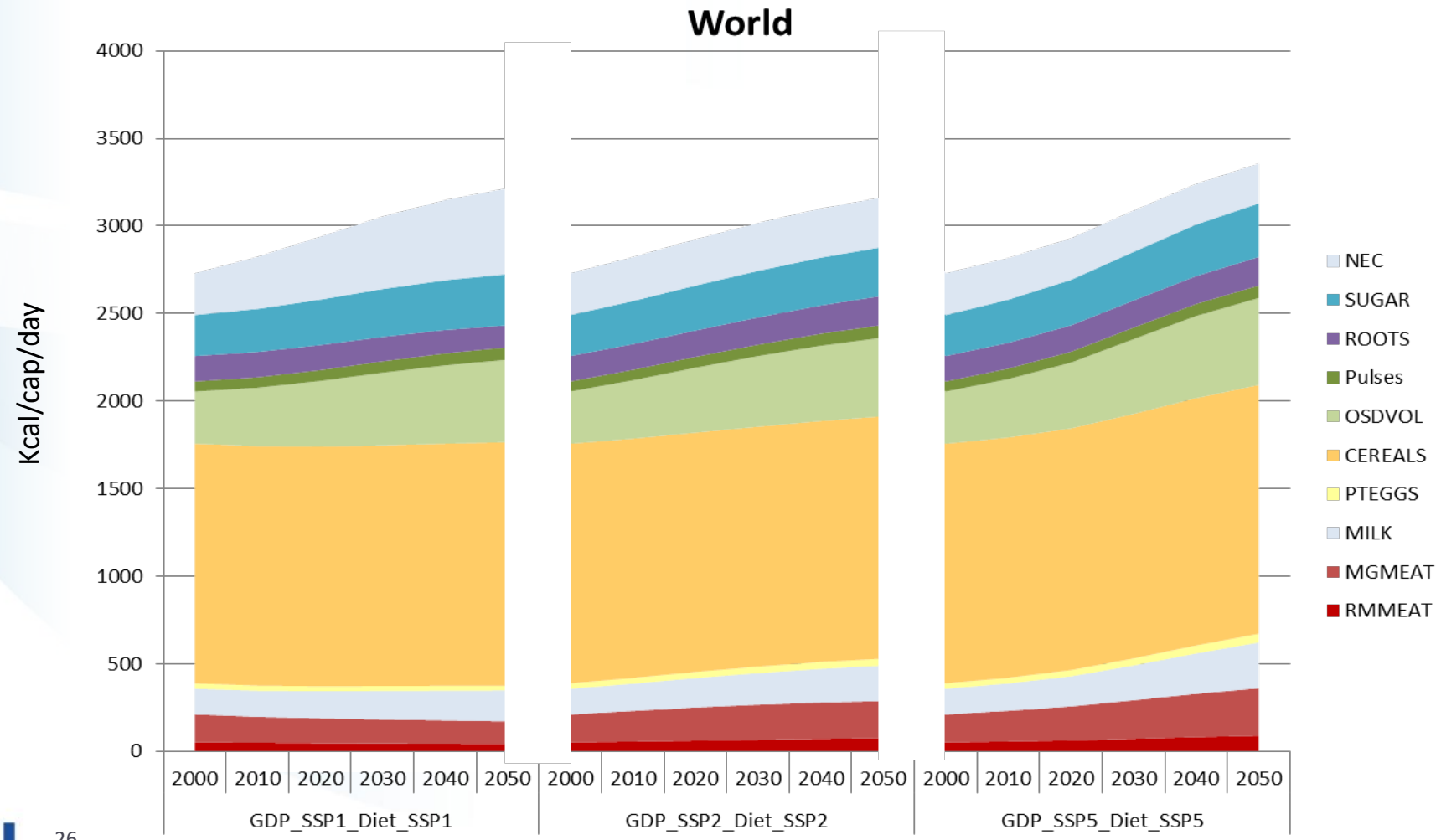


Exemple of scenarios input for diets

- How do we do it today to explore potential impacts:
  - Business as usual (SSP2)
    - FAO trends based on linear extrapolation
  - Sustainable diets (SSP1)
    - Sustainable diets targetting proteins and energy intake taking into account initial level of consumption in each product
  - Western diets (SSP5):
    - Countries converge to diets of USA & Europe composition

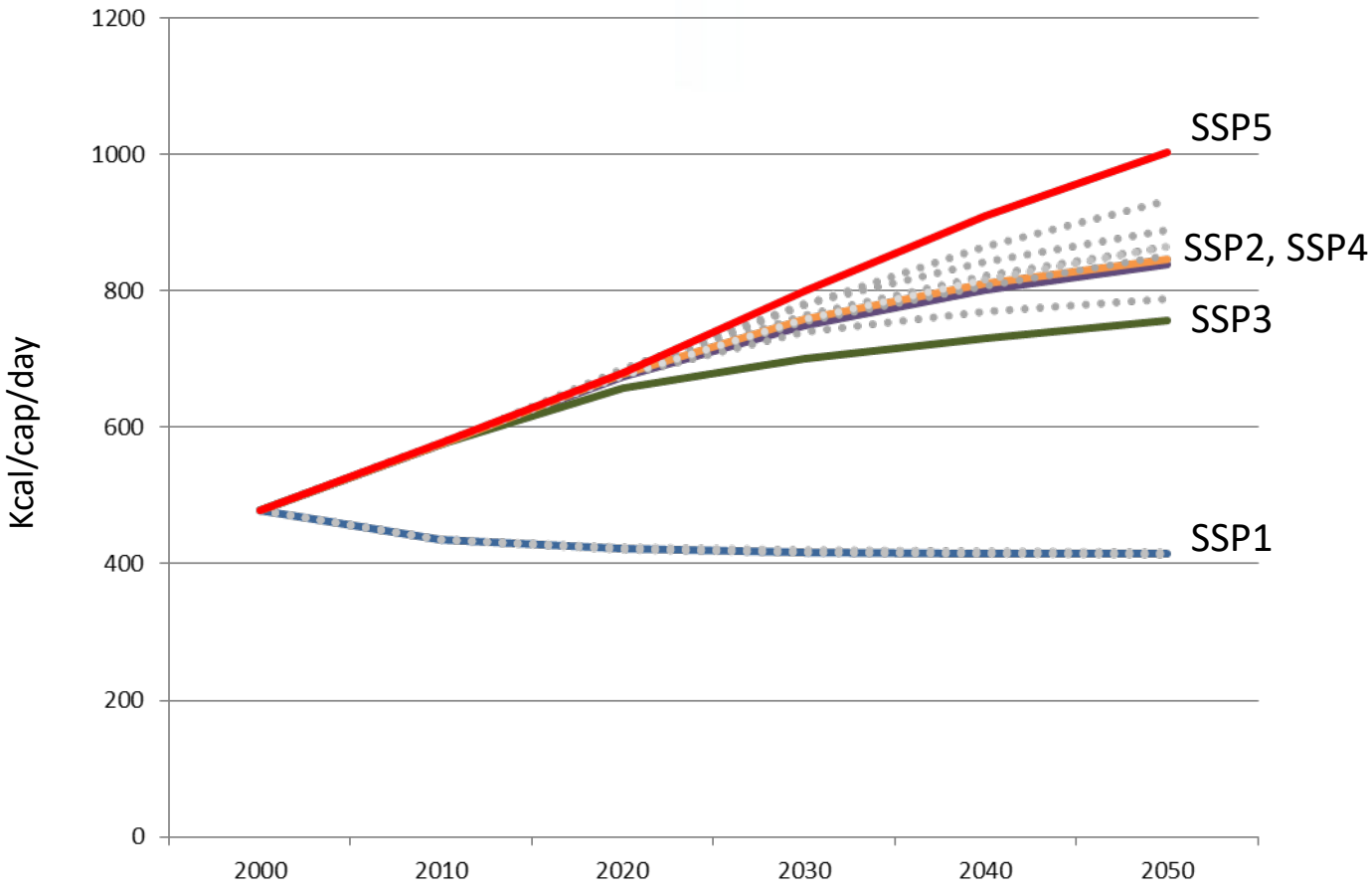
Quantification of diet preferences

- EXODEM_G / EXODEMCAP_G



China – Animal products food consumption

- EXODEM_G / EXODEMCAP_G



Losses and wastes across the supply chain

- GrowthRel2000_LossWaste_Data

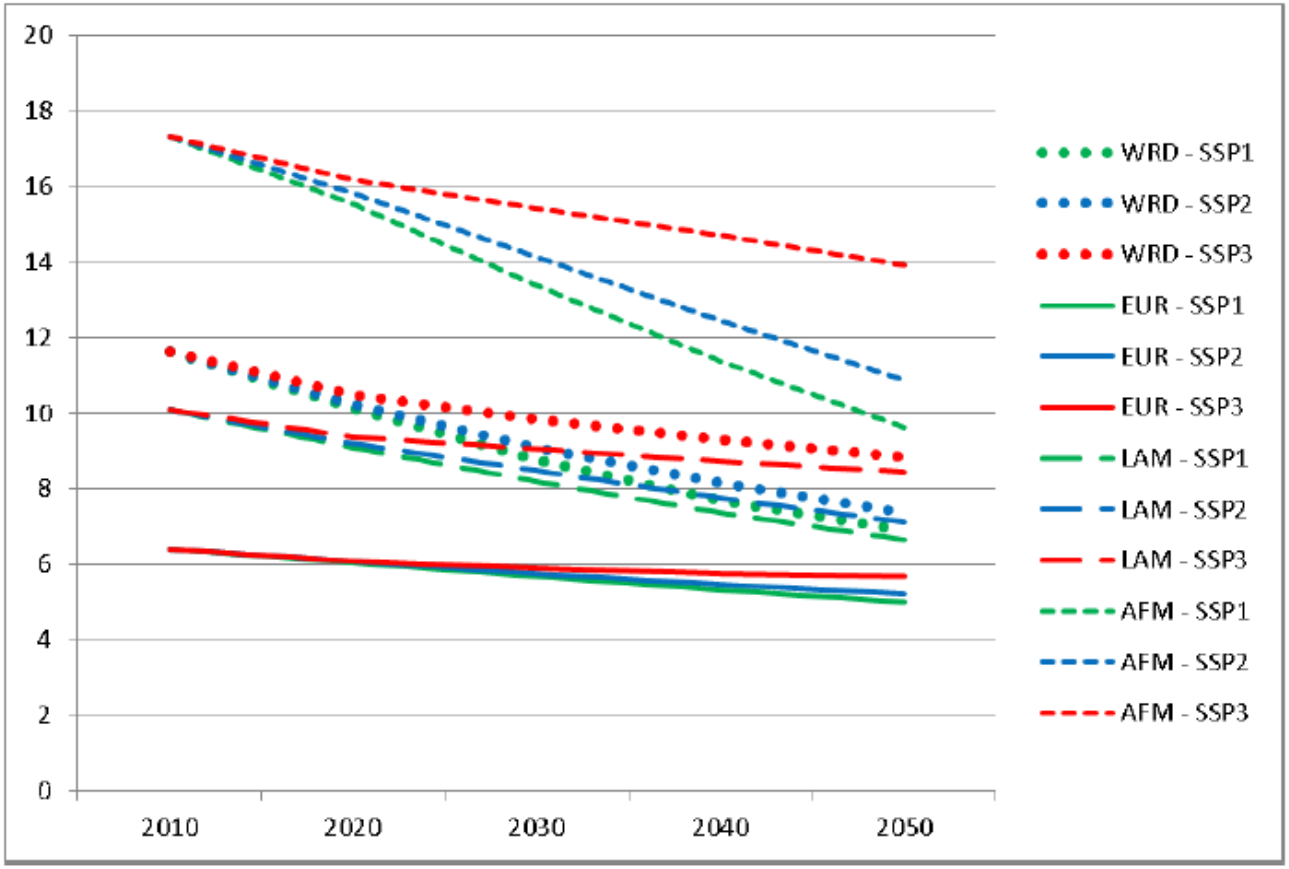


Figure 8: Losses and wastes development in the Oilseeds&Pulses sector [%].

Other scenario elements

- Afforestation levels (from G4M model)
  - Different scenarios available in **G4Mbase_Data**
- 1st generation biofuel scenario
  - Projections used from AgMIP (Lotze-Campen et al., 2013)
  - **BFL_CROP_1G** and **BFL_CONS_1G**
- Other biomass for bioenergy
  - MESSAGE SSP scenarios (IIASA SSP database)
  - **SolidTotal_MSGSCEN_Data** / **SolidBySource_MSGSCEN_Data**
- Trade
  - Trade cost /2 or x2 depending on the storyline.
    Assumptions in **Trade_Scen_Data**

A few other important files

- Cost reinitialization files:
  - Recursive_luc.gms
  - Recursive_trade.gms

These files handle the dynamic recursivity of the model

- Tuple file group
  - Calc_tuple.gms
  - Calc_moretuple.gms
  - Calc_constants.gms (for demand parameters)

The LOOP section – engine of the model

- The LOOP section manages the iteration of the model
  - Across the scenarios definitions (3 first statements)
  - Across the time-steps
    - LOOP(ScenYear, …

- Within the LOOP, dynamic sets switches are set to a unique value defined by the mappings
- The define_scenario.gms file updates the scenario parameter values to each of the set values (scenario, mapping, years)

First results?

- Find the objective value of GLOBIOM in 2030
- What are the population projection assumption of GLOBIOM for the world in 2030? And for GDP?
- What is the assumption for increase in rice yield in China by 2030? (technical change)
- By how much should the rice demand in China increase by 2030?

Reading the model output

Different ways to read the model output

- All scenarios are run after the 6_scenarios.gms stage
- Direct reading of results in the .lst file or the .gdx file
  - A number of variables are available through the rep_compareXXX.gms files
  - Parameters can be found in the gdx as XXX_Compare
- However, these results are usually in native GLOBIOM format and cannot be easily interpreted
- Solution: post-treatment of results with the 7_ouput.gms file
- Also possible to use other tools to produce maps (e.g. R script), but rather used for regional versions

Extracting GLOBIOM results

What is the 7_output.gms doing?

- Two main files:
  - 7a_output_results.gms

  This file “translates” all the GLOBIOM results in a standardized output indicator **“OUTPUT”**

  - 7b_output.gms

  This file aggregates all the results according to a predefined list of products and regions

  - Output file name to be declared in the 0_executebatch
  - One argument CSV=1 to extract the results as CSV otherwise, output as GDX

  - Let’s give it a try… (should run in 1 min)

Looking into the GDX results file

- Different set and parameters key to interpret your results
- List of indicator definitions: VAR_ID
- List of region and items for aggregation:
  - REGION_AG and ITEM_AG
- List of mappings
- Other important sets

The OUTPUT parameters

- Four levels of reading
  - OUTPUT all regions and items
  - OUTPUT_AG all aggregates together
  - OUTPUT_REG regional aggregate only
  - OUTPUT_ITEMS item aggregate only

- List of indicators with their units

Indicators available: Production

- Crop production
  - AREA Area cultivated [1000 ha]
  - HARV Area harvested [1000 ha]
  - ARRF Area cultivated - rainfed [1000 ha]
  - ARIR Area cultivated - irrigated [1000 ha]
  - YEXO Exogenous crop yield [t/ha]
  - YILD Crop yield, harvested [t/ha]
  - YILM Crop yield, planted [t/ha]
  - YIRF Crop yield, harvested - rainfed [t/ha]
  - YIIR Crop yield, harvested - irrigated [t/ha]

- Livestock production
  - ANIM Animal number [1000 TLU]
  - FEEF Feed productivity (endogenous) [kg prot/t dm feed]
  - FEXO Exogenous feed productivity trend [kg prot/t dm feed]
  - LYLD Land productivity (endogenous) [kg prot/ha]
  - LYXO Exogenous land productivity trend [kg prot/ha]
  - ANFD Animal feed intake [1000 t dm]

Indicators available: Markets

- Macroeconomics
  - POPT Total population [Mln pers]
  - GDPT Total GDP [Bln USD 2005]
  - QBFL Mandated bioenergy [PJ, %]

- Market balances
  - PROD Production [1000 t, PJ]
  - CONS Domestic use [1000 t]
  - IMPO Imports [1000 t]
  - EXPO Exports [1000 t]
  - NETT Net trade [1000 t]
  - NTMS Net trade share in market volume [%]

  - FOOD Food use [1000 t]
  - FEED Feed use [1000 t]
  - BIOU Biofuel use [1000 t]
  - OTHU Other use [1000 t]

  - XPRP Real producer price [USD/t or USD/GJ]
  - XPRI Real producer price index [USD/t or USD/GJ] (aggregated as Laspeyres)

Indicators available: Impacts

- Environment
  - LAND Land cover [Mha]
  - LRNT Land rent [USD/ha]
  - WATR Water for irrigation [km3]
  - FRTN Fertiliser N [1000 t]
  - FRTP Fertiliser P [1000 t]
  - EMIS Emissions from agriculture [MtCO2eq]
  - ECO2 CO2 emissions [MtCO2eq]
  - ECH4 CH4 emissions [MtCO2eq]
  - EN2O N2O emissions [MtCO2eq]
  - ENCO Non CO2 emissions [MtCO2eq]
- Food security
  - XCPI Real consumer price index [USD/t or USD/GJ or USD/1000 kcal] (aggregated as Laspeyres)
  - CALO p.c. calory availability [kcal/cap/d]
  - CALT p.c. calory diet target [kcal/cap/d]

Moving into practice

First exercise: SSP2 results

- What is the future demand for food in 2050?
  - What is the role of price change in the demand to 2050
- How much does feed and other uses increase by 2050

- What is the impact of demand change on land use?
  - Cropland, grassland, forest
- What are the development of GHG emissions?
  - Agriculture
  - Land use change

- What is the story told by the model for the future of your region?

First exercise on baseline

Variable to search	Base value 2010	Value 2050	% Difference
Population change			
GDP per capita			
Food demand per capita (kcal)			
Food consumption (total)			
Feed consumption			
Other consumption			
Net trade			
Total production			
Average crop yield			
Cropland			
Grassland			
Natural area			
GHG emissions agriculture			
GHG emissions LUC			

First exercise on baseline: answers (World)

Variable to search	Base 2010	Value 2050	% Difference
Population change [million]	6,829	9,077	33%
GDP per capita [USD per cap]	7,358	15,278	108%
Food demand per capita (kcal/cap/d)	2,871	3,188	11%
Food consumption [1000 t]	3,741,195	5,687,400	52%
Feed consumption [1000 t]	1,487,183	3,213,120	116%
Other consumption[1000 t]	1,372,026	2,692,952	96%
Net trade (not relevant)			
Total production [1000 t]	6,600,404	11,593,472	76%
Average crop yield [dm t/ha]	3.32	4.70	42%
Cropland [1000 ha]	947,903	1,121,832	18%
Grassland [1000 ha]	1,721,526	1,967,388	14%
Natural area [1000 ha]	6,690,796	6,271,005	-6%
GHG emissions agriculture [$MtCO_2eq/yr$]	3,084	4,058	32%
GHG emissions LUC [$MtCO_2eq/yr$]	1,561	1,402	-10%

Second exercise

- Adding a few indicators to the output.gdx

- Emission intensity of production:
  - EMIT: emission intensity [kg CO2e / kg t dm (or CW)]
    - Crops
    - Livestock
- Food security:
  - IMDR: import dependency ratio for cereals (%)
    - Net imports of cereals (zero if negative) compared to production

- Emission intensity of diet
  - EMFD: emission intensity (kCO2e / kcal)

Second exercise correction

- See dropbox

Comparing baselines (RelDif 2050)

Variable to search	SSP1	SSP2	SSP3
Population change			
GDP per capita			
Food demand per capita (kcal)			
Food consumption (total)			
Feed consumption			
Other consumption			
Net trade			
Total production			
Average crop yield			
Cropland			
Grassland			
Natural area			
GHG emissions agriculture			
GHG emissions LUC			