**THE DRAWDOWN YIELD MODEL**

Notes for Chad:

* Every time I open the model it says there are circular references. However I have tracked them all down and the ones it is objecting to are not in fact circular to my knowledge. I’ll have to leave this to your expertise, but we certainly don’t want that happening the moment someone downloads it off of the web.
* There are a few highlighted areas that have questions for you.

**INTRODUCTION and PURPOSE**

The Drawdown Yield Model is an integration model that connects solutions across sectors including food demand, food production, and land use. It was created to answer questions about the complex interactions of land use and the food system. The central question is:

* **To what degree does the combined impact of Drawdown’s solutions meet food demand during the period 2014-2050 without the need for land use change (conversion of forest and grassland to cropland) and the high associated emissions?**

One set of solutions reduce food demand, or at least slow the growth in food demand (see Table 1). A second set of agricultural production solutions often, but not always, increase per-hectare yields (see Table 2). A third set of solutions are implemented on grassland and thus reduce grazing area (see Table 3). Finally, surplus grain not needed for other purposes is the limit for production in the *bioplastic* solution (see Table 4).

**Table 1. Demand-Side Solutions Integrated in the Yield Model**

| **Cluster** | **Solutions** |
| --- | --- |
| Women and girls | *Family planning, educating girls* |
| Food system | *Plant-based diet, food waste reduction* |

**Table 2. Supply-Side Solutions Integrated in the Yield Model**

| **Cluster** | **Solutions** |
| --- | --- |
| Annual crop production | *Conservation agriculture, regenerative agriculture, improved rice, System of Rice Intensification, tree intercropping* |
| Perennial crop production | *Multistrata agroforestry, tropical tree staples* |
| Grazing systems | *Managed grazing, silvopasture* |
| General agriculture | *Women smallholders, biochar, farmland restoration* |

**Table 3. Land Use Solutions Integrated in the Yield Model**

| **Cluster** | **Solutions** |
| --- | --- |
| Biomass and timber production | *Afforestation, bamboo, perennial bioenergy* |

**Table 4. Materials Solutions Integrated in the Yield Model**

| **Cluster** | **Solutions** |
| --- | --- |
| Materials | *Bioplastic* |

To see if food demand can be met, the following questions must be answered.

* **What is the global food *demand* for years 2014-2050?** This must include reduced population growth trends due to the *family planning* and *educating girls* solutions, and changes in food demand via the *plant-rich diet* and *reduced food waste* solutions.
* **What is the global food *supply* for years 2014-2050?** Many of Drawdown’s supply-side agricultural production solutions increase per-hectare yields, while some reduce them. Some conventional cropping and grazing continues but is increasingly displaced as adoption increases. Meanwhile some non-food production solutions (like afforestation) are implemented on grassland, reducing global grazing area.

Five scenarios are modeled from 2014-2050, including the *Plausible, Drawdown,* and *Optimum* Scenarios, as well as business-as-usual scenarios both with (Reference 2) and without the population impact of Family Planning and Educating Girls (Reference 1).

The following questions must also be answered scenario-by-scenario:

* **Does food supply meet demand for this scenario?**
* **If food demand is not met, how much land use change is required and what emissions are associated?**
* **If food supply exceeds demand, how much surplus food is available for use as feedstock for the Bioplastic solution?**
* **What percentage of emissions reduction from avoided land use change can be credited to Family Planning, Educating Girls, Plant-Rich Diet, and Reduced Food Waste respectively?**

**Notes.**

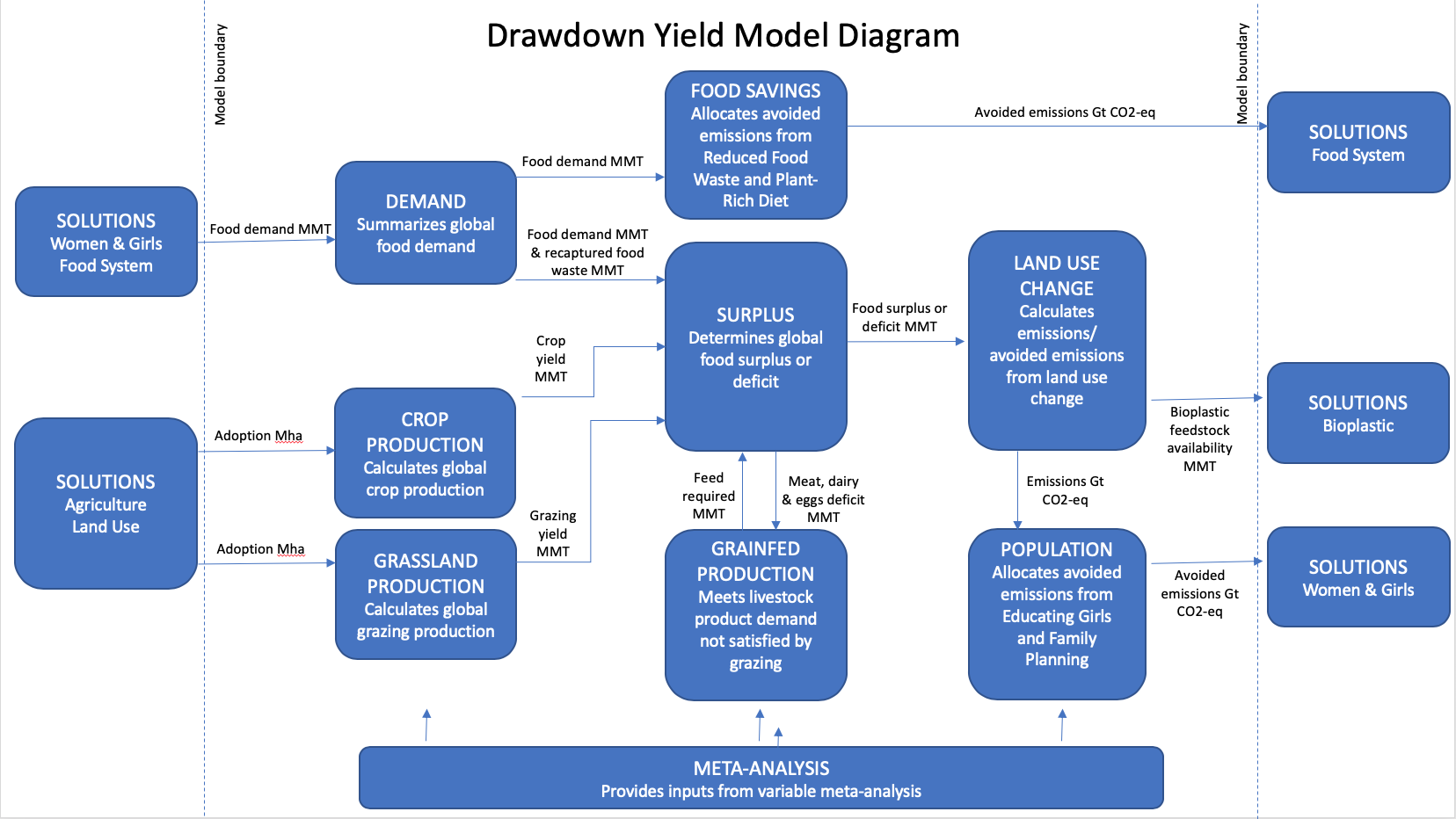
* Some sheets display both the Reference 1 and Reference 2 Cases, while others combine them. They are separated in cases of demand, in order to distinguish the impact of population solutions, while they are combined for supply solutions as they are both “business as usual” with no implementation of new food production solutions.
* The model tracks data for milk, cream, and butter and ghee, but not other dairy products like yoghurt and cheese. This is how FAO tracks the data – all cheese and yoghurt is converted back to milk equivalent, and thus that is how it is tracked here.
* The mode does not include fish. It is not because: a) roughly half of all fish and seafood is wild-caught, and thus requires neither pastureland nor cropland as a source of feed, and b) much aquacultured livestock is either not fed (bivalves like mollusks, some carp) or fed “bycatch” (undesirable ocean fish) and thus, again, does not require pasture or cropland and has little impact on the issues this model is concerned with. However, an increasing amount of aquaculture uses grain from cropland and thus fish and seafood should be added to future editions of this model.

**STRUCTURE**

The Yield model brings in data from demand-side solutions and uses it to calculate food demand 2014-2050. Data on adoption and yield impacts of supply-side solutions, along with adoption of land use solutions on grassland, is used to calculate food production 2014-2050 on from cropland and grassland. This model assumes that all demand for livestock products will be met, and whatever grain is required to do so will be produced, and that whatever land that must be cleared to produce that grain will be cleared and planted. Emissions from land use change are accounted for, and avoided land use change emissions are allocated to demand reduction solutions.If there is a surplus of grain, it is used to provide feedstock for Drawdown’s *bioplastic* solution.

Five scenarios are modeled, year by year from 2014-2050. The sheets are clustered by scenario and include: demand, crops, grazing, surplus, grainfed, land use change, food savings, and scenarios (a summary). Note that the model imports data from the BIOSEQ and AEZ models.

**Figure 1. Structure of the Yield Model**

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**For each of five scenarios, year by year 2014-2050:**

* **Demand** for plant-based and livestock-based food incorporating population, diet change, and food waste reduction.
* **Crops** plugs in adoption in Mha of land solutions based on AEZ model allocation, plugged into individual models. These are used to generate global crop yield.
* **Grazing** calculates total production of meat and dairy on global grasslands, including impact of grazing and non-grazing solutions on grassland.
* **Surplus** matches crop and grazing livestock production with demand, incorporating reduced needs due to re-captured food waste. It determines livestock food demand that is not met by grazing, and exports that information to the Grainfed sheets. It imports total grain livestock feed demand from Grainfed to determine total surplus or deficit of “grain”.
* **Grainfed** determines total grain required to meet remaining unmet need for livestock products.
* **Land use change** determines Mha that must be cleared to supply grain deficit, if there is one, and calculates associated emissions. In case of surplus, calculates total bioplastic production potential from use of surplus “grain”.
* **Food Savings** determines total savings in MMT due to food waste reduction vs. diet change.
* **Population** summarizes emissions and reduced emissions from the 5 scenarios and calculates the impact of *family planning* and *educating girls*.

**Key Terms**

**Bovine –** cattle and water buffalo

**CO2-eq** – carbon dioxide equivalent, emissions with the same climate forcing impact as carbon dioxide even if including methane, nitrous oxide or other greenhouse gases.

**Dedicated meat animals** – animals which are raised with meat as their primary purpose, including a) animals only raised for meat like pigs, and b) animals which can be raised for dairy or egg production but in this case only for meat, as in beef steers and broiler chickens.

**Dry matter –** Here, the annual production of grasses and other vegetation on grazing land on a dry weight basis.

**Grain –** All crops (the great majority of which are grains)

**Grainfed –** Livestock which are fed grain, including monogastrics like pigs and chickens which mostly eat grain, and ruminants like cows which can either graze or consume grain.  
**Gt** – gigaton, one billion metric tons.

**Live weight –** The total weight of a living livestock animal.

**MMT –** million metric tons.

**Monogastric** – Livestock species lacking a rumen, and thus unable to subsist on grazing alone. For example, pigs and chickens.

**Offal –** edible organ meat.

**Pigmeat –** pork.

**Ruminant –** Livestock with a rumen, enabling them to subsist on grazing alone. For example, cows and sheep.

**Yield modifier –** factor by which implementation of a agricultural solution increases or decreases the standard crop or dry matter pasture yield.

**MAIN CONTROLS**

The main controls sheet summarizes results from the model.

**Cumulative Results 2020-2050**

Line 4 imports cumulative demand 2014-2050 in MMT from the Demand sheet AA for all five scenarios.

Line 5 imports cumulative grain deficit or surplus 2014-2050 in MMT from the Surplus sheet Column I for all five scenarios.

Line 6 imports cumulative Mha of land use change 2014-2050 required to meet demand from the Land Use Change sheet Column E.

Line 7 imports cumulative emissions from land use change 2014-2050 in Gt CO2-eq from the Land Use Change sheet column G.

Line 8 imports cumulative emissions reduction from plant-rich diet 2014-2050 in Gt CO2-eq/yr from the Food Savings sheet Column R.

Line 9 imports cumulative emissions reduction from food waste reduction 2014-2050 in Gt CO2-eq/yr from the Food Savings sheet Column R.

Line 10 imports MMT cumulative bioplastic production from surplus grain 2014-2050 from the Land Use Change sheet Column J.

**Results for 2050**

Line 13 imports total MMT yearly food demand in 2050 from the Demand Sheet Column AA.

Line 14 imports total MMT yearly grain deficit or surplus in 2050 from the Surplus Sheet Column I.

Line 15 imports total Mha yearly land use change in 2050 by importing data from the Land Use Change sheet Column E and using the formula:

Line 16 imports total Gt CO2-eq yearly emissions from land use change in 2050 by importing data from the Land Use Change sheet Column G and using the formula:

Line 17 imports total yearly production of bioplastic in MMT in 2050 from the Land Use Change sheet Column J.

**Results for Family Planning and Educating Girls**

Line 20 calculates the cumulative reduced emissions 2014-2050 from *family planning* and *educating girls* using the formula:

Line 21 calculates the yearly reduction in emissions from land use change from *family planning* and *educating girls* in 2050 using the formula:

**POPULATION**

The Population sheet imports data from the Land Use Change sheet and shows land use change emissions for each solution. This is used to calculate the emissions reduction from family planning and educating girls.

**Reference One Case**

Column D imports cumulative emissions 2014-2050 from land use change from the Land Use Change sheet column G. Column E calculates the annual emissions from land use change using the formula:

**Reference Two Case**

Column J imports cumulative emissions 2014-2050 from land use change from the Land Use Change sheet column G. Column K calculates the annual emissions from land use change using the formula:

Column L calculates reduction in land use change emissions using the formula:

**FOOD SAVINGS**

This sheet imports grain deficits or surplus from the Demand sheet and allocates avoided emissions impacts to the *food waste reduction* and *plant-rich diet* solutions.

***Plausible* Scenario**

Row 5, Columns B through M import cumulative food demand from 2014-2050 in MMT from the Demand Sheet Reference Case 2. Cell M5 calculates the total using the formula:

Row 6, Columns B through M import cumulative food demand from 2014-2050 in MMT from the Demand Sheet *Plausible*  Scenario. Cell M6 calculates the total using the formula:

Row 7 calculates the savings in MMT from *plant-rich diet* using the formula:

Cell M7 calculates the total using the formula:

Cell N7 calculates the percent reduction of demand from Reference Case 2 to the *Plausible* Scenariofrom *plant-rich diet* using the formula:

Cell O7 calculates the percentage of demand reduction that is due to *plant-rich diet* using the formula:

Row 8, Columns B through M import cumulative food waste reduction from 2014-2050 in MMT from the Demand Sheet *Plausible* Scenario. Cell M8 calculates the total using the formula:

Cell N8 calculates the percent reduction of demand in the *Plausible* Scenariofrom *reduced food waste* using the formula:

Cell O8 calculates the percentage of demand reduction that is due to *food waste reduction* using the formula:

Cell R4 calculates the avoided emissions from land use change in the *Plausible* Scenario in Gt CO2-eq 2014-2050 by importing the cumulative emissions from land use change in Reference Case 2 and the *Plausible* Scenario from the Land Use Change sheet using the formula:

Cell R5 calculates the total avoided land use change emissions due to *food waste reduction* in Gt CO2-eq 2014-2050 using the formula:

Cell R6 calculates the total avoided land use change emissions due to *plant-rich diet* in Gt CO2-eq 2014-2050 using the formula:

***Drawdown* Scenario**

Row 12, Columns B through M import cumulative food demand from 2014-2050 in MMT from the Demand Sheet *Drawdown* Scenario. Cell M12 calculates the total using the formula:

Row 13 calculates the savings in MMT from *plant-rich diet* using the formula:

Cell M13 calculates the total using the formula:

Cell N13 calculates the percent reduction of demand from Reference Case 2 to the *Drawdown* Scenariofrom *plant-rich diet* using the formula:

Cell O13 calculates the percentage of demand reduction that is due to *plant-rich diet* using the formula:

Row 14, Columns B through M import cumulative food waste reduction from 2014-2050 in MMT from the Demand Sheet *Drawdown* Scenario. Cell M14 calculates the total using the formula:

Cell N14 calculates the percent reduction of demand in the *Drawdown* Scenariofrom *reduced food waste* using the formula:

Cell O14 calculates the percentage of demand reduction that is due to *food waste reduction* using the formula:

Cell R11 calculates the avoided emissions from land use change in the *Drawdown* Scenario in Gt CO2-eq 2014-2050 by importing the cumulative emissions from land use change in Reference Case 2 and the *Drawdown* Scenario from the Land Use Change sheet using the formula:

Cell R12 calculates the total avoided land use change emissions due to *food waste reduction* in Gt CO2-eq 2014-2050 using the formula:

Cell R13 calculates the total avoided land use change emissions due to *plant-rich diet* in Gt CO2-eq 2014-2050 using the formula:

***Optimum* Scenario**

Row 18, Columns B through M import cumulative food demand from 2014-2050 in MMT from the Demand Sheet *Optimum* Scenario. Cell M18 calculates the total using the formula:

Row 19 calculates the savings in MMT from *plant-rich diet* using the formula:

Cell M19 calculates the total using the formula:

Cell N19 calculates the percent reduction of demand from Reference Case 2 to the *Optimum* Scenariofrom *plant-rich diet* using the formula:

Cell O19 calculates the percentage of demand reduction that is due to *plant-rich diet* using the formula:

Row 20, Columns B through M import cumulative food waste reduction from 2014-2050 in MMT from the Demand Sheet *Optimum* Scenario. Cell M20 calculates the total using the formula:

Cell N20 calculates the percent reduction of demand in the *Drawdown* Scenariofrom *reduced food waste* using the formula:

Cell O20 calculates the percentage of demand reduction that is due to *food waste reduction* using the formula:

Cell R17 calculates the avoided emissions from land use change in the *Optimum* Scenario in Gt CO2-eq 2014-2050 by importing the cumulative emissions from land use change in Reference Case 2 and the *Optimum* Scenario from the Land Use Change sheet using the formula:

Cell R18 calculates the total avoided land use change emissions due to *food waste reduction* in Gt CO2-eq 2014-2050 using the formula:

Cell R19 calculates the total avoided land use change emissions due to *plant-rich diet* in Gt CO2-eq 2014-2050 using the formula:

**DEMAND**

The Demand sheet provides food demand requirements based on the adoption of demand-side solution. Data is copied manually into this sheet from solution models related to population (*family planning* and *educating girls*) and the food system (*food waste reduction* and *plant-rich diet*). The data is converted to million metric tons (MMT) and exported to the Surplus sheet to determine whether supply meets demand. Data from this sheet is also exported to the Main Controls.

This sheet is broken down as follows:

* Reference 1 (rows 5-43),
* Reference 2 (rows 45-85)
* *Plausible* Scenario diet change (rows 87-127)
* *Plausible* Scenario food waste reduction (rows 129-168)
* *Drawdown* Scenario diet change (rows 171-211)
* *Drawdown* Scenario food waste reduction (rows 213-252)
* *Optimum* Scenario diet change (rows 255-295)
* *Optimum* Scenario food waste reduction (rows 297-336)

**Reference 1** (rows 5-43)

These rows contain food demand data copied manually from the Reference 1 case, representing food demand in the absence of *family planning, educating girls, food waste reduction,* and *plant-rich diet.*

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 43 calculates the sums of rows 6-42 for each column, representing the cumulative demand in MMT for that food product from 2014-2050.

Cell AA42 calculates the total MMT of food demand in 2050 using the formula:

Cell AA43 calculates total cumulative demand in MMT from 2014-2050 using the formula:

**Reference 2** (rows 45-85)

These rows contain food demand data copied manually from the Reference 2 case, representing food demand with implementation of *family planning, educating girls,* but in the absence of *food waste reduction,* and *plant-rich diet.*

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 85 calculates the sums of rows 48-84 for each column, representing the cumulative demand in MMT for that food product from 2014-2050.

Cell AA84 calculates the total MMT of food demand in 2050 using the formula:

Cell AA85 calculates total cumulative demand in MMT from 2014-2050 using the formula:

***Plausible* Scenario diet change** (rows 87-127)

These rows contain food demand data copied manually from the *Plausible* Scenarioof the *plant-rich diet* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 127 calculates the sums of rows 90-126 for each column, representing the cumulative demand in MMT for that food product from 2014-2050.

Cell AA126 calculates the total MMT of food demand in 2050 using the formula:

Cell AA127 calculates total cumulative demand in MMT from 2014-2050 using the formula:

***Plausible* Scenario food waste reduction (rows 129-168)**

These rows contain data on the total amount of food waste reduced, copied manually from the *Plausible* Scenarioof the *food waste reduction* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show reduced demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 168 calculates the sums of rows 131-167 for each column, representing the cumulative reduced demand in MMT for that food product from 2014-2050.

Cell AA167 calculates the total MMT of reduced food demand in 2050 using the formula:

Cell AA168 calculates total cumulative reduced demand in MMT from 2014-2050 using the formula:

***Drawdown* Scenario diet change (rows 171-211)**

These rows contain food demand data copied manually from the *Drawdown* Scenarioof the *plant-rich diet* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 211 calculates the sums of rows 174-210 for each column, representing the cumulative demand in MMT for that food product from 2014-2050.

Cell AA210 calculates the total MMT of food demand in 2050 using the formula:

Cell AA211 calculates total cumulative demand in MMT from 2014-2050 using the formula:

***Drawdown* Scenario food waste reduction (rows 213-252)**

These rows contain data on the total amount of food waste reduced, copied manually from the *Drawdown* Scenarioof the *food waste reduction* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show reduced demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 252 calculates the sums of rows 215-251 for each column, representing the cumulative reduced demand in MMT for that food product from 2014-2050.

Cell AA251 calculates the total MMT of reduced food demand in 2050 using the formula:

Cell AA252 calculates total cumulative reduced demand in MMT from 2014-2050 using the formula:

***Optimum* Scenario diet change (rows 255-295)**

These rows contain food demand data copied manually from the *Optimum* Scenarioof the *plant-rich diet* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 295 calculates the sums of rows 258-294 for each column, representing the cumulative demand in MMT for that food product from 2014-2050.

Cell AA294 calculates the total MMT of food demand in 2050 using the formula:

Cell AA295 calculates total cumulative demand in MMT from 2014-2050 using the formula:

***Optimum* Scenario food waste reduction (rows 297-336)**

These rows contain data on the total amount of food waste reduced, copied manually from the *Optimum* Scenarioof the *food waste reduction* solution.

“Grain” indicates plant-based food of all kinds. This data is imported as MMT in row B and copied to row C.

Rows D, F, H, J, L, N, P, R, T, V and X show reduced demand for various meat, dairy, and egg products. The data is imported as metric tons and in each case is converted to MMT using the formula:

Row 336 calculates the sums of rows 299-335 for each column, representing the cumulative reduced demand in MMT for that food product from 2014-2050.

Cell AA335 calculates the total MMT of reduced food demand in 2050 using the formula:

Cell AA336 calculates total cumulative reduced demand in MMT from 2014-2050 using the formula:

**LAND USE CHANGE**

This sheet determines whether land use change is required to meet demand based on grain surplus or deficit. In case of deficit, determines Mha of land that must be converted to crop production and associated land use change emissions. In the case of grain surpluses it calculates the total feedstock available for bioplastic production.

Column B imports grain surplus in MMT from the Surplus sheet Column I. Column C calculates grain deficit using the formula:

Column D imports the weighted global value for tons of grain per hectare per year form the Meta-Analysis sheet cell S52. Column E calculates million hectares of land use change required to meet grain deficit using the formula:

Column F imports the value for emissions from land use change in Gt CO2-eq per million hectares from cell M8. Column G calculates total emissions from land use change in Gt CO2-eq using the formula:

Column H imports the figure for tons of grain feedstock per ton bioplastic from the Meta-Analysis sheet cell S818. Column I calculates the total MMT of bioplastic that can be produced from surplus grain feedstock using the formula:

Column J removes negative numbers from the total MMT of bioplastic using the formula:

Column K calculates the smoothed total land use change emissions using the formula:

Cells M5, M46, M87, M128, and M169 import the value for Mha of grassland with prime quality soils available for conversion into cropland from the Meta-Analysis sheet cell S153. Cells M6, M47, M88, M129, and M170 import the value for Mha of forest land with prime quality soils available for conversion into cropland from the Meta-Analysis sheet cell S852.

Cells N5, N46, N87, N128, and N169 import the value for emissions from land use change of grassland in tons CO2/eq/ha from the Meta-Analysis sheet cell S85. Cells N6, N47, N88, N129, and N170 import the value for emissions from land use change of forest in tons CO2/eq/ha from the Meta-Analysis sheet cell S119.

Cells O5, O46, O87, O128, and O169 calculate the value for Gt CO2-eq emissions per million hectares of land use change for grassland using the formula:

Cells O6, O47, O88, O129, and O170 calculate the value for Gt CO2-eq emissions per million hectares of land use change for forest using the formula:

Cells M8, M49, M90, M131, and M172 calculate the weighted average emissions in GtCO2-eq/Mha for the combined grassland and forest area using the formula:

**SURPLUS**

This sheet determines is demand is met from crop production and grazing land. It imports food demand and reduced food waste from the Demand sheets, and imports production of crops and livestock from Crop Production and Grassland Production sheets. Deficits in livestock foods are exported to the Grainfed Livestock sheets. The sheet imports the total feed requirement from Grainfed Livestock and thus determines global surplus or deficit of food, which is exported to the Land Use Change sheet.

**Crop Supply and Demand**

Column B imports the total MMT of “grain” (plant-based foods) required for direct human consumption from Column C of the Demand sheet. Column C of the Surplus sheet imports the total global production of grain in MMT from the Crop Production sheet column B. Column D imports a figure from Meta-Analysis sheet cell S784 showing the percent of global crop production that is used as feedstock for non-food, non-livestock feed purposes (like cotton for fiber, maize for ethanol etc). Column E calculates how much grain is available for food and feed using the formula:

Column F imports the figure for MMT of grain used for livestock feed from the Grainfed Livestock sheet Column B. Column G imports the total MMT of plant-based food waste that is captured and re-enters the food system from the Demand sheet Column C. Column H calculates the total plant-based food available for human consumption using the formula:

Column I calculates grain surplus or deficit using the formula:

**Mixed Grazed and Grainfed Livestock Product Supply and Demand**

Column J imports the total MMT demand for bovine meat from the Demand sheet Column E. Column K imports the total MMT produced by grazing from the Grassland Production sheet Column AE. Column L imports the total MMT of reduced waste of bovine meat from the Demand sheet Column E. Column M calculates the total remaining demand that must be met by grainfed production using the formula:

MMT bovine meat from grazing - MMT bovine meat reduced food waste

Column N imports the total MMT demand for butter and ghee from the Demand sheet Column G. Column O imports the total MMT produced by grazing from the Grassland Production sheet Column N. Column P imports the total MMT of reduced waste of bovine meat from the Demand sheet Column G. Column Q calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT butter and ghee from grazing - MMT butter and ghee reduced food waste*

Column R imports the total MMT demand for butter and ghee from the Demand sheet Column I. Column S imports the total MMT produced by grazing from the Grassland Production sheet Column P. Column T imports the total MMT of reduced waste of bovine meat from the Demand sheet Column I. Column U calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT cream from grazing - MMT cream reduced food waste*

Column AB imports the total MMT demand for milk from the Demand sheet Column O. Column AC imports the total MMT produced by grazing from the Grassland Production sheet Column S. Column AD imports the total MMT of reduced waste of milk from the Demand sheet Column O. Column AE calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT milk from grazing - MMT milk reduced food waste*

Column AF imports the total MMT demand for mutton and goat meat from the Demand sheet Column Q. Column AG imports the total MMT produced by grazing from the Grassland Production sheet Column AA. Column AH imports the total MMT of reduced waste of mutton and goat meat from the Demand sheet Column Q. Column AI calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT from grazing - MMT reduced food waste*

Column AP imports the total MMT demand for animal fat from the Demand sheet Column W. Column AQ imports the total MMT produced by grazing from the Grassland Production sheet Column AF. Column AR imports the total MMT of reduced waste of animal fat from the Demand sheet Column W. Column AS calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT from grazing - MMT reduced food waste*

Column AT imports the total MMT demand for offal from the Demand sheet Column Y. Column AU imports the total MMT produced by grazing from the Grassland Production sheet Column AG. Column AV imports the total MMT of reduced waste of offal from the Demand sheet Column Y. Column AW calculates the total remaining demand that must be met by grainfed production using the formula:

*MMT from grazing - MMT reduced food waste*

**Purely Grainfed Livestock Product Supply and Demand**

Column V imports the MMT of eggs required from Demand sheet Column K. Column W imports the total MMT of reduced waste of eggs from the Demand sheet Column K. Column X determines the totalMMT of eggs which much be produced to meet demand using the formula:

Column Y imports the MMT of other meat required from Demand sheet Column M. Column Z imports the total MMT of reduced waste of other meat from the Demand sheet Column M. Column AA determines the totalMMT of eggs which much be produced to meet demand using the formula:

Column AJ imports the MMT of pigmeat required from Demand sheet Column S. Column AK imports the total MMT of reduced waste of pigmeat from the Demand sheet Column S. Column AL determines the totalMMT of pigmeat which much be produced to meet demand using the formula:

Column AM imports the MMT of poultry meat required from Demand sheet Column U. Column AN imports the total MMT of reduced waste of poultry meat from the Demand sheet Column U. Column AO determines the totalMMT of poultry meat which much be produced to meet demand using the formula:

**CROP PRODUCTION**

This sheet calculates the total crop production from the world’s cropland and some grasslands and forest land used for crop production. Data is entered into this sheet on adoption from the solution models. A figure for average global yield is imported from the Meta-Analysis Sheet, as are yield modifiers from the solution models. These are multiplied together to determined total world crop yield for each year from 2014-2050. Conventional cropping shrinks over time as cropland is converted to cropping solutions. Crop production from grasslands converted to cropping solutions (e.g. *farmland restoration, tropical tree staples*) is also accounted for, as is some crop production from current adoption of *multistrata agroforestry* which is classed as forest land. Data on total crop yield is exported to the Surplus sheet.

The sheet has two primary components. The first determines total global productivity of grasslands in MMT of dry matter pear year, based on the adoption of solutions that either increase or displace yields of grazing systems. The second component converts dry matter to meat and dairy products to determine the contribution of global grazing land to meeting meat and dairy demand. The second component is presented here first.

Generally speaking only one biosequestration solution is modeled on a unit of land in the Drawdown Agroecological Zone model, which sets the available land for solution adoption. Emissions reduction solutions, however, can be applied to a unit of land where biosequestration is practiced (for example, you can reduce fertilizer use on land where conservation agriculture is practiced and assume that both emissions reduction and biosequestration function fairly independently of each other). An exception is also made for application of biochar, as the production of feedstock takes place elsewhere. For purposes of the Yield model, two solutions, *biochar* and *women smallholders,* are doubled up on land also used for biosequestration. Adoption and yield impact of each is calculated as for other solutions. This same adoption is subtracted from the adoption of *conservation agriculture* and *regenerative agriculture.* These solutions were chosen because they have lower yield gains than *biochar* and *women smallholders*. Only the yield gain from *biochar* and *women smallholders* is implemented on these lands – no additive yield gains are modeled. This allows for their yield gain to be measured without double counting despite their being applied to lands where biosequestration solutions are already in place.

Another complication addressed by this sheet is that not all crop production occurs on cropland. Current adoption of *multistrata agroforestry* occurs on both cropland and forestland, while new adoption of *farmland restoration, tropical tree staples,* and *multistrata agroforestry* occurs on degraded grassland.

This sheet imports it’s standard crop yield figure from the Meta-Analysis sheet. The weighted average yield used in Drawdown solution models is based on grain yields (the great majority of world cropland is in grain production), but this resulted in the model under-estimating global total crop yields as reported by FAO Statistical Service. The high result from the meta-analysis calibrated the model to almost perfectly match 2014 global crop yields as reported by FAO. This is likely because other widely-grown crops like root crops are higher in water content and thus tend to have higher yields per hectare than grain crops.

This sheet is broken down as follows:

* Reference 1 & 2 (rows 3-41),
* *Plausible* Scenario (rows 44-82)
* *Drawdown* Scenario (rows 85-123)
* *Optimum* Scenario (rows 126-164)

***Total Global Crop Yield in MMT***

Column B calculates the total crop yield in MMT by adding the sum of yields from cropland as well as yield of crops from certain grasslands and forest land.

*=MMT yield from conservation agriculture + MMT yield from multistrata agroforestry on cropland + MMT yield from regenerative agriculture + MMT yield from improved rice + MMT yield from SRI + MMT yield from tree intercropping + MMT yield from tropical tree staples on cropland + MMT yield from biochar + MMT yield from women smallholders + MMT yield from conventional cropping + MMT yield from farmland restoration on grassland + MMT yield from tropical tree staples on grassland + MMT yield from multistrata agroforestry on forest and grassland*

***Conservation Agriculture***

These columns track the adoption in Mha of *conservation agriculture* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column E contain data copied manually from the respective scenarios of the *improved rice* solution model. Column F calculates adoption minus the total adoption of biochar as described above, using the formula:

Column G lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column H contains the yield modifier for this solution, entered manually from the *conservation agriculture* solution model. Column I calculates the total crop production in MMT from all land where this solution has been adopted (excepting the area in biochar adoption), using the formula:

***Multistrata Agroforestry (current adoption on cropland)***

These columns track the portion of current adoption of *multistrata agroforestry* in Mha, and it’s associated impacts on crop yield. Note that (as addressed below) some current adoption is on forestland, while new adoption is on grassland. All scenarios show only the portion of current adoption which is on cropland, entered manually in Column L from the solution model. Column M lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column N contains the yield modifier for this solution, entered manually from the *multistrata agroforestry* solution model. Column O calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

***Regenerative Agriculture***

These columns track the adoption in Mha of *regenerative agriculture* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column R contain data copied manually from the respective scenarios of the *regenerative agriculture* solution model. Column S calculates adoption minus the total adoption of *women smallholders* as described above, using the formula:

Column T lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column U contains the yield modifier for this solution, entered manually from the *regenerative agriculture* solution model. Column V calculates the total crop production in MMT from all land where this solution has been adopted (excepting the area in biochar adoption), using the formula:

***Improved Rice***

These columns track the adoption in Mha of *improved rice* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column Y contain data copied manually from the respective scenarios of the *improved rice* solution model. Column Z lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column AA contains the yield modifier for this solution, entered manually from the *improved rice* solution model. Column AM calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

***SRI***

These columns track the adoption in Mha of *SRI* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column AE contain data copied manually from the respective scenarios of the *improved rice* solution model. Column AF lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column AG contains the yield modifier for this solution, entered manually from the *improved rice* solution model. Column AH calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

***Tree Intercropping***

These columns track the adoption in Mha of *tree intercropping* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column AK contain data copied manually from the respective scenarios of the *tree intercropping* solution model. Column AL lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column AM contains the yield modifier for this solution, entered manually from the *tree intercropping* solution model. Column AN calculates the total crop production in MMT from all land where this solution has been adopted, using the formula: *(Mha adoption of solution) times (standard crop yield/ha) times (yield modifier).*

***Tropical Tree Staples (current adoption on cropland)***

These columns track the portion of current adoption of *tropical tree staples* in Mha, and it’s associated impacts on crop yield. Note that (as addressed below) all current adoption is on forestland, while new adoption is on grassland. All scenarios show only the portion of current adoption which is on cropland, entered manually in Column AQ from the solution model. Column AR lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column AS contains the yield modifier for this solution, entered manually from the *tropical tree staples* solution model. Column AT calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

***Biochar***

The biochar model measures adoption in tons biochar produced, not in Mha adoption. Thus Column AW imports tons biochar produced from the *biochar* solution model. Column AX imports the figure for tons of biochar applied per hectare from the *biochar* solution model. Column AY calculates the hectares to which biochar is applied using the formula:

Column AZ converts hectares to Mha using the formula:

Column BA lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column BB contains the yield modifier for this solution, entered manually from the *biochar* solution model. Column BC calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

***Women Smallholders***

These columns track the adoption in Mha of *women smallholders* and associated impacts on crop yield. Both current and new adoption occur on cropland only. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BF contain data copied manually from the respective scenarios of the *women smallholders* solution model. Column BG lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column BH contains the yield modifier for this solution, entered manually from the *women smallholders* solution model. Column BI calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

**Conventional Cropping**

Here the total area and crop production of conventional cropping systems is accounted for. Column BL tracks adoption of conventional cropping, which shrinks over time as it is replaced by other crop production solutions. The formula for this is:

Column BM lists the standard crop yield from the Meta-Analysis sheet cell S52. Column BN contains the yield modifier for this solution, which is one as this practice represents the baseline to which other solutions are compared. Column BO calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

**Farmland Restoration**

This solution converts abandoned farmland currently classed as degraded grassland to cropland. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BR contain data copied manually from the respective scenarios of the *farmland restoration* solution model. Column BS lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column BT contains the yield modifier for this solution, entered manually from the *farmland restoration* solution model. Column BU calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

**Tropical Tree Staples (new adoption on grassland)**

These columns account for the new adoption of *tropical tree staples* which takes place on grassland only. Column BX shows total adoption including both current adoption on cropland and new adoption on grassland, entered manually from the solution model. Column BY calculates new adoption on grassland using the formula:

Column BZ lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column CA contains the yield modifier for this solution, entered manually from the *tropical tree staples* solution model. Column CB calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

**Multistrata Agroforestry (new adoption on grassland)**

These columns account for the new adoption of *multistrata agroforestry* which takes place on grassland only. Column CE shows total adoption including both current adoption (on both cropland and forestland) and new adoption (on grassland only), entered manually from the solution model. Column CF calculates new adoption on grassland using the formula:

Column CG lists the standard crop yield in tons per year from the Meta-Analysis sheet cell S52. Column CH contains the yield modifier for this solution, entered manually from the *multistrata agroforestry* solution model. Column CI calculates the total crop production in MMT from all land where this solution has been adopted, using the formula:

**GRASSLAND PRODUCTION**

This sheet calculates the total meat and dairy production from the world’s grazing lands. The sheet has two primary components. The first determines total global productivity of grasslands in MMT of dry matter pear year, based on the adoption of solutions that either increase or displace yields of grazing systems. The second component converts dry matter to meat and dairy products to determine the contribution of global grazing land to meeting meat and dairy demand. The second component is presented here first.

The figure for dry matter per year is a weighted average imported from the Meta-Analysis sheet. However this figure was used to calibrate the model such that the total production of grassland protein leaves enough unmet demand that 1/3 of crop production is required for feed in 2014 – as is widely reported by FAO and others. This calibration is likely required because the productivity of tropical livestock is so much lower than livestock from OEDC countries, but due to lack of available data this is not reflected in the meta-analysis figures for milk production per ton live weight, percent edible portion of carcass, and tons live weight per ton dry matter forage.

This sheet is broken down as follows:

* Reference 1 & 2 (rows 3-41),
* *Plausible* Scenario (rows 44-82)
* *Drawdown* Scenario (rows 85-123)
* *Optimum* Scenario (rows 126-164)

***Calculating Total Grassland Meat and Dairy Production***

Column B calculates the total dry matter production of global grazing land by adding up the dry matter production of conventional grazing, grazing solutions, and non-grazing solutions adopted on grassland. It uses the formula:

*=MMT DM managed grazing + MMT DM silvopasture + MMT DM farmland restoration + MMT DM afforestation + MMT DM bamboo + MMT DM multistrata agroforestry + MMT DM perennial bioenergy + MMT DM tropical tree staples + MMT DM grassland protection + MMT DM BAU grazing*

Column C imports the value of live weight of livestock per ton of dry weight fodder produced from the Meta-Analysis sheet cell S341. Column D calculates the total live weight MMT of grazing animals using the formula:

Column E imports the total percentage of grazing ruminants that are dairy animals from Meta-Analysis sheet cell S444. Column F calculates the percentage of meat animals using the formula:

Column G calculates the total liveweight of dairy animals in MMT using the formula:

Column H imports the value for tons of milk per ton live weight from the Meta-Analysis sheet cell U410. Column I calculates the initial yield of milk in MMT using the formula:

Columns J and K enable to user to enter percentages of milk use for butter (J) and cream (K). Column L then determines the percent used only for milk production using the formula:

Column M imports the figure for butter as a percent of milk by weight from Meta-Analysis sheet S376. Column N calculates the total MMT production of butter on grasslands using the formula:

Column O imports the figure for cream as a percent of milk by weight from Meta-Analysis sheet S306. Column P calculates the total MMT production of cream on grasslands using the formula:

Column Q calculates the total MMT of skim milk produced on grassland as a byproduct of butter production using the formula:

Column R calculates the total MMT of skim milk produced on grassland as a byproduct of cream production using the formula:

Column S calculates total milk yield using the formula:

*initial milk yield \* percent used for milk) + MMT skim milk from butter production + MMT skim milk from cream production*

Column T notes the quantity of meat from “retired” dairy cows as a percentage of the total weight of milk, as imported from the Meta-Analysis Sheet cell S216. Column U calculates the total amount of meat from dairy cows using the formula:

Column V calculates the total live weight in MMT of dedicated meat animals using the formula:

Column W imports the percent of ruminant livestock that are sheep and goats from the Meta-Analysis sheet cell S478. Column X calculates the percent of ruminants that are bovine using the formula:

Column Y calculates the live weight MMT of sheep and goats using the formula:

Column Z imports the value for percent edible portion of a carcass from the Meta-Analysis sheet cell S512. Column AA calculates the total MMT of sheep and goat meat using the formula:

Column AB calculates the total live weight of bovine dedicated meat animals in MMT using the formula:

Column AC imports the value for percent edible portion of a carcass from the Meta-Analysis sheet cell S512. Column AD calculates the total MMT of bovine meat from dedicated meat animals using the formula:

Column AE calculates the total MMT of bovine meat including from “retired” dairy animals using the formula:

Column AF calculates production of animal fat at the rate of 16% of bovine meat as calculated from data in the Demand sheet using the formula:

Column AG calculates production of offal at the rate of 21% of bovine meat as calculated from data in the Demand sheet using the formula:

***Managed Grazing***

These columns track the adoption in Mha of *managed grazing* and associated impacts on dry matter yield. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column AJ contain data copied manually from the respective scenarios of the *managed grazing* solution model. Column AK lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column AL contains the yield modifier for this solution, entered manually from the *managed grazing* solution model. Column AM calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Silvopasture**

These columns track the adoption in Mha of *silvopasture* and associated impacts on dry matter yield. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column AP contain data copied manually from the respective scenarios of the *silvopasture* solution model. Column AQ lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column AR contains the yield modifier for this solution, entered manually from the *silvopasture* solution model. Column AS calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Abandoned Farmland**

These columns track the adoption in Mha of *farmland restoration*, a solution that takes degraded grassland out of grazing production and converts it to cropland. Note that food production impacts from adoption of this solution on grassland are accounted for in the Crop Production sheet but not here in Grassland Production. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column AV contain data copied manually from the respective scenarios of the *farmland restoration* solution model. Column AW lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column AX contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column AY calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Afforestation**

These columns track the adoption in Mha of *afforestation*, a solution that takes degraded grassland out of grazing production and converts it to timber and biomass production. For this solution current adoption is on forest land but new adoption is on grassland. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BB contain data copied manually from the respective scenarios of the *afforestation* solution model. Column BC calculates the total adoption on grassland using the formula:

Column BD lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column BE contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column BF calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Bamboo**

These columns track the adoption in Mha of *bamboo*, a solution that takes degraded grassland out of grazing production and converts it to timber and biomass production. For this solution current adoption is on forest land but new adoption is on grassland. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BI contain data copied manually from the respective scenarios of the *bamboo* solution model. Column BJ calculates the total adoption on grassland using the formula:

Column BK lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column BL contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column BM calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Multistrata Agroforestry**

These columns track the adoption in Mha of *multistrata agroforestry*, a solution that takes degraded grassland out of grazing production and converts it to agroforestry food production. For this solution current adoption is on forest and cropland but new adoption is on degraded grassland. Note that food production impacts from adoption of this solution on grassland are accounted for in the Crop Production sheet but not here in Grassland Production. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BP contain data copied manually from the respective scenarios of the *multistrata agroforestry* solution model. Column BQ calculates the total adoption on grassland using the formula *(total adoption) minus (current adoption on forest and cropland).*

Column BR lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column BS contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column BT calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Perennial Bioenergy**

These columns track the adoption in Mha of *perennial bioenergy*, a solution that takes degraded grassland out of grazing production and converts it to biomass production. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column BW contain data copied manually from the respective scenarios of the *farmland restoration* solution model. Column BX lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column BY contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column BZ calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Tropical Tree Staples**

These columns track the adoption in Mha of *tropical tree staples*, a solution that takes degraded grassland out of grazing production and converts it to perennial food production. For this solution current adoption is on grassland and cropland but new adoption is on degraded grassland. Note that food production impacts from adoption of this solution on grassland are accounted for in the Crop Production sheet but not here in Grassland Production. The Reference 1 and 2 rows show the impact of current adoption of this solution only. The *Plausible, Drawdown,* and *Optimum* rows of Column CC contain data copied manually from the respective scenarios of the *tropical tree staples* solution model. Column CD calculates the total adoption on grassland using the formula *(total adoption) minus (current adoption on forest and cropland).*

Column CE lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column CF contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column CG calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**Grassland Protection**

These columns track the adoption in Mha of *grassland protection*, a solution that takes protects natural grasslands from conversion to grazing or agriculture. This land is currently not grazed and is protected in the Drawdown AEZ Model even though a proper solution model has not yet been developed. Column CJ shows the adoption of this solution, which is 500 Mha in all scenarios. Column CK lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column CL contains the yield modifier for this solution, which is zero as this solution replaces grassland. Column CM calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**BAU Grazing**

Here the total area and dry matter production of conventional grazing systems is accounted for. Column CP tracks adoption of conventional grazing, which shrinks over time as it is replaced by a) grazing solutions like managed grazing and silvopasture, and b) non-grazing solutions which are adopted on grassland (like afforestation and farmland restoration). The formula for this is:

Column CQ lists the standard yield in tons of dry matter (DM) per year from the Meta-Analysis sheet cell U254. Column CL contains the yield modifier for this solution, which is one as this practice represents the baseline to which other solutions are compared. Column CS calculates the total dry matter production in MMT from all land where this solution has been adopted, using the formula:

**GRAINFED LIVESTOCK**

The Yield model assumes that all demand for livestock products will be met. Thus whatever grain is required to do so will be produced, if additional land must be cleared to produce that grain, this will be done. Grazing alone is not sufficient to meet demand in any scenario, so this sheet imports all demand for meat, dairy and eggs that is not met by grazing from the Surplus sheet. It determines the amount of grain required the meet this demand and exports the total feed requirement back to the Surplus sheet.

This sheet is broken down as follows:

* Reference 1 (rows 3-41),
* Reference 2 (rows 44-82)
* *Plausible* Scenario (rows 87-123)
* *Drawdown* Scenario (rows 126-164)
* *Optimum* Scenario (rows 167-205)

For all scenarios the columns and calculations are as described below.

***Total Feed Grain Requirement***

Column B calculates the total feed grain required in MMT from all grainfed meat, dairy, and eggs products using the formula:

This data is exported to the Surplus sheet and is the reason for the existence of the Grainfed Livestock sheet.

***Milk, Butter, and Cream***

These columns first determine how much butter and cream is required, including how much milk is required for butter and cream production and how much skim milk is produced as a by-product. This skim milk is subtracted from total milk demand. At this point the grain required to produce all of these dairy products is calculated.

Column C imports demand for grainfed milk in MMT from the Surplus sheet column AE (“grainfed milk produced to meet remaining demand MMT”) for the appropriate year and scenario. Column D subtracts the skim milk produced as a by-product of butter and cream production using the formula:

Column E imports the figure for tons of grain per ton milk from the Meta-Analysis sheet cell S546. Column F calculates the total grain required to produce grainfed milk excluding skim milk using the formula:

Column G imports demand for grainfed butter in MMT from the Surplus sheet column Q (“grainfed butter and ghee produced to meet remaining demand MMT”) for the appropriate year and scenario. Column H imports the figure for butter as a percent of milk by weight from Meta-Analysis sheet S376. Column I determines the amount of milk required for butter production using the formula:

Column J determines the MMT of grain required to produce butter and the associated skim milk by-product using the formula:

Column K determines the MMT of skim milk produced as a by-product of butter production using the formula:

Column L imports demand for grainfed cream in MMT from the Surplus sheet column U (“grainfed cream produced to meet remaining demand MMT”) for the appropriate year and scenario. Column M imports the figure for butter as a percent of milk by weight from Meta-Analysis sheet S306. Column N determines the amount of milk required for cream production using the formula:

Column O determines the MMT of grain required to produce cream and the associated skim milk by-product using the formula:

Column P determines the MMT of skim milk produced as a by-product of butter production using the formula:

***Eggs***

These columns determine how much grain is required to meet demand.

Column AF imports demand for grainfed eggs in MMT from the Surplus sheet column X (“grainfed egg production MMT”) for the appropriate year and scenario.

Column AF imports data from the Meta-Analysis sheet cell S716 which determine tons of feed grain per ton of eggs. Column AH determines the total MMT of grain required for egg production using the formula:

***Bovine Meat***

These columns first determine the amount of bovine meat produced as a by-product of dairy production, and then determine the remaining demand and how much grain must be produced to meet it.

Column Q imports demand for grainfed bovine meat in MMT from the Surplus sheet column M (“grainfed bovine meat produced to meet remaining demand MMT”) for the appropriate year and scenario.

Column R notes the quantity of meat from “retired” dairy cows as a percentage of the total weight of milk, as imported from the Meta-Analysis Sheet cell S216. Column S calculates the total amount of meat from dairy cows using the formula:

Column T calculates the total MMT of bovine meat required after subtracting meat from dairy cows using the formula:

Column U imports data from the Meta-Analysis sheet cell S580 which determine tons of feed grain per ton of bovine meat. Column V determines the total MMT of grain required for bovine meat production using the formula:

***Mutton and Goat Meat***

These columns determine how much grain is required to meet demand.

Column W imports demand for grainfed mutton and goat meat in MMT from the Surplus sheet column AI (“grainfed mutton and goat meat produced to meet remaining demand MMT”) for the appropriate year and scenario.

Column X imports data from column U (itself from Meta-Analysis sheet cell S580) which determines tons of feed grain per ton of bovine meat, under the assumption that the figure is the same for sheep and goats, which are closely related to bovines. Column Y determines the total MMT of grain required for mutton and goat meat production using the formula:

***Pigmeat***

These columns determine how much grain is required to meet demand.

Column Z imports demand for grainfed pigmeat in MMT from the Surplus sheet column AL (“grainfed pigmeat produced to meet remaining demand MMT”) for the appropriate year and scenario.

Column AA imports data from Meta-Analysis sheet cell S648, which determines tons of feed grain per ton of pigmeat. Column AB determines the total MMT of grain required for pigmeat production using the formula: *(pig meat required) times (tons of grain per ton pigmeat).*

***Other Meat***

These columns determine how much grain is required to meet demand.

Column AC imports demand for grainfed other meat in MMT from the Surplus sheet column AA (“grainfed other meat produced to meet remaining demand MMT”) for the appropriate year and scenario.

Column AD imports data on tons of feed grain per ton of pigmeat from Column AA (itself imported from Meta-Analysis sheet cell S648), on the assumption that the “other meats” category, which contains livestock that are neither ruminant, poultry, nor fish, will be monogastric livestock similar to pigs in their metabolism and feed conversion efficiency. Column AE determines the total MMT of grain required for other meat production using the formula:

***Poultry Meat***

These columns first determine the amount of poultry meat produced as a by-product of egg production, and then determine the remaining demand and how much grain must be produced to meet it.

Column AI imports demand for grainfed poultry meat in MMT from the Surplus sheet column AO (“grainfed poultry meat produced MMT”) for the appropriate year and scenario. Column AJ notes the quantity of meat from spent (no longer productive) laying hens as a percentage of the total weight of eggs, as imported from the Meta-Analysis Sheet cell S271. Column AK calculates the total amount of meat from spent layer hens using the formula:

Column AL calculates the total MMT of poultry meat required after subtracting meat from spent layer hens using the formula:

Column AM imports data from the Meta-Analysis sheet cell S750 which determine tons of feed grain per ton of poultry meat. Column AN determines the total MMT of grain required for poultry meat production using the formula:

***Animal Fat and Offal***

No grain is required to produce fat and offal as they are by-products of meat production.

Column AO imports demand for grainfed animal fat in MMT from the Surplus sheet column AS (“grainfed animal fat produced to meet remaining demand MMT”) for the appropriate year and scenario. As animal fat is a by-product of meat production, no feed grain is required as shown in columns AS and AT.

Column AR imports demand for grainfed offal in MMT from the Surplus sheet column ASW(“grainfed offal produced to meet remaining demand MMT”) for the appropriate year and scenario. As offal is a by-product of meat production, no feed grain is required as shown in columns AS and AT.

**META-ANALYSIS**