The ASMGHG Model – A Brief Technical Overview

ASMGHG is an U.S. agricultural sector model specifically built for the assessment of greenhouse gas emission mitigation options through agriculture and forestry. The model is setup as mathematical program optimizing aggregate agricultural production activities subject to resource endowments, international demand and supply conditions, available technologies, and governmental policies. Available technologies are represented through production budgets. Each production budget specifies fixed quantities of inputs and outputs. Instead of optimizing the level of each production input individually, choices are made between different sets of fixed input output combinations. Thus, technological choices in ASMGHG are discrete in nature. However, sufficient flexibility is possible by specifying a large number of alternative production budgets.

In ASMGHG, representative crop production budgets exist for 63 U.S. regions (index r), 20 crop types (index c), 2 irrigation alternatives (index w), 3 tillage intensities (index t), 4 soil types (index s), and several nitrogen fertilization alternatives (index n). Livestock production budgets describe technologies for 11 animal types (index k) and alternative feeding strategies (index i) in 63 U.S regions (index r). Processing budgets identify various first, second, or third level processing opportunities (index h) carried out by producers.

Agricultural production activities are linked to both input and output markets. Commodities can be consumed domestically (D), shipped to or from other U.S. regions (U), exported (X) or imported (M) to foreign countries (index j), processed (PR), or directly fed to animals. Equation (1) shows a simplified crop balance equation. Regional, climate and management specific crop yields are represented by $a_{r,c,t,w,n,s,\tilde{c}}$.

The coefficient $a_{c,h}$ identifies the amount of crop c used in process h and $a^{V}_{r,k,i,c}$ the amount of crop c added to the diet of animal k, raised under intensity i in region r.

(1)

$$\begin{aligned}&-\sum_{t,w,f,s,\tilde{c}} a_{r,c,t,w,n,s,\tilde{c}} \cdot L_{r,c,t,w,n,s} + D_{r,c} + \sum_{h} a_{c,h} \cdot RP_{r,h} - \sum_{k,i} a^{V}_{r,k,i,c} \cdot V_{r,k,i} \\ &-\sum_{\tilde{r}} U_{\tilde{r},r,c} + \sum_{\tilde{r}} U_{r,\tilde{r},c} - \sum_{j} M_{j,r,c} + \sum_{j} X_{j,r,c} \leq 0\end{aligned}$$

Livestock production (2) is balanced at the national level without consideration of imports and exports. Each production alternative $V_{r,k,i}$ yields $a^{V}_{r,k,i,q}$ units of livestock product q.

(2)

$$D_{r,q} - \sum_{\tilde{r}} U_{\tilde{r},r,q} + \sum_{\tilde{r}} U_{r,\tilde{r},q} + \sum_{h} a_{q,h} \cdot RP_{r,h} - \sum_{k,i} a^{V}_{r,k,i,q} \cdot V_{r,k,i} \leq 0$$

Processed commodities can be sold domestically, exported, used as inputs for further processing, or fed to animals. Note that processing (index h) is modeled at the national level ($NP_h = \sum_{r} RP_{r,h}$). A negative sign of $a_{z,h}$ identifies commodity z as input while a positive sign identifies z as output of process h. Processing in ASMGHG occurs at up to three vertical levels.

(3)

$$\sum_{h} a_{z,h} \cdot NP_h + D_z + \sum_{r,k,i} a^{V}_{r,k,i,z} \cdot V_{r,k,i} + X_z - M_z \leq 0$$

The competitive market equilibrium is computed by maximizing the sum of consumers' surplus in all output markets plus the sum of producers' surplus in all input markets. Since prices are treated endogenously, this Marshallian welfare measure cannot be computed directly. Maximization of the sum of the areas underneath the inverse commodity demand curves (p[·]) minus the sum of the areas underneath the inverse factor and import supply curves, however, yield equivalent results. All demand and supply curves are specified as partial equilibrium CES functions. The resulting objective function is shown in equation (4)[1].

The first term in equation (4) represents the area underneath the domestic demand curves for all crops, livestock products, and processed commodities. Subsequently, the terms in lines 2 and 3 account for the area underneath the inverse import supply and export demand curves. Terms 4 to 8 integrate the area underneath the endogenously priced factor supply curves of labor, water, land, and animal unit month (AUMS). Explicitly included are changes in sectoral land use (dL), i.e. conversion of cropland to forest or grassland. The coefficient $a_{r,f}^{dL}$ takes on a value of 1 if the sectoral land shift (index f) demands land of soil type s and –1 if the shift supplies land of soil type s. Term 9 incorporates exogenously priced inputs (index inp) of both crop and livestock production and processing.

Term 10 incorporates transportation costs and term 11 the cost of a basic greenhouse gas policy. Such a policy would apply a dollar value (p^{CE}) to carbon equivalent net emissions. Note that this policy design implies additional revenue to producers if net emissions are negative.

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[1] In displaying the objective function of ASMGHG model, several modifications have been made to ease readability and limit the number of equations: a) the integration terms are not shown explicitly (ASMGHG allows for both nonlinear and stepwise linear specification), b) the factor supply balance equations have been substituted into the objective function (ASMGHG has regional factor balance equations of which the computed shadow price represents the resource cost), c) farm program terms are omitted, and d) artificial variables for detecting infeasibilities are omitted. A complete description of the objective function is available from the authors.

(4)

$$
\begin{aligned}
\text{Max} \quad & \sum_{y}\left[\int_{y} p^{y}\left(\sum_{r} D_{r,y}\right) d(\cdot)\right] \\
& +\sum_{j,c}\left[\int p^{c}\left(\sum_{r} X_{j,r,c}\right) d(\cdot)\right] \\
& -\sum_{j,c}\left[\int p^{c}\left(\sum_{r} M_{j,r,c}\right) d(\cdot)\right] \\
& -\sum_{r,s}\left[\int p^{L}_{r,s}\left(\sum_{c,t,w,n} a^{L}_{r,c,t,w,n,s} \cdot L_{r,c,t,w,n,s} + \sum_{k,i} a^{L}_{r,k,i} \cdot V_{r,k,i} + \sum_{f} a^{dL}_{r,f} \cdot dL_{r,f}\right) d(\cdot)\right] \\
& -\sum_{r}\left[\int p^{LB}_{r}\left(\sum_{c,t,w,n,s} a^{LB}_{r,c,t,w,n,s} \cdot L_{r,c,t,w,n,s} + \sum_{k,i} a^{LB}_{r,k,i} \cdot V_{r,k,i}\right) d(\cdot)\right] \\
& -\sum_{r}\left[\int p^{W}_{r}\left(\sum_{c,t,w,n,s} a^{W}_{r,c,t,w,n,s} \cdot W_{r,c,t,w,n,s}\right) d(\cdot)\right] \\
& -\sum_{r}\left[\int p^{AU}_{r}\left(\sum_{k,i} a^{AU}_{r,k,i} \cdot V_{r,k,i}\right) d(\cdot)\right] \\
& -\sum_{r,inp}\left\{p^{inp} \cdot \left[\sum_{c,t,w,n,s}\left(a_{r,c,t,w,n,s,inp} \cdot L_{r,c,t,w,n,s}\right) + \sum_{k,i}\left(a_{r,k,i,inp} \cdot V_{r,k,i}\right) + \sum_{h}\left(a_{inp,h} \cdot PR_{h}\right)\right]\right\} \\
& -\sum_{r}\left\{\left[\sum_{y} p^{U}_{r,\tilde{r}} \cdot \sum_{\tilde{r}}\left(U_{r,\tilde{r},y} + U_{\tilde{r},r,y}\right)\right] + \left[\sum_{j,c} p^{M/X} \cdot \left(X_{j,r,c} + M_{j,r,c}\right)\right]\right\} \\
& -p^{CE} \cdot \sum_{g}\left(EM_{g} - ER_{g}\right)
\end{aligned}
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Greenhouse gas emissions (EM) and emission reductions (ER) are accounted for all major sources, sinks and offsets (index g) from agricultural activities (equations (5) and (6)) for which data were available or could be generated. For a detailed description of the derivation of emission coefficients (e) see Schneider. Generally, ASMGHG considers

- Direct carbon emissions from fossil fuel use (diesel, gasoline, natural gas, heating oil, liquefied petroleum gas) in tillage, harvesting, or irrigation water pumping as well as altered soil organic matter (cultivation of forested lands or grasslands),

- Indirect carbon emissions from fertilizer manufacturing,
- Carbon savings from increases in soil organic matter (reduced tillage intensity and conversion of arable land to grassland) and from tree planting,
- Carbon offsets from biofuel production (ethanol, power plant feedstock via production of switchgrass, poplar, and willow),
- Nitrous oxide emissions from fertilizer usage and livestock manure,
- Methane emissions from enteric fermentation, livestock manure, and rice cultivation,
- Methane savings from manure management changes, and
- Methane and nitrous oxide emission changes from biomass power plants.

(5)

$$\begin{aligned} EM_g = & \sum_{r,c,t,w,n,s} \left(e_{r,c,t,w,n,s,g} \cdot L_{r,c,t,w,n,s} \right) \Big|_{e_{r,c,t,w,n,s,g}>0} \\ & + \sum_{r,f} \left(e_{r,f,g} \cdot dL_{r,f} \right) \Big|_{e_{r,f,g}>0} \\ & + \sum_{r,k,i} \left(e_{r,k,i,g} \cdot V_{r,k,i} \right) \Big|_{e_{r,k,i,g}>0} \\ & + \sum_{h} \left(e_{g,h} \cdot PR_h \right) \Big|_{e_{g,h}>0} \end{aligned}$$

(6)

$$\begin{aligned} ER_g = & \sum_{r,c,t,w,n,s} \left(-e_{r,c,t,w,n,s,g} \cdot L_{r,c,t,w,n,s} \right) \Big|_{e_{r,c,t,w,n,s,g}<0} \\ & + \sum_{r,f} \left(-e_{r,f,g} \cdot dL_{r,f} \right) \Big|_{e_{r,f,g}<0} \\ & + \sum_{r,k,i} \left(-e_{r,k,i,g} \cdot V_{r,k,i} \right) \Big|_{e_{r,k,i,g}<0} \\ & + \sum_{h} \left(-e_{g,h} \cdot PR_h \right) \Big|_{e_{g,h}<0} \end{aligned}$$

In ASMGHG, producers' crop choice is constraint to fall in a convex combination of 28 years of historically observed crop choices (7). This set of constraints serves several purposes. First, regional specific crop rotations are preserved. Note that only relative crop shares are restricted. The sum of the regionally specific mix variables over time ($\sum_{year} MIX_{r,year}$) is not forced to add to unity, therefore allowing the total crop acreage to expand or contract. Second, many unobservable constraints faced by agricultural producers are implicitly included vis-à-vis duality theory. Underlying is the assumption that historical crop mixes represent profit maximizing choices subject to crop rotation considerations, perceived risk, and a variety of natural conditions. Third, these constraints prevent extreme specialization by adding a substantial number of constraints in each region. A common problem to large linear programming (LP) models is that the number of variables by far exceeds the number of constraints. Because an optimal LP solution will always occur at an extreme point, the number of non-zero variables cannot exceed the number of constraints.

(7) $$\sum_{t,w,n,s} L_{r,c,t,w,n,s} - a_{r,c,year} \cdot MIX_{r,year} \Big|_{\underline{c} \le E[c^*] \le \bar{c}} = 0$$

If the acreage allocated to certain crops is expected to expand under mitigation incentives far beyond the upper or contract below the lower bound of historical relative shares, i.e.

$$E\left[\sum_{t,w,n,s} L_{r,c,t,w,n,s} \Big/ \sum_{c,t,w,n,s} L_{r,c,t,w,n,s}\right] > \overline{\sum_{t,w,n,s} L_{r,c,t,w,n,s} \Big/ \sum_{c,t,w,n,s} L_{r,c,t,w,n,s}} \text{ or}$$

$$E\left[\sum_{t,w,n,s} L_{r,c,t,w,n,s} \Big/ \sum_{c,t,w,n,s} L_{r,c,t,w,n,s}\right] < \underline{\sum_{t,w,n,s} L_{r,c,t,w,n,s} \Big/ \sum_{c,t,w,n,s} L_{r,c,t,w,n,s}}$$, then these crops are not part of the crop mix equations. Similar constraints as in (7) are applied to irrigation acreage and to livestock production.