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Interactive comment on "MAgPIE 4 – A modular open source framework for modeling global land-systems" *by* Jan Philipp Dietrich et al.

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We would like to thank the referee for the time spent on reviewing our paper and the valuable remarks which pointed out some important issues and helped to further improve the paper.

[REFEREE COMMENT 1] General Comments This paper describes the model MAgPIE 4, its history and release as an open source modelling framework. It serves as an introduction to the modelling framework as it is released, and as such it is well-suited as a citation for future users. There is good explanation of the structure of the model, including its modularity and references to further documentation. However, the effects of running modules under different setups

is not explored. The article also presents a case study with a focus on Brazil that demonstrates the regional flexibility of the framework and how different regional definitions may affect results. This last topic is particularly interesting and deserves to be expanded a bit. In particular what may be behind the different results that arise from changing regional definitions. Finally, the absence of any description of the objective function of the model framework is an omission that should be corrected. Therefore, I recommend that this article be accepted with minor revisions as detailed below.

[AUTHORS RESPONSE 1] Please see our answers below.

[REFEREE COMMENT 2] There is much emphasis on the modularity structure of the framework, but the article does not go beyond description of this modularity. It lacks any mention of how choices of modular setup may affect results. For example, how does a module behave in standalone versus integrated mode? Or how does changing a specific module realization affect other modules? This analysis should be included here as, for example, a case study of one specific module. Even if this is performed in a separate article or online documentation resource, a quick summary of the results of such an experiment should be included for illustrative purposes.

[AUTHORS RESPONSE 2] We agree with the referee that detail was missing here. To address this issue we moved the discussion of key evaluation examples to the appendix and replaced in with a comparison of three applications of the modularity approach (2 cases in which alternative realizations were used and 1 standalone case). The new text reads as follows:

[TEXT EDIT 2] "Figure 2 shows three different applications of the flexible, modular structure in MAgPIE in comparison to a run with default settings. The first application (soil organic matter) is a case in which a model feature can be either switched on or off. While this module is slightly improving the overall accuracy of the model

through improved fertilizer estimates it has high computational requirements, nearly doubling the run-time of the model. By default it is switched off but can be activated when needed, e.g. for studies focusing on fertilizer application. The second application (volume-based factor costs) is an example of a dispute about the representation of a process, in this case the relationship between factor requirement costs and production. We compare here two realizations of factor requirement costs, one of which mainly links them to the area under production (default realization) and the other of which mainly links them to the production itself. As the available data sources did not allow to clearly link costs to area or production we were experimenting with different realizations of it. The flexible modular structure allowed to easily implement different hypotheses and compare them which each other. The third application (standalone food demand) is an example in which a module is enabled to run standalone. Here, the food demand calculations, estimating regional food demand based on GDP projections and demographics, can also be run independent of other modules. This is especially useful for studies focusing on food demand itself or for general improvements in the projections itself.

The evaluation plots show different stages and major components of a MAgPIE simulation. As figure 2 shows the population, which is an exogenous parameter driving the simulations, is identical for all four runs. As one of the drivers of food demand, the population is also available in the food demand standalone case. We get a similar picture for the per capita food demand, which is the main output of the food demand model. The output is available for all runs and due to identical scenario assumptions also identical (for different assumptions see a variation across SSPs in Appendix A2).

As all other aspects shown in the figure go beyond what is used or simulated in the food demand module, all remaining values could only be reported by the non-standalone runs. The combination of per capita food demand and total population provides the total food demand in the model which triggers total feed demand through livestock consumption. Also here the identical scenario assumption leads to the same results in *all three runs. Differences can be observed in the global land cover and the productivity measures (land use intensity and average crop yields). Cropland shows higher expansion in the alternative scenarios compared to the default scenario while both scenarios show less intensification and lower yields. While the differences are rather small in the case of soil organic matter, the difference are quite pronounced in the alternative factor requirement case. In the case of soil organic matter this effect is triggered via the natural availability of nitrogen in the soil. Having SOM switched off the model assumes, that all required nitrogen has be provided as fertilizer, while simulating SOM explicitly uncovers the already available nitrogen in the soil. This reduces the overall fertilizer requirements and slightly incentivizes land expansion as it gives the model access to more nitrogen. As the food demand is rather independent of this decision more land expansion leads to lower intensification requirements, lowering land use intensity as well as average yields. Having factor requirements primarily linked to the production rather than to the area on which it is produced strongly reduces the incentive in the model to intensify. Area dependent factor requirements strongly favor high yielding locations for production giving the model a strong incentive to concentrate production on high productive areas and to further boost productivity via intensification. Production dependent factor requirements on the other hand do not favor locations based on productivity making also rather unproductive areas interesting for production and thereby reducing the incentive for intensification. In combination this leads to significantly higher cropland expansion, higher forest reduction, less intensification and significantly lower crop yields. One can also observe that the difference in average yields is higher than in land use intensity, owing average yields to drop for two reasons: the lower land use intensification and the expansion into low productive areas.*

CO2 emissions show strong fluctuations in all scenarios due to missing constraints linking carbon stocks with the goal function of the model (e.g. carbon pricing). This makes it in many cases an arbitrary decision for the optimizer to expand cropland into carbon rich or carbon poor areas. Besides its fluctuations the plot also shows higher overall emissions in the case of volume-based factor costs due to the overall higher *expansion of cropland and reduction in forest areas."*

[REFEREE COMMENT 3] The optimization methodology should be better explained. There is only a brief mention of the method in the description of the optimization module, which states that the model "minimizes total system cost" (p7, l14). How is this done? Is the model dynamic recursive? This has been explained in other articles using MAgPIE, but it should be included here, either in the main text or the appendices. A description of the objective function and the optimization method is in order.

[AUTHORS RESPONSE 3] This is indeed a critical omission. We extended the text in various locations with information about the optimization methodology (which is indeed dynamic recursive cost minimization). Details which go beyond that can be found in the referenced model documentation. In detail we added it to the first sentence in the MAgPIE history:

[TEXT EDIT 3] "MAgPIE was first introduced in Lotze-Campen et al. (2008) as recursive dynamic cost minimization model, simulating crop production, land-use patterns, and water use for irrigation in a spatial resolution of three by three degrees and inter-regional trade between 10 world regions."

[AUTHORS RESPONSE 3] As the recursive dynamic logic is part of the inner layer of the framework we added it to its description in the framework architecture section:

[TEXT EDIT 3] "The inner layer written in GAMS (GAMS Development Corporation, 2016) contains the optimization model with all its equations and constraints, the recursive dynamic logic which triggers the optimization for each time step consecutively and forwards results to the next time step and the code modularity implementation."

[AUTHORS RESPONSE 3] Additionally, we extended the description of the optimization module to:

[TEXT EDIT 3] "Minimizes total costs of the optimization problem for each time step

using different optimization strategies to reduce run time.”

[REFEREE COMMENT 4] Another important issue is the expansion of the discussion on what drives the changes in results from different regional aggregation. In particular, the difference in global forest cover changes by about 10% when using the Brazil setup should be explored in more detail. Even if it is simply the result of coarser resolution in the ROW region, it would be interesting to hear more about the interpretation of these results. Is 10% an acceptable uncertainty level? Which global regions are most affected by the changing the regional definitions? Why? This would expand the discussion section as well.

[AUTHORS RESPONSE 4] Discussion of this part came indeed a bit short. Looking more into it we found that the global forest cover numbers in the Brazil setup should not be used as they arise from unrealistic production shifts within the ROW region. We added a paragraph to the discussion specifically addressing this issue:

[TEXT EDIT 4] “Comparison with historical data sets as well as projections on forest cover show that the differences between mappings are rather small compared to the overall uncertainty in these numbers. Nevertheless, a deeper look into the simulations uncovers that the global numbers of the Brazil-centric setup are unreliable as the reduced deforestation rate compared to the default setup is a consequence of the applied mapping. As the ROW region basically acts as a huge free trade region it can fulfill strong demand pressure coming from Sub-Saharan Africa with production from elsewhere, while trade limitations in the default setup limit this exchange and trigger deforestation within Sub-Saharan Africa Africa (Dietrich, 2018, compare m4p_default_validation.pdf p1558 and m4p_brazil_validation.pdf p1465). In the case of LAM both runs show a rather similar picture in the aggregated forest cover projections for the region and it is not possible to clearly reject one of them. This is particular important as the regional aggregates in LAM are in the scope of both mappings and therefore should be sound. When choosing between them, one has to decide whether spatial details in Brazil or global trade patterns are the more decisive factor for accurate

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estimates of regional forest cover in LAM."

[AUTHORS RESPONSE 4] Furthermore, we added a section discussing the specialization observed in the spatial patterns, where it comes from and how it affects global dynamics:

[TEXT EDIT 4] "The observed specialization is a consequence of the homogeneous biophysical characteristics within each cluster which lead to either-or-decisions in the model. It will either fully take a cluster into production or ignore it completely. In the default setup this effect is very pronounced due to the low number of clusters within Latin America. With more clusters, as in the Brazil setup, clusters better grasp the real spatial distributions of biophysical characteristics in the region and therefore lead to a more diverse picture. Whereas this effect is especially relevant for regional studies with focus on spatial patterns, it is less critical for global dynamics as long as the spatial aggregation is not introducing any systematic biases to the model."

[REFEREE COMMENT 5] Also, the initial land cover map most likely plays an important role on the future projections. As such, it would be advisable to include a figure with the base year land cover map, even though this may be extracted from Hurtt et al. (2018). In fact, land cover maps for other milestone years the authors deem important may also help the user to understand model dynamics.

[AUTHORS RESPONSE 5] We agree with the referee that initial land cover is a crucial input which is affecting future projections. However, due to the nature of the paper focusing on the MAgPIE framework we felt that the benefit of showing land cover maps in the paper would be limited. For interested readers we added a sentence to the SSP results discussion (Appendix A2) mentioning that further details (including the land cover maps in NetCDF format) can be found in the uploaded supplementary material, including the land cover maps of the corresponding runs:

[TEXT EDIT 5] "More information information about the runs can be found in the corresponding evaluation documents (Dietrich, 2019b) and model runs (Dietrich, 2019a).

The latter contains for instance NetCDF-files with spatial land cover information of the corresponding runs (cell.land_0.5.nc).”

[REFEREE COMMENT 6] Technical Comments P13 l4: repeated “with”

[AUTHORS RESPONSE 6] We deleted the duplicate “with”

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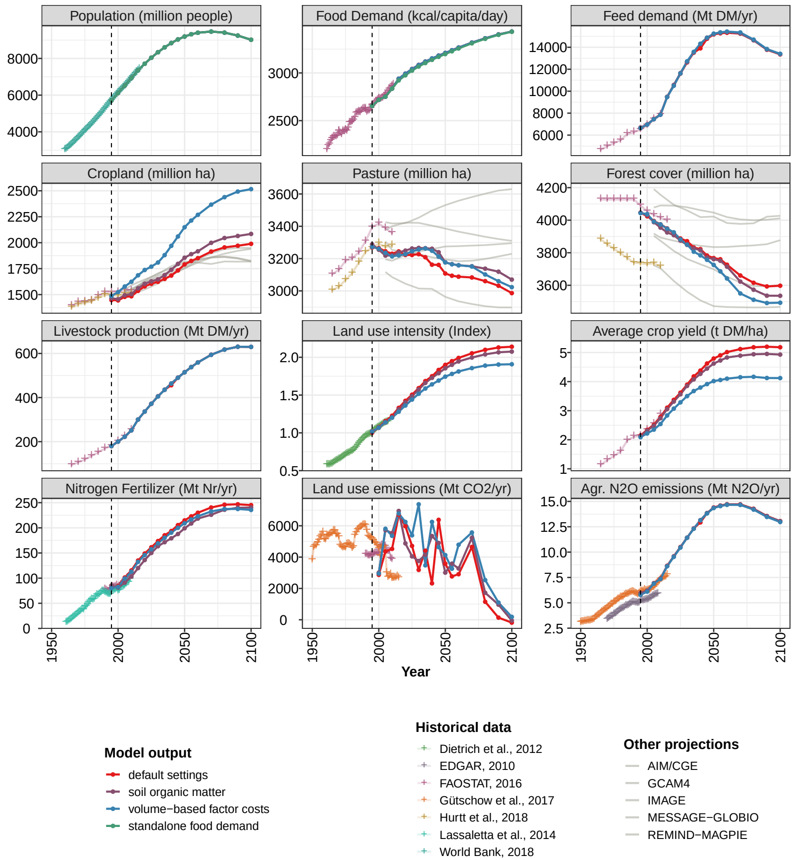

Fig. 1.

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