Reinforcing feedback loop between climate impact and agriculture emissions – A global perspective

Roberto Pasqualino
Global Sustainability Institute
Anglia Ruskin University
183 East Rd, Cambridge, CB11BG, UK
roberto.pasqualino@anglia.ac.uk

Prof Aled Jones
Global Sustainability Institute
Anglia Ruskin University
183 East Rd, Cambridge, CB11BG, UK
aled.jones@anglia.ac.uk

Key words: Hot House Effect, Agricultural emissions, Climate change, World3, Energy Transition

Funding Source: Economic and Social Research Council (ESRC), as part of the Centre for the Understanding of Sustainable Prosperity (CUSP) grant (ESRC grant no: ES/M010163/1).

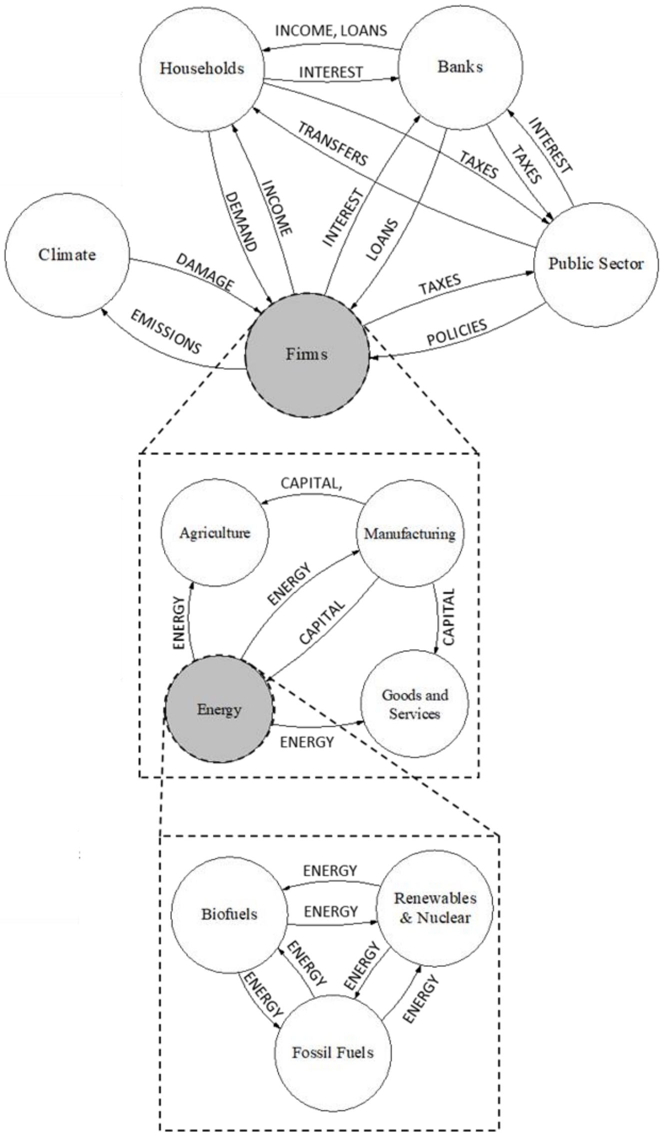
Extended Abstract

This paper presents a newly developed System Dynamics (SD) Economic Risk Resources and Environment (ERRE) model, a global impact assessment model whose purpose is to address the social and financial risks emerging from the dynamics of long term growth while interacting with global limits. The aim of this paper is to demonstrate, that while climate change increases in its magnitude, food losses are generated. However, there is a relative balancing effect from food systems to increase assets and production to still satisfy demand despite the loss in productivity. In the absence of mitigating policies and technologies, this can lead to the reinforcing feedback loop where the worse the impact of climate on food, the higher the emissions from agriculture, and then the worse the impact on food. After a calibration of the model, we provide a sensitivity analysis on extreme climate change scenarios. The analysis shows the existence of such a feedback loop, which must be taken in consideration by policy makers while tackling issues over lower than global domains. In fact, future development of the ERRE in the area of lower scale system modelling are identified focusing on what can be called Complex Inertial Networks or Macro-Agent Based modelling.

Figure 1 shows the ERRE models the economic resource systems in a network of nine highly aggregated sectors (fossil fuels, green energy and nuclear, agriculture and biofuels, capital, consumer goods and services, households, financial sector, government, and climate module). The major variables that drive the dynamic of the systems are prices, wages and interest rates while led both by environmental limits and the non-linear decision control feedback of boundedly rational business sectors (Pasqualino and Jones 2020b). The basic research questions the model is designed to approach include: the energy transition from fossil fuels to green energy, impact of energy on food system via mutual feedback between food demand and biofuel production, impact of fiscal and monetary policies on the systems, and impact of climate on the economy. The results of the model calibration on a database of twenty time series makes us feel like the model should be considered as a level of evidence B based on Homer (2014) classification. Of course no global model should be used to try to answer precise questions, and that is why we feel that an A type of model would require further work with richer databases and most likely on the national scale.

The ERRE model is a relatively large model, composed of approximately 300 stock variables, 3500 auxiliaries, 600 parameters and 100 non-linear relationships. The model simulates from the year 2000 to 2050 and beyond. and calibrates on historical data from 2000 to 2018. It employs a standard top-down view on systems which justifies continuous time modelling. The integration method is Euler, with time step is 0.03125 years (approximately 11 days). The model is better placed to address medium to long term (5-10 years and beyond) system dynamics rather than short term business cycles. The full treatment of the ERRE model is out of scope for this paper, and it is suggested to consult the source Pasqualino and Jones (2020a) for a practical and theoretical description of the model, and the online material inclusive of all system equations, diagrams and behavioral tests performed at https://doi.org/10.25411/aru.10110710 (Pasqualino and Jones 2020b).

Figure 1: System boundaries and architecture of the ERRE

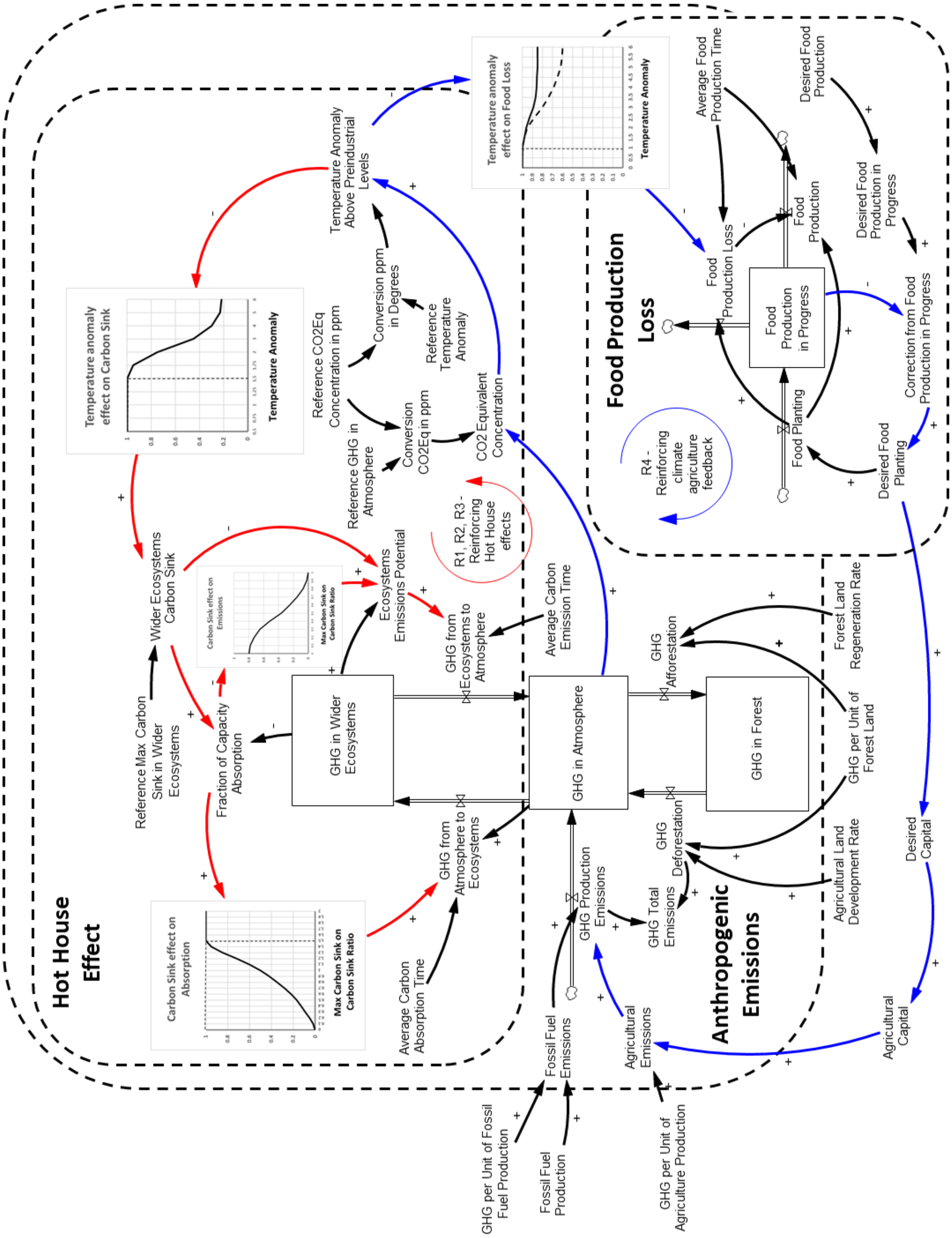


Climate Hot House and food loss

Recent literature and measurements based on a major ecological self-reinforcing feedback loop was proposed in Steffen et al. (2018) as the Hot House Earth effect. Steffen et al. (2018) argued that the strength of such a loop could have been underestimated by previous climate models resulting in unbalancing ecosystems and far greater risks for the economy than anticipated. In particular, despite the climate target of +2 degrees defined in 21st United Nations Conference of the Parties as part of the Paris Agreement, Steffen demonstrates that far before this increase in temperature, self-reinforcing ecological systems that could increase carbon in the atmosphere could be activated.

The hot house feedback loop is the only element of the climate system that was represented in the ERRE model, and that is where this paper focuses. Figure 2 shows the climate structure and impact on food loss adopted in the ERRE. As figure shows, anthropogenic emissions are dependent on fossil fuel production and agricultural capital (R4). These accumulate as carbon in the atmosphere, which is assumed being proportional to the temperature anomaly. Based on the structure adopted in the ERRE, temperature anomaly can lead to further carbon emissions and higher temperature anomaly via two major feedback loops (R1, R2. R3).

Figure 2: Climate structure and impact on food loss



Sensitivity analysis seeking reinforcing feedback

Figures 3 and 4 show the four major inputs tables applied to differentiate four scenario indicating the simulation as if the whole world is affected as a tropical or temperate area, in combination to the presence or not of the hot house effect. In particular, Figure 3 represents the relationship between change in temperature anomaly from 1850s level, and the impact on food loss. Targeting the worse scenarios as presented in IPCC (2014), both the two extremes of the relationship assume no mitigation measures and that the impact on wheat output could be extended as proxy to the entire food chain for both tropical and temperate areas worldwide.

Figure 3: Climate impact on food non-linearities to differentiate among the Temperate and Tropical scenarios

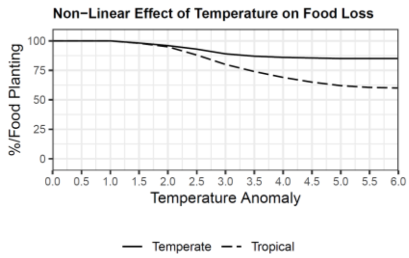
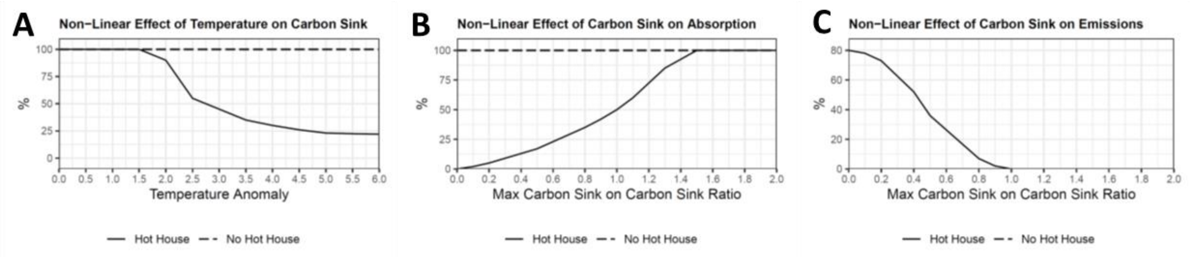


Figure 4A indicates what we test as a potential for the carbon emissions and the feedback generated from temperature anomaly back to the capacity of ecosystems carbon sinks to take all the carbon absorbed. Figure 4B and 4C control the in- and out-flow from Carbon in wider Ecosystems carbon to carbon in atmosphere and vice-versa.

Figure 4: Application of non-linearities to differentiate among the 'No Hot House' and the 'Hot House' scenarios



The comparative analysis adopted in this paper consists in the simulation and comparison of five scenarios:

1. Base run – Climate effect is not considered and the economy and food systems can grow as normal
2. Temperate Regions Without Hothouse – It is assumed that climate can have negative impact on food loss as described by the table Figure 6's low level risk curve, corresponding to what we consider here as the potential maximum case for temperate world regions.
3. Tropical regions Without Hot House - It is assumed that climate can have negative impact on food loss as described by the table Figure 3's high level risk curve, corresponding to what we consider here as the potential worse case for tropical world regions.

4. Temperate regions With Hothouse - It is assumed that climate can have negative impact on food loss as described by the table Figure 3’s low level risk curve, in combination with all non-linear relationships describing the hot house effect (Figure 4) are active.
5. Tropical regions With Hothouse - It is assumed that climate can have negative impact on food loss as described by the table Figure 3’s high level risk curve, in combination with all non-linear relationships describing the hot house effect (Figure 4) are active.

Results show that:

1. As today, we are on the trend for the +2 degrees carbon pattern by the year 2050.
2. Assuming Hot house effects (as with the non-linear relationships considered here) this can go to +3 degrees by mid century, in particular when not considering any mitigation policy.
3. The higher is the temperature anomaly, the higher is the emission from food.
4. The higher the temperature increase the higher would be the impact on food loss
5. Farmers, who need to generate income and respond to food demand, would tend to increase their production level while facing higher loss, and maintaining a satisfactory level of supply for the coming demand.
6. Without mitigation policies the increase in production is led by an increase in capital. This latter is proportional to emissions from agriculture, explaining the feedback dynamic in business as usual conditions.

Limitations

Given the global scale, no policy or technology change were considered in the analysis. Recommendation for future development include the possibility to regionalize the structure of the ERRE to national or regional levels, with the potential to connect these regions via networks. Since emphasis remains in a top-down perspective and continuous time modelling, we believe that the approach considered should be called Complex Inertial Networks, or rather Macro-Agent Based modelling. By lowering the scale of the system, this could enable to close the gap with specific governments that might be more affected by these type of feedback forces, calibrate the model with more precise data and potentially deepen the analysis including policy recommendations and technology scenarios.

References

Bardi, U. (2014). Extracted: How the quest for mineral wealth is plundering the planet. Chelsea Green Publishing.

Fiddaman, T. (2020a) Meta-SD: The Energy Transition and the Economy. Available online at: https://metasd.com/2010/03/the-energy-transition-and-the-economy/ (Accessed January 2020)

Fiddaman, T. (2020b) Meta-SD: World3-03. Available online at: https://metasd.com/2010/04/world3-03/ (accessed January 2020).

Fiddaman, T. S. (1997). *Feedback complexity in integrated climate-economy models.* Massachusetts Institute of Technology.

Forrester, J. W. (1980). Information-sources for modeling the national-economy-rejoinder. *Journal of the American Statistical Association*, *75*(371), 572–574.

Forrester, J. W. (2003). Economic theory for the new millennium (2003). *System Dynamics Review*, *29*(1), 26–41.

Homer, J. (2014). Levels of evidence in system dynamics modeling. System Dynamics Review, 30(1-2), 75-80.

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change / R. Pachauri and L. Meyer (editors) , Geneva, Switzerland, IPCC, 151 p., ISBN: 978-92-9169-143-2 .

Lloyd's Report. (2015). Food system shock – the insurance impacts of acute disruption to global food supply. Lloyd's Emerging Risk Report 2015, London.

Martin, R., & Schlüter, M. (2015). Combining system dynamics and agent-based modeling to analyze social-ecological interactions—an example from modeling restoration of a shallow lake. Frontiers in Environmental Science, 3, 66.Nordhaus, W. D. (1992). The'dice'model: Background and structure of a dynamic integrated climate-economy model of the economics of global warming (No. 1009). Cowles Foundation for Research in Economics, Yale University.

Meadows, D. H., Meadows, D. L., & Randers, J. (1992). *Beyond the limits: Global collapse or a sustainable future*. Earthscan Publications Ltd.

Meadows, D. H., Meadows, D. L., & Randers, J. (2003). *The limits to growth: The 30-year update*. Routledge.

Meadows, D. L., Behrens, W. W., Meadows, D. H., Naill, R. F., Randers, J., & Zahn, E. (1974). Dynamics of growth in a finite world. Wright-Allen Press, Cambridge, MA.

Meadows, D.H.; Meadows, D.L.; Randers, J.; Behrens, J. The Limits to Growth; Universe Books: New York, NY, USA, 1972.

NASA. (2019). *Data on carbon dioxide and temperature anomaly*. Available online: https://climate.nasa.gov/vital-signs/carbon-dioxide/ (accessed June 2019).

Pasqualino R. and Jones, A.W. (2020a). "Resources, Financial Risk and the Dynamics of Growth – Systems and Global Society". Routledge, Oxford, United Kingdom.

Pasqualino R. and Jones, A.W. (2020b) "Appendixes of: Resources, Financial Risk and the Dynamics of Growth – Systems and Global Society". Available online at https://doi.org/10.25411/aru.10110710 (Accesses February 2020).

Randers J, Rockström J, Stoknes P-E, Goluke U, Collste D, Cornell SE, Donges J (2019). Achieving the 17 Sustainable Development Goals within 9 planetary boundaries. Global Sustainability 2, e24, 1–11. https://doi.org/10.1017/sus.2019.22

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., . . . Crucifix, M. (2018). Trajectories of the earth system in the anthropocene. Proceedings of the National Academy of Sciences, 115(33), 8252–8259.

Sterman, J. (2018). System dynamics at sixty: the path forward. System Dynamics Review, 34(1-2), 5-47.Stern, N. (2006). Stern review on the economics of climate change, 2006. Government of the United Kingdom, London.

Sterman, J. D. (1981). *The energy transition and the economy: A system dynamics approach* (2 Vols.). MIT Alfred P. Sloan School of Management, Cambridge, MA.

Sterman, J. D. (2000). Business dynamics: Systems thinking and modeling for a complex world, McGraw-Hill, New York, USA.

Sterman, J. D. (2014). Interactive web-based simulations for strategy and sustainability: The MIT sloan learning edge management flight simulators, part I. System Dynamics Review, 30(1–2), 89–121.

Sterman, J. D., Fiddaman, T., Franck, T., Jones, A., McCauley, S., Rice, P., . . . Siegel, L. (2012). Climate interactive: The C-ROADS climate policy model. System Dynamics Review, 28, 295–305.

Teose, M., Ahmadizadeh, K., O'Mahony, E., Smith, R. L., Lu, Z., Ellner, S. P., ... & Grohn, Y. (2011, June). Embedding system dynamics in agent based models for complex adaptive systems. In Twenty-Second International Joint Conference on Artificial Intelligence.

Wijkman, A., & Rockström, J. (2013). Bankrupting nature: Denying our planetary boundaries. Routledge