Time series analysis of radiative forcing in a co-fired power system

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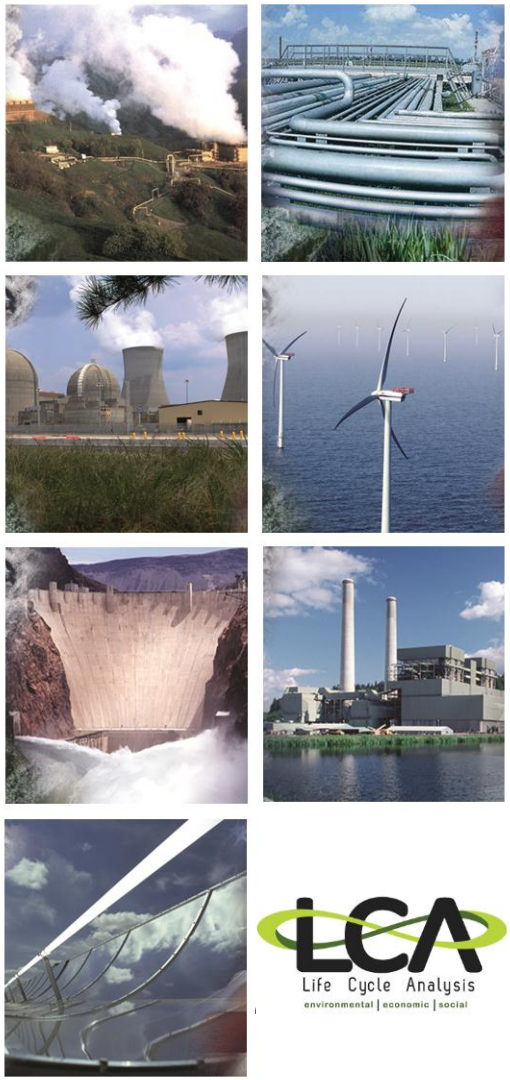
Overview of this study

- **A comparison of GHG emissions from a power plant using different feedstocks**
  - Coal and hybrid poplar
  - Coal and roundwood
  - Only coal
- **Accounting for temporal aspect of emissions and uptake**
- **Focus today is on methods and interesting aspects of the biomass systems**
  - Applicability of GWP metric
  - Direct & indirect land use change (DLUC & ILUC)
  - Temporal difference between biomass uptake and emission
  - Modeling choice of uptake/emission order



GWP is widely used and can be a reasonable climate metric

- **Works best when comparing systems that have similar emission types and temporal profiles**

- **Is defined using cumulative radiative forcing (CFR)**
  - Tracks well with integrated temperature potential*
  - Accounts for total impacts over a time horizon

- **Comparing fossil and biomass systems can result in different temporal boundaries**
  - We decided to look more closely at the actual climate effects of each system over time

Peters, G. P., Aamaas, B., Berntsen, T. & Fuglestvedt, J. S. (2011) The integrated global temperature change potential (iGTP) and relationships between emission metrics. Environmental Research Letters, *6(4), 0044021.*

Details of the system

- **Power plant**
  - New 200 MW circulating fluidized bed (CFB) facility
  - 100% coal or 70% coal and 30% biomass feedstock
  - 30 years of operation

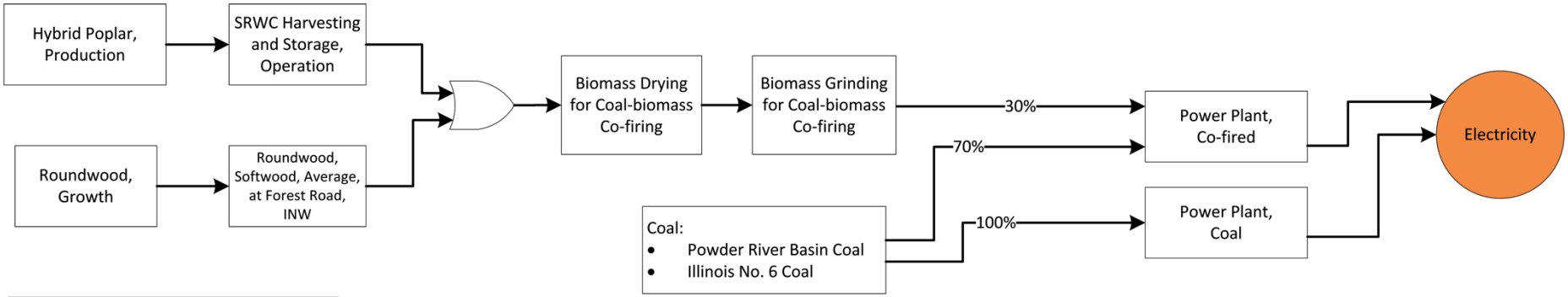
- **Feedstocks**
  - Inner Northwest (INW) roundwood has 60+ year growth cycle
    - *Not a realistic fuel source for power, used to test time series effects*
  - Hybrid poplar from corn belt
  - National average of bituminous and subbituminous coal

- **GHG timing issues**
  - Roundwood growth before or after combustion
  - Hybrid poplar land use change emissions for last 80 years

- **Cumulative radiative forcing used as metric**
  - Calculated using data from IPCC AR5 without climate-carbon feedbacks

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., ... & Midgley, P. M. (2013). Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

System diagram



Legend

- Process
- Final product
- Or gate (multiple inputs)

Data sources:

- Coal, hybrid poplar, and forest residue feedstocks developed by NETL
- Roundwood feedstock developed by CORRIM
- Power plant performance data from NETL reports and public Virginia City Hybrid Energy Center data

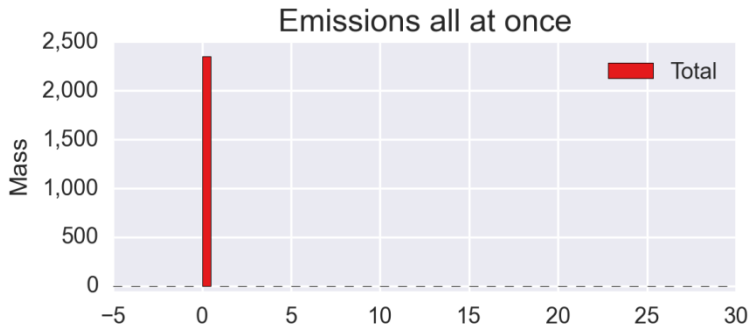
A standard LCA does not address timing well

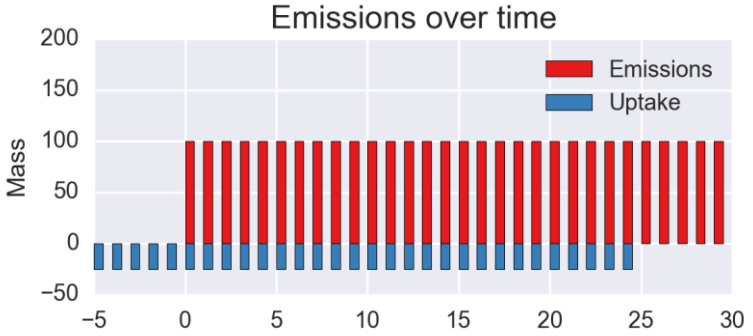
Standard LCA

- All emissions (and uptake) modeled as a pulse at t=0
- Results are given in CO_2e units, which represent cumulative radiative forcing
- 100 year GWP is usually reported, 20 year GWP sometimes used

This analysis

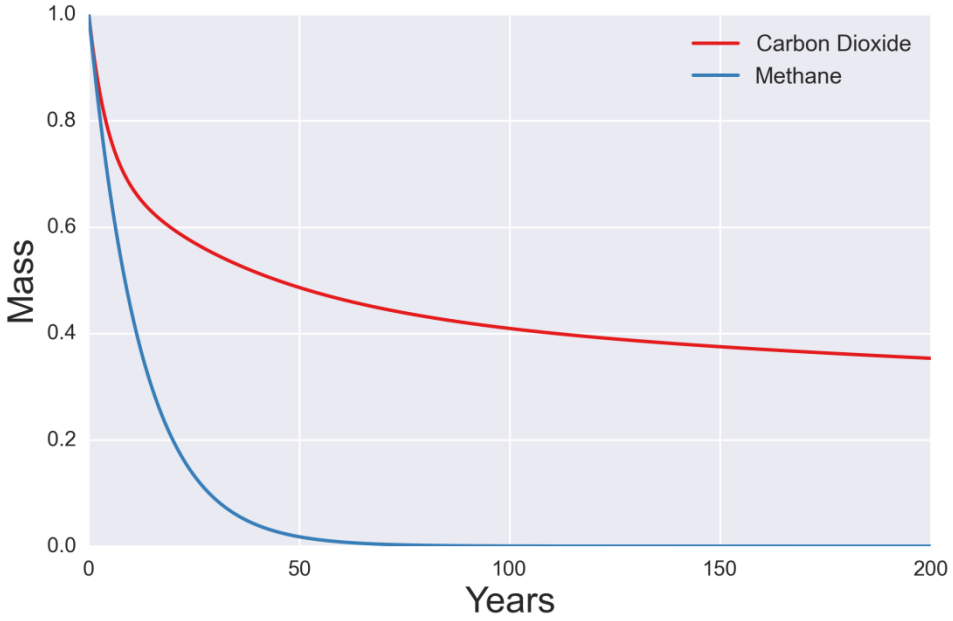
- Emissions spread out over time, accounting for 30 years of operation
- Uptake, land use change, and biomass combustion each take place on different time scales
- Results given in physical units
- Not limited to time frames of 20 and 100 years





Why does a standard LCA ignore emission timing?

Part 1: Impulse Response Function (IRF)



- Impulse: Release of 1 kg (or more) into the atmosphere
- Response: What happens to the mass over time
- GWP assumes that all emissions are released in the same pulse, but IRF can also be used with emissions that take place over time

Generic IRF

$$\mathrm{IRF}_x(t) = \exp\left(\frac{-t}{\tau_x}\right)$$

CO_2 IRF

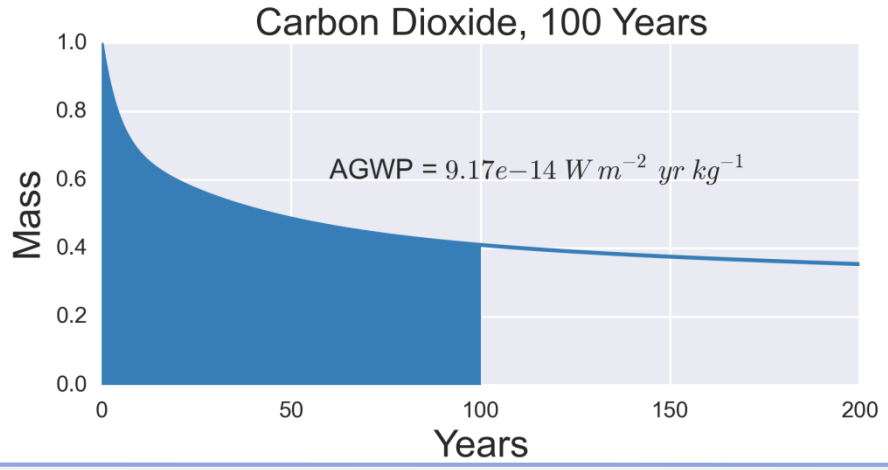
$$\mathrm{IRF}_{CO_2}(t) = a_0 + \sum_i a_i \cdot \exp\left(\frac{-t}{\tau_i}\right)$$

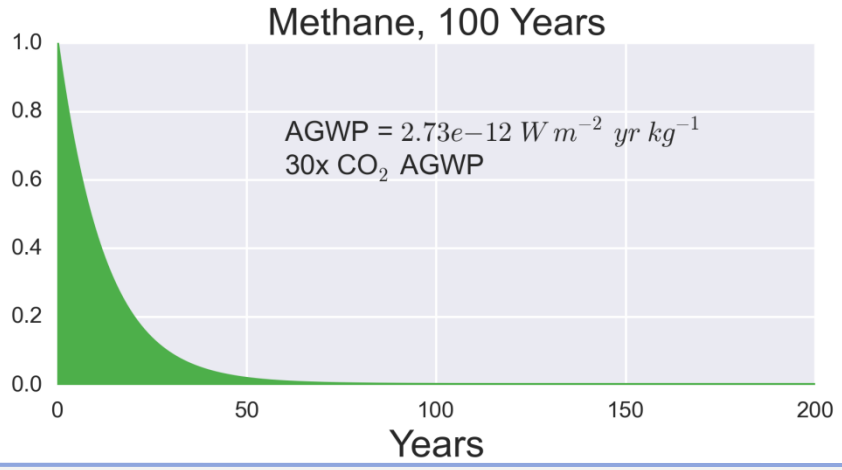
Joos, F., Roth, R., Fuglestvedt, J. S., Peters, G. P., Enting, I. G., Bloh, W. V., ... & Weaver, A. J. (2013). Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis. Atmospheric Chemistry and Physics, 13(5), 2793-2825.

Why does a standard LCA ignore emission timing?

Part 2: Cumulative Radiative Forcing

- **Radiative forcing is *mass x radiative efficiency**
  - Radiative efficiency of methane is 120 time larger than for CO2
  - Absolute global warming potential (AGWP) is the integrated (cumulative) radiative forcing of a pulse
- **Dividing the AGWP of CO_2 at 100 years into methane gives a GWP of 30**
- **GWP does not evaluate impact of all emissions from a system – which take place at different times – 20 or 100 year in the future**
  - Effectively collapses all emissions to a single point in time and evaluates at the time horizon based on that point

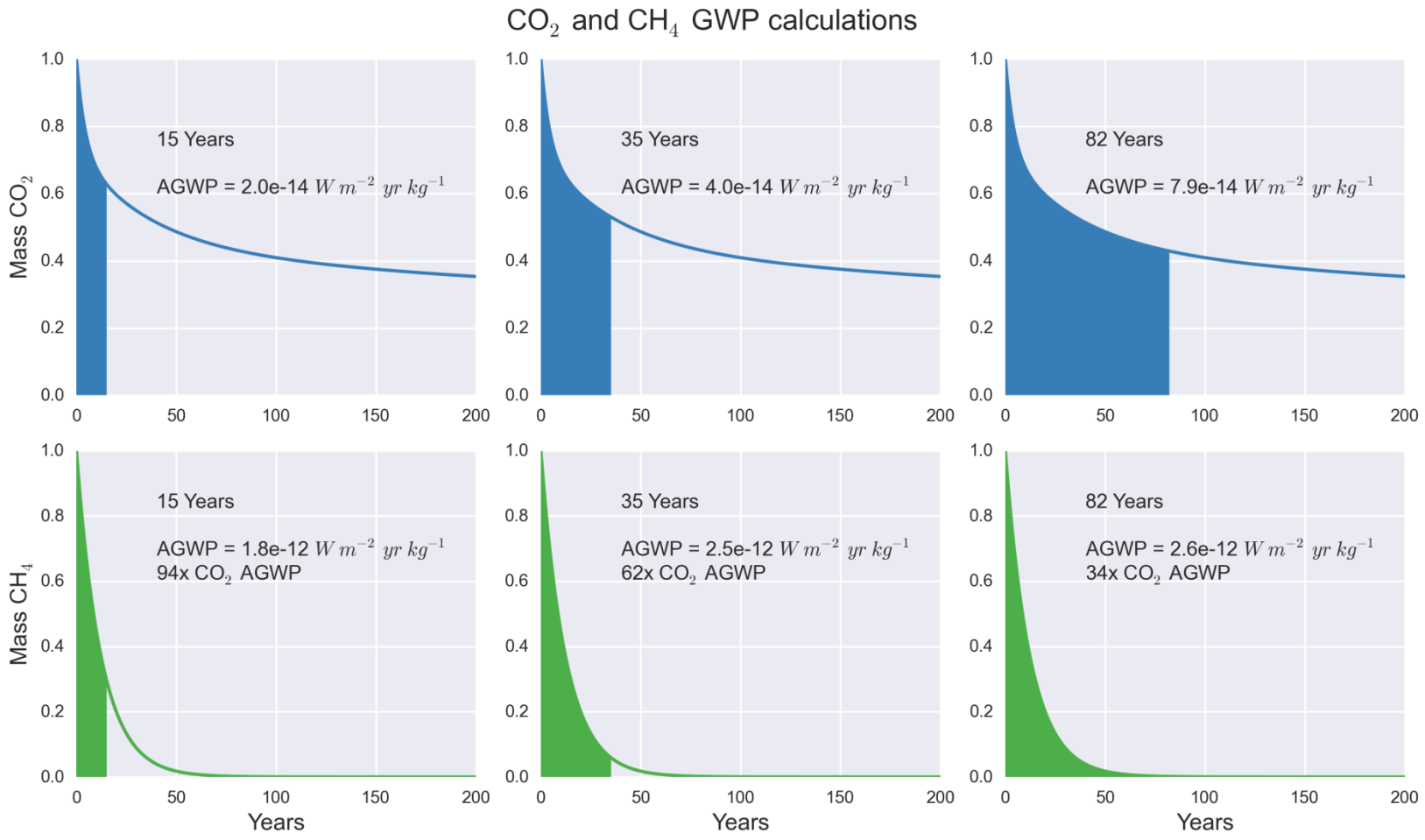




*Methane has extra indirect effects - Boucher, O., Friedlingstein, P., Collins, B., & Shine, K. P. (2009). The indirect global warming potential and global temperature change potential due to methane oxidation. Environmental Research Letters, 4(4).

Time horizons of 20 & 100 years are arbitrary

Calculation of other time horizons



Possible to calculate AGWP at any point in time; doing so allows evaluation of all emissions at a single point in time

Biomass systems have unique timing issues
Not well represented by GWP

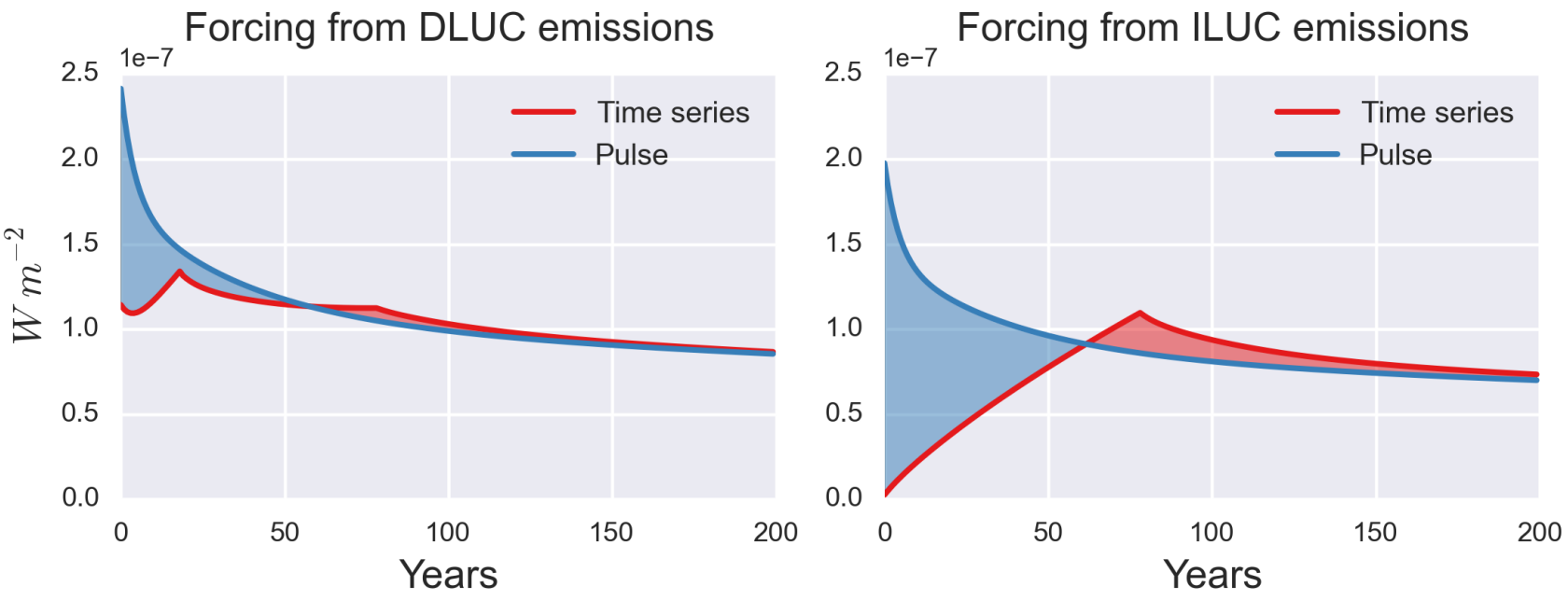
- **Land use change (LUC)**
  - Covers a long timeframe, even when looking at only 1 year of power generation
  - Modeled here as a fixed timeframe – no additional cultivation after start

- **CO_2 uptake and release**
  - Modeling choice: burn then grow, or grow then burn
  - Time element means integrated forcing will be non-zero either way
  - Biomass uptake reduces atmospheric concentration, reducing absorption by the ocean*

*Cherubini, F., Guest, G., & Strømman, A. H. (2012). Application of probability distributions to the modeling of biogenic CO2 fluxes in life cycle assessment. Global Change Biology Bioenergy, 4(6), 784-798.

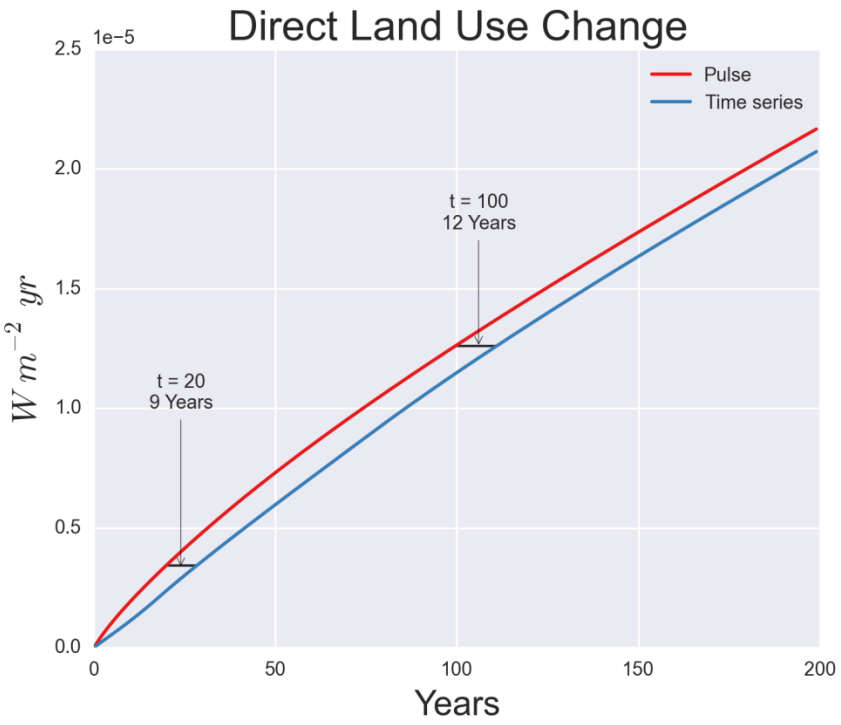
Some LUC emissions take place in the future

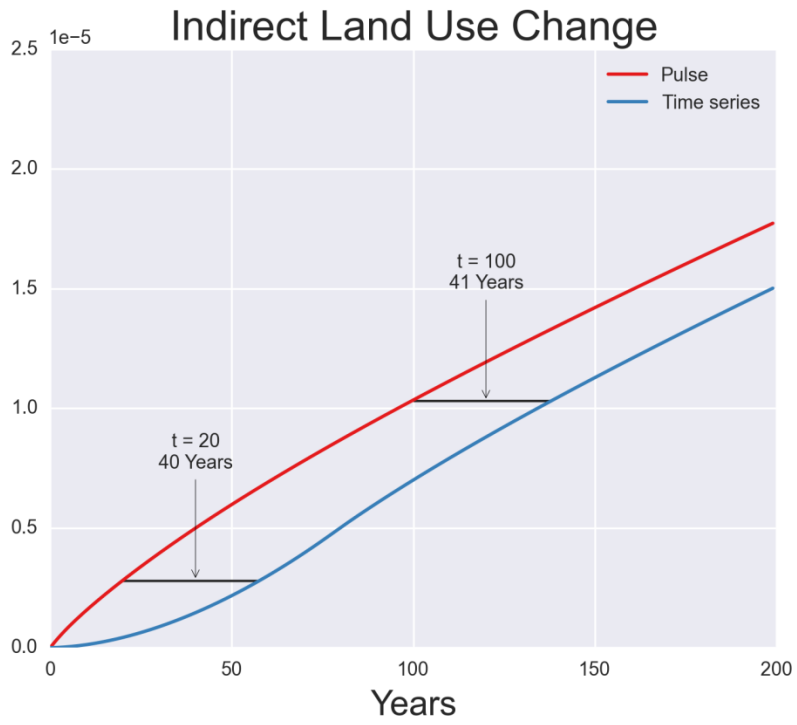
Forcing is reduced in early years



- **Almost half of DLUC emissions are in first year**
- **ILUC emissions are modeled as constant over time**
- **Both type of LUC approach the same level of forcing as the pulse assumption.**

ILUC has larger effect on cumulative forcing

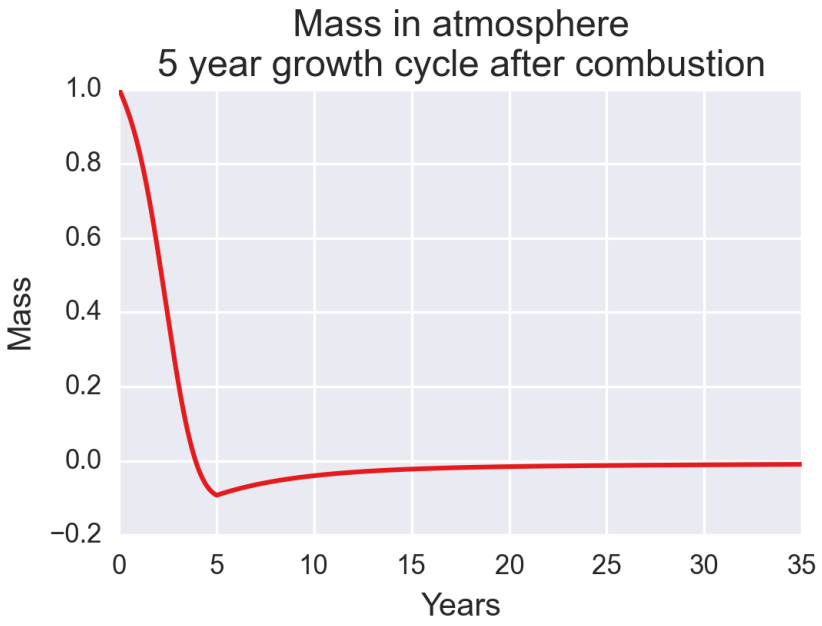


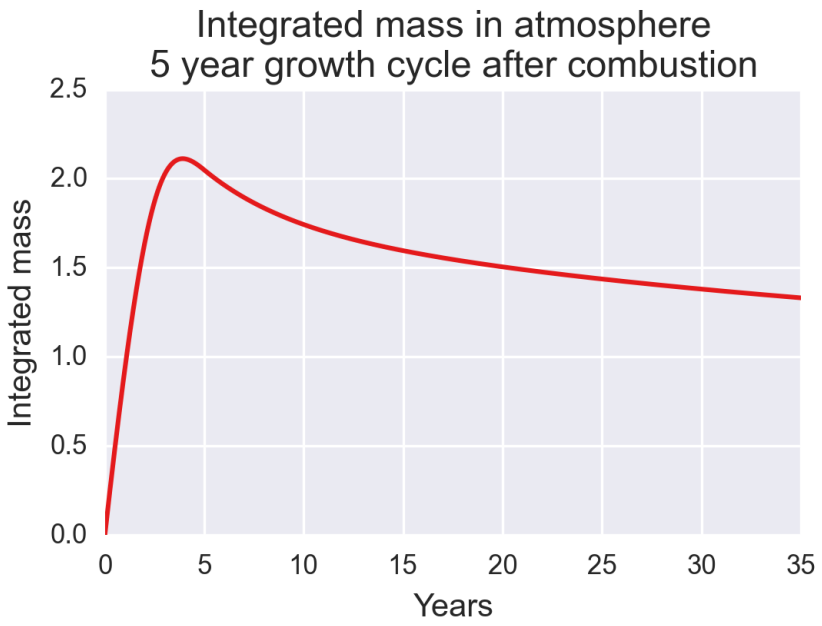


- **The difference in emission timing between DLUC and ILUC is apparent from the larger delay between equal ILUC AGWP values**
- **This leads to a delay of approximately 25 years for anticipated CRF from total LUC**

Time series shows that biomass uptake does not cancel emissions

- **Assume growth curves follow a normal distribution**
- **Uptake can be modeled as before or after combustion**
- **Following method of Cherubini *et al*, assuming that biomass uptake induces some emissions (or reduced uptake) from ocean**

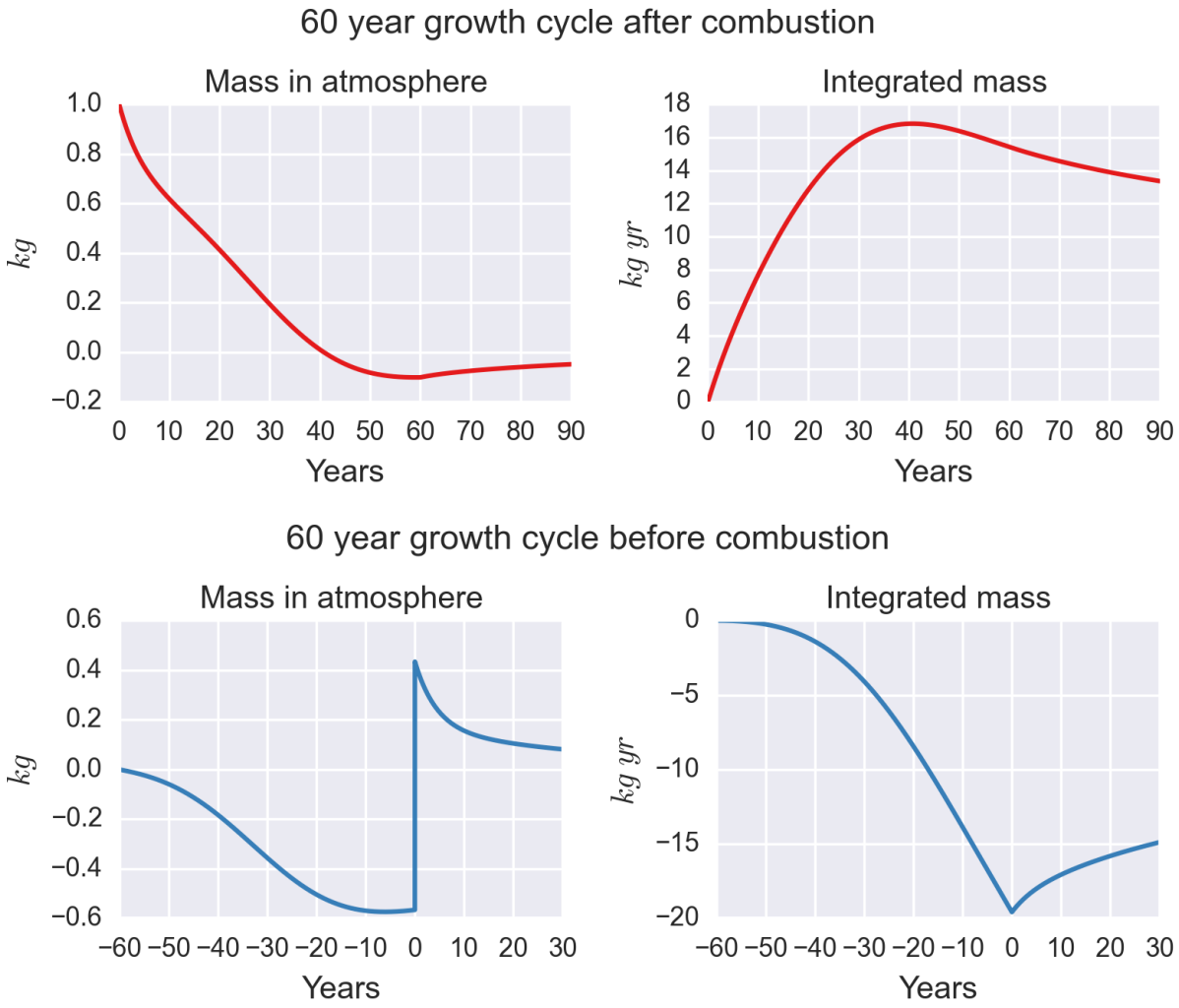




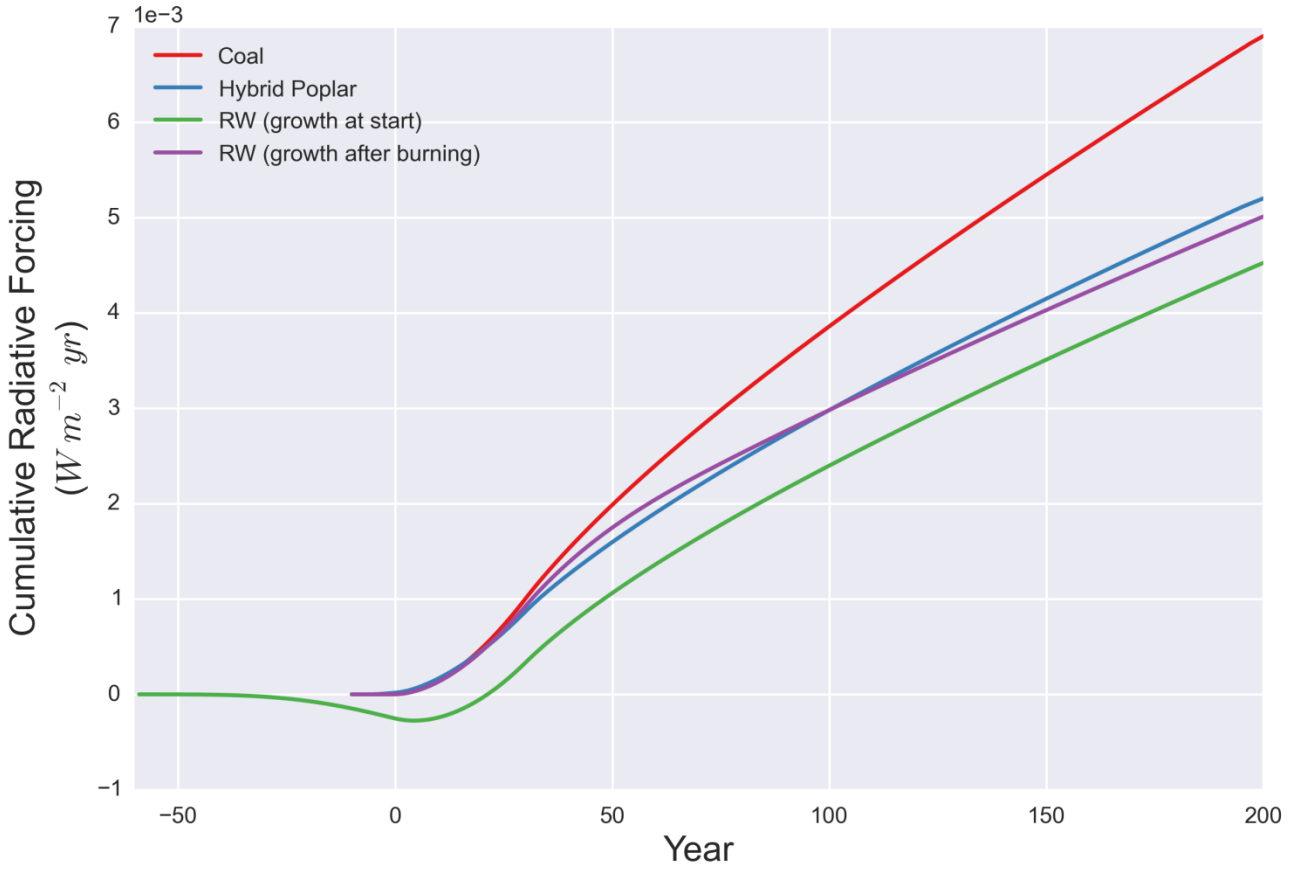
Cherubini, F., Guest, G., & Strømman, A. H. (2012). Application of probability distributions to the modeling of biogenic CO2 fluxes in life cycle assessment. Global Change Biology Bioenergy, 4(6), 784-798.

Growth before or after combustion matters for long rotation biomass

- **This is a modeling choice**
- **Cumulative mass/forcing is >0 when burning first**
- **Cumulative mass/forcing is <0 when growing first**
- **Again, long-growth biomass is an unlikely fuel source for power**

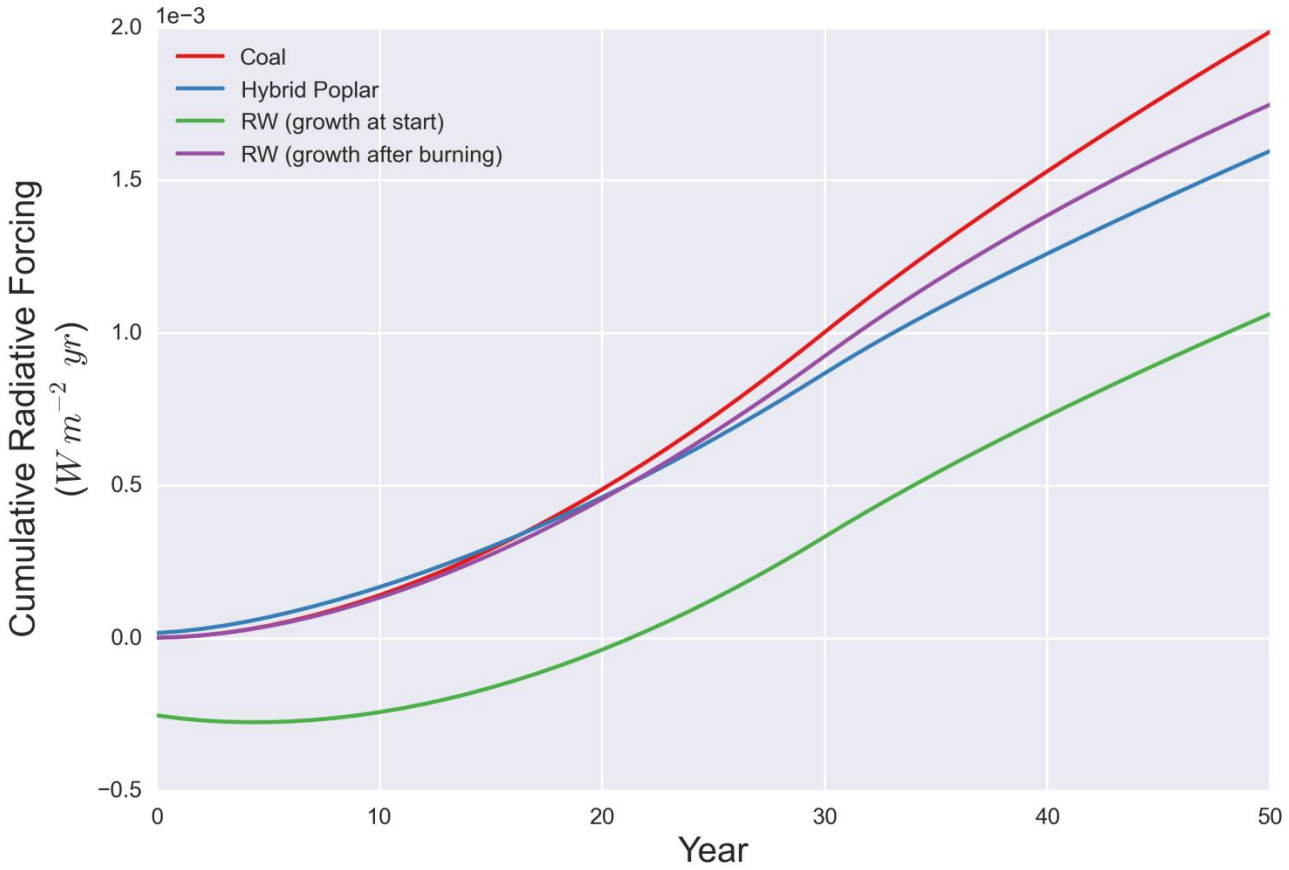


Co-fired biomass results in lower CRF over long time frames



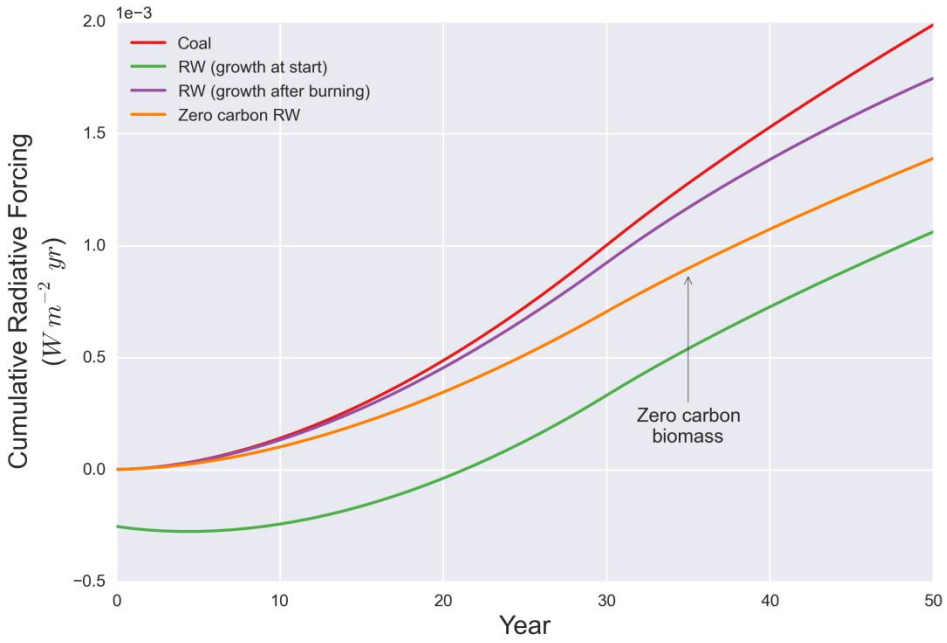
- **Difference between coal and co-fire systems continues to grow over time**
- **Within the co-fire systems, hybrid poplar and roundwood with growth after combustion are similar, switch in rank at 100 years**

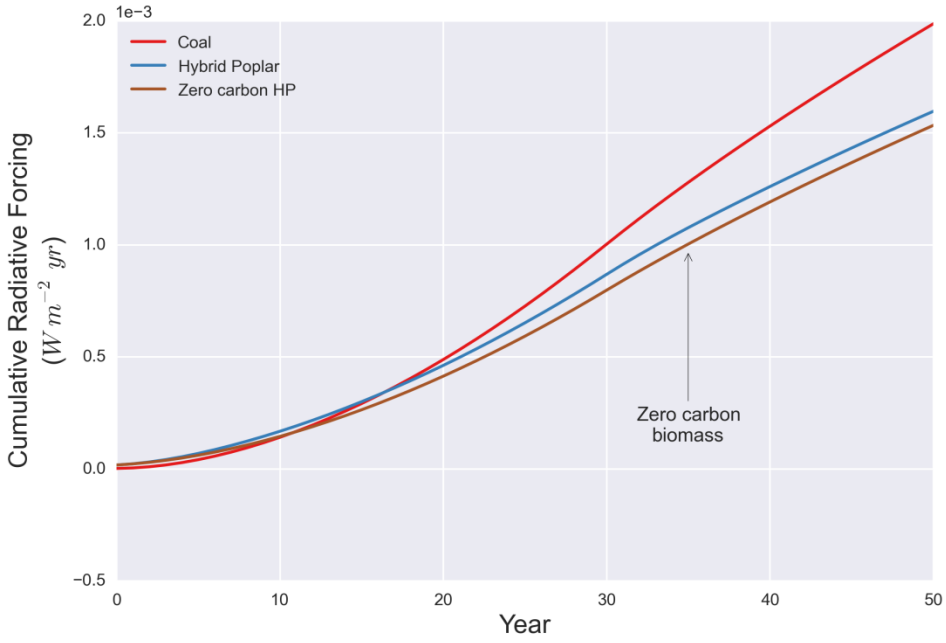
Most results are close during power plant operation



- **Hybrid poplar starts with largest CRF due to land use change**
- **Coal has higher AGWP after 17 years of electricity production**
- **Roundwood with growth first is always significantly better**

Ignoring biomass growth time has a larger effect on long rotation systems





- **Larger difference between RW growth after combustion and zero carbon biomass than coal and RW**
- **Smaller, but non-zero, effect on short rotation biomass**

Conclusions

- **The climate impact of a biomass system may not be well characterized by GWP**
  - Land use change happens over long time frames
  - Biomass uptake does not cancel out direct combustion emissions
  - Unable to examine model timing choices with GWP

- **Directly modeling forcing and CRF helps to show interesting aspects of emission timing**
  - Emissions that happen before power generation begins
  - Cross-over points in results
  - Large up-front effect of land use change

- **Recommendations**
  - At a minimum, visualize the spread of emissions/uptake over time
  - Use more sophisticated metrics or calculation methods if possible

Contact Us

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