Caroline

- Looked at three questions
    - What time-related challenges are there in AESA?
    - What are the current approaches to AESA of long-lived systems, and when are they not suitable?
    - How can the representation of changes over time be improved?
- Conducted two meta-reviews to answer question 1, and a review to answer question 2. Iterative evaluation of challenges and current approaches to answer question 3.
- Identified key challenges (in paper)
- In addressing challenges examined 13 review papers
- For overview of current approaches, 14 AESA studies were found
- Not a lot of consensus today on how to address changes over time across LCI, LCIA, Boundary approach, sharing data, or coverage of impact categories
- Overall recommendation:
    - More consistency in time horizons (terms, methods, application)
    - It is important to use more consistent approaches for future scenarios in all types of time horizons and phases of AESA
        - (SSPs and RCPs)
- Phases
    - Inventory
        - More consistently apply future scenarios through pLCA
        - Prospective foreground and background datasets
    - Impact assessment
        - Development of more prospective CFs, e.g. by:
            - Changes of response to emissions
            - Interactions in ecosystems
        - Differences in the impact of different time horizons and impacts = different temporal resolutions may be needed
    - Boundaries
        - Include/develop more prospective and dynamic boundaries, e.g. by:
            - Changes of response to emissions
            - Interactions in ecosystems
            - Effects of exceedance
    - Sharing boundaries
        - Include dynamic and/ prospective data from SSPs
- Questions

- Are there recommendations for handling uncertainty? How can compare a deterministic LCA result or range of LCA results against a range of SOS as various downscaling aspects can be applied?
  - Uncertainty in sharing/downscaling is often addressed through sensitivity analysis - so by applying a set of multiple different sharing principles so that we get a range of where the product impacts need to be approximately
- Do you have any suggestions/recommendations for considering uncertainty in AESA? When there are so many options for downscaling, how can we compare absolute impacts against a range of boundaries?
  - Summary: I would love any reference that you could share for examples if IAMs and SSPs in the building sector. To the best of her knowledge, this is a knowledge gap. There are examples of dynamic data for housing globally https://www.sciencedirect.com/science/article/pii/S0360132322011660
- Could you elaborate on what you mean with 'ecosystem interactions'? Like, how a particular function in an ecosystem can be affected by multiple pressures?
  - An example of an interaction in ecosystems/biosphere can be that modifications in land cover can result in the release of carbon, which contributes to climate change. In turn, increased atmospheric carbon concentrations can affect land cover in some regions. This specific example is from Lade et al. (2020) https://www.nature.com/articles/s41893-019-0454-4 .Thank you Caroline. You mentioned life time as a major uncertainty. Shouldn't this data point be the easiest to estimate for the producers?
  - It's not always straightforward. It is difficult to assess the lifetime of the products from the building perspective. Even though producers are certain of their lifetime estimates, the full building lifetime is still difficult to estimate.
- When the carbon budgets tend to go towards net-zero, for example, 2040, how beneficial is AESA, as all products need to reach net-zero?
  - Summary: Net zero depends on the boundary you apply. Some boundaries commonly applied in AESA do not work in net zero. Overall, there are similarities between the two, especially at the product level, but also nuances. https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.13481

Michael

- Returning within the planetary boundaries
  - Conduct an analysis on how future scenarios can bring us back within the planetary boundaries

    - Using the IPCC scenarios we can use some of the scenarios to explore how we can return within the planetary boundaries
- Looking at Future Hydrogen Production
    - See a growing need or reliance on hydrogen for future scenarios
    - But what are the impacts of this increased production?
    - Have worked to define a safe operating space (SOS) for hydrogen production
        - Once the SOS is established, then can conduct AESA
        - Look at potential interactions between boundaries when aiming to operate in SOS
        - Goal is to reduce impacts on all boundaries
    - Conduct a multi-objective optimization approach guided by the Earth system process interaction
        - Using Premise and AR6 to conduct prospective AESA
        - Utilize a range of scenarios rather than specific ones
    - Findings
        - Hydrogen production would rely on electrolytic and fossil fuels, with CCs production
            - But this requires a lot of renewable electricity
            - Would hinge on renewable energy
            - Meaning we would need even more than the current installed capacity
            - This is a challenge because a lot of electricity is needed for the decarbonisation of other sectors and industries that do not require hydrogen
        - At the planetary boundary level
            - The environmental boundaries space (SOS) shrinks faster than the processes can improve
            - It is not viable to reduce the impact of climate change at the expense of another boundary, as they will reach an equilibrium.
        - Process contribution to interaction
            - Again, here energy is a major factor
            - Renewable energy is the environmental hotspot to tackle
        - Which hydrogen production route is preferred
            - Bio-based consistently preforms worse than fossil + CCs and Electrolytic. Biogenic carbon does not work for hydrogen (we would emit carbon faster than the uptake during cultivation)
        - So how can we mitigate within the planetary boundaries
            - Carbon capture and sequestration is essential
                - At least |5kgCO2eq/kgH2 would be required

            - Biochemical flows are still an issue because of copper mining
            - However, we still trade off environmental sustainability with economic sustainability.
            - The system is likely to be economically unviable
    - Limitations
        - The Earth-system process interaction model is still at an early stage of development. It should be considered initial and conservative.
        - Lots of uncertainty not addressed (interaction model, characterisation factor, foreground and background system data etc..)
        - Global nature and geographic nuances are challenges and should be the focus of future work
        - Prospective LCA scenario is REMIND-based, different IAM models(IMAGE, GCAM etc..) need to be included to tackle the bias in REMIND scenarios.
        - Economically unfeasible, need to integrate the economics in the approach.
        - Economy-wide consequential assessment needed to capture the decarbonisation potential of hydrogen.
- Questions:
    - To me, producing & consuming less as a society seems like a more obvious solution than compensation with DACS. Is this something you (plan to) address this in your article? E.g. do you also discuss to what ends hydrogen is produced and what those production forecasts entail?
        - Summary: Hydrogen is a decarbonization tool; therefore, decreasing the demand for hydrogen production would be counterproductive. Perhaps the focus could then be on decreasing the electricity consumption instead. Demand-side solutions should be explored but it is beyond our scope.
    - Thanks Michael for your work. You mentioned DACS as a mitigation option, indeed mentioning the major economic tradeoff. I can confirm that costs are currently not allowing scalability of DACS. Would you be conformable to say that AESA confirms that *de-facto* bio-based materials are a false solution?
        - Summary: This needs to be contextualized with the end-use. Hydrogen is a short-term product, so it would not make sense. Emissions happen faster than the carbon uptake. But for other long-term products like plastics, it is a different story. The carbon would be sequestrated in polymer and biomass has time to regrow.
        - The economics are not studied in this work, but we know there is a surely a trade-off with economic sustainability.
        - From audience: Burning biomass to produce electricity to make hydrogen to make then fuels is the false-solution

        - Michael: In general, biomass should be avoided. That's what our results show.
        - But, biomass is not burned to make electricity and then make hydrogen. We gasify the biomass which is different. Waste biomass to make biogas is already something we do at scale. The question is scalability to meet the hydrogen demand. We also need to ask ourselves why make hydrogen when we have already a good energy carrier (methane). So it really has to do with the end-use for hydrogen. That's however beyond our scope.
  - Hi, I have a basic question about AESA. I am wondering how you get an absolute limit for an intermediate product as hydrogen (or electricity) and not a final use product (as housing, transporting, feeding humans). In other terms, how do you settle sharing principles for an activity (as H2 production) which is just an intermediate product (H2)to meet a final need (eg mobility) ?
    - summary: There is energy supply and energy demand. We limited our scope to the production o of hydrogen and defined an allocation principle accordingly. If your focus is mobility, then you need to allocate a safe operating space for mobility, not hydrogen. Your allocated space should be in line with your goal and scope definition (e.g., functional unit) so you can normalise your impact with your allocated space.

Felix and Bastien

- Looking at mitigation strategies for aviation industry
  - AeroMAPS project
    - Created tool to allow aviation stakeholders to explore different scenarios
    - Takes the scenario -> overlays climate models (FaIR emulator)-> temperature increase ->identifies carbon budget or temperature increase
- Proposed the integration of prospective LCA in ***AeroMAPS***
  - Time-dependent models, building on Brightway and LCA algebraic
  - Example case
    - Long-term global aspirational goals (LTAG) for international aviation
    - Inventory – ecoinvent SSP2-RCP2.6 & IAM remind 3.0
    - LCIA – ReCiPe 2016
    - Main results
      - See increased land use from 2050 on due to biofuels
      - Highlights the CO2 is important but the non-CO2 impacts are also significant
    - AESA
      - Key Qs:

        - how to deal with already transgressed stock PBs
        - assessed statically (long term, no historic modelling) and dynamically (a variety of temporal time horizons, and historical data incorporated)
      - Economic-based approach (is equal to contribution to global GDP)
      - Ethic based approach (share of PB to aviation = emissions in "safe & just reference countries")
  - Are LCIA frameworks adapted to assess trajectories of AESA?
    - ♣ Dynamic AESA is able to assess the full emission profile.
- Questions:
  - To clarify the stock vs. flow boundaries: do you not treat climate impacts as both stock and flow? E.g., lifetime difference between CO2 and contrails means one is considered as more of a stock and the other more of a flow. I agree that this kind of logic is required for dynamic LCIA (and missing from current methods)
    - ♣ Indeed, climate impacts are treated as both stock and flow through the different contributions to radiative forcing (RF). The lifetime differences are directly reflected in the RF evolution: a decrease in CO2 will only slowly affect the RF (≈ stock), while a decrease in short-lived climate forcers will lead to a rapid change in RF (≈ flow).
  - Very nice presentations. With your results, would you be able to work "in reverse" and design a "maximum allowed demand" trajectory per country e.g. in flights per year (per person?)? I think it would be important to contribute to the policy discussion on aviation.
    - ♣ Absolutely. This was done for example in ISAE-SUPAERO's "Aviation and Climate Report" available here. In Chapter 9, different technological scenarios were assumed, and sustainable air traffic (de)growth rates were derived depending on the carbon budget allocated to aviation. The analyses were carried out with a carbon budget approach (+1.5 and +2°C temperature increases).
    - ♣ If using the historical responsibility approach combined with the Planetary Boundaries framework (e.g. +1 W/m2 boundary on climate change already transgressed), the resulting "maximum allowed demand" at a global scale would actually be zero flights per person per year (at least until the accumulated CO_2 degradation takes effect and aviation returns within its allocated share). Another possible outcome is that some level of carbon dioxide removal would be required first, in order to regenerate a budget that could then be redistributed as flights per person per year. However, if we move away from the global level and consider more

granular scales (regions, countries, age groups, or socio-economic classes for example) the picture could become more nuanced. Historical responsibilities and unequal contributions to PBs transgressions could justify differentiated flight allowances per person. This would directly link the analysis to distributive justice questions, which are indeed central for informing fair and effective aviation policies.

    - Note that the AeroMAPS version that was presented is a simplified interface for e.g. the general public. More advanced capabilities are available open-source through Jupyter notebooks hosted on the GitHub repository (https://github.com/AeroMAPS/AeroMAPS

- Why did you choose Remind, SSP2 & RECP2.6 (out of all available options) for your analysis within AeroMAPS?
    - It's only an illustrative case. More IAM-SSP-RCP are used in the paper. SSP2-RCP2.6 is "middle of the road" just as the aviation scenario under study. It is really important to choose an underlying scenario for pLCA that is consistent with our foreground (aviation) scenario.