Aviation Energy Transformation in Sweden

A case study of environmental assessment of the future transition pathways in socio-technical systems

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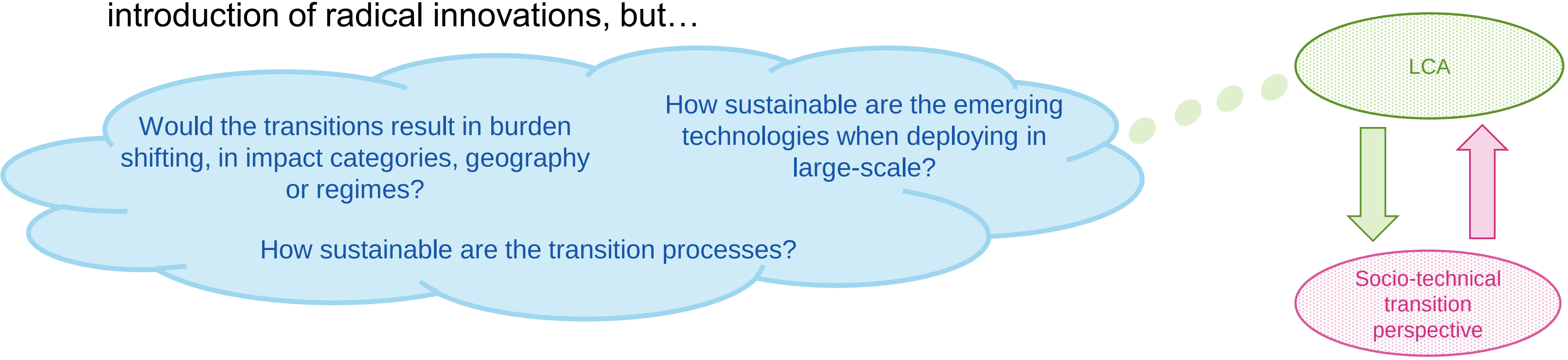
Problem formulation

- Aviation, a socio-technical system, relies 100% on fossil fuel.
- In Sweden, net zero emission at 2045 goal is forcing aviation to move away from fossil fuel.
- The call for aviation energy transformation is stimulating technological innovations.

- Transition research scholars study systematic changes and societal transformations enabled by the introduction of radical innovations, but…



Research question

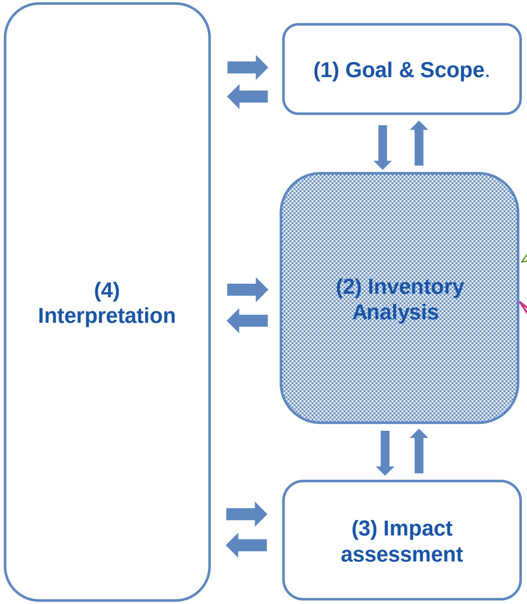
What are the potential environmental impacts of a future Swedish aviation energy system in year 2045, in comparison to a fossil fuel dependent system?

Preliminary LCA scope

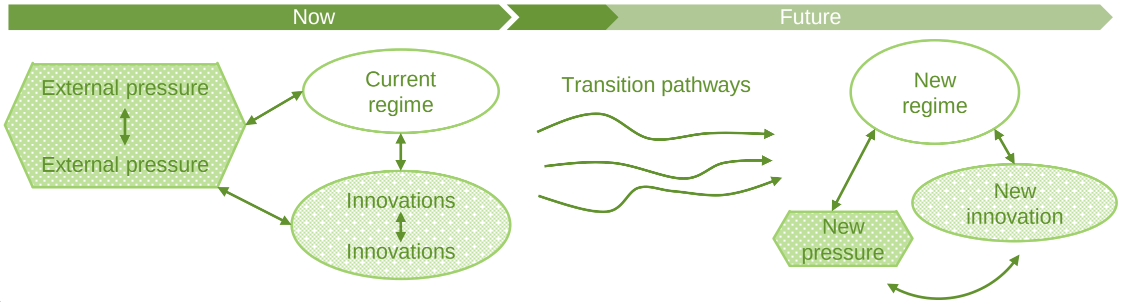
Functional unit	Environmental impact per MJ of a return flight
System boundary	Well to wake (or cradle to grave)
Geographical limit	Primarily Sweden, but may also consider Nordic region and destination countries
Time boundary	2045 – Sweden's net zero emission goal
Impact categories	Climate change, land use, resource depletion, acidification and eutrophication
Allocation rules	By economic values or cut-off method – To be determined

Methods

- **Prospective LCA**



- **Socio-technical scenario** *(Elzen & Hofman, 2007)*



- **Cross consistency assessment** *(Ritchey, 2015)*

		Consumer education	
		High	Low
Acceptance of technology	High	-	x
	Low	x	-

Preliminary findings

- Socio-Technical scenario

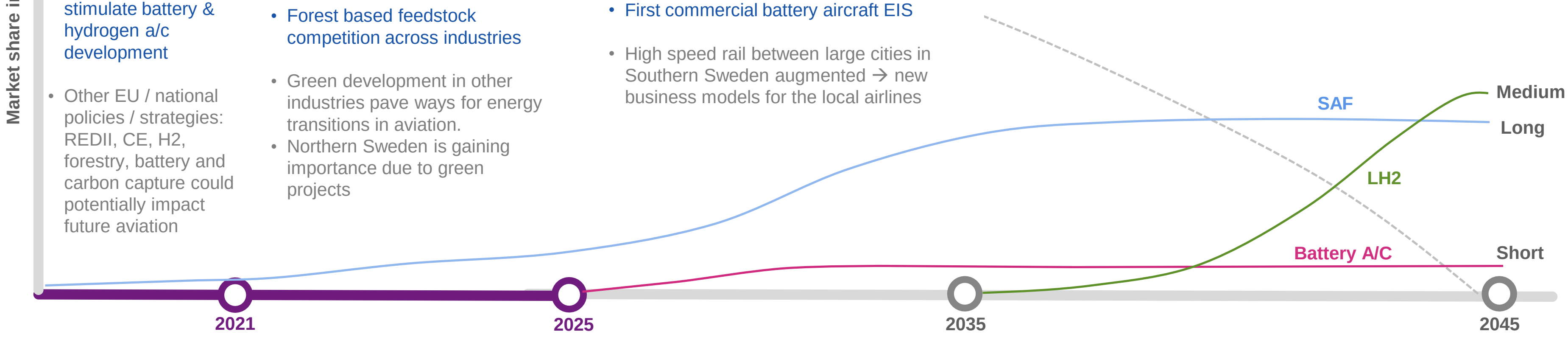
Fossil fuel

- Novel SAF production pathways under investigations
- Limitations of SAF stimulate battery & hydrogen a/c development
- Other EU / national policies / strategies: REDII, CE, H2, forestry, battery and carbon capture could potentially impact future aviation

- Local R&D budget
- Consumers' demand
- Incumbent regime actors form coalition to accelerate fossil free aviation
- Actors willing to adapt to and invest in novel technologies
- Forest based feedstock competition across industries
- Green development in other industries pave ways for energy transitions in aviation.
- Northern Sweden is gaining importance due to green projects

- Consumers willing to pay for SAF
- Large-scaled optimized SAF production facility
- Lack of BECCU to support electrofuel
- SAF import is necessary to meet 30% vol. blend
- First commercial battery aircraft EIS
- High speed rail between large cities in Southern Sweden augmented → new business models for the local airlines

- Construction of H2 infrastructure based on industrial experiences & EU H2 strategy
- First LH2 a/c prototype available for test flight
- Green electricity production expansion
- BECCU policy in place
- Airports are equipped with diversified infrastructure for varying needs.
- Collaborations between SAF suppliers in Nordic countries to secure supply



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Preliminary findings

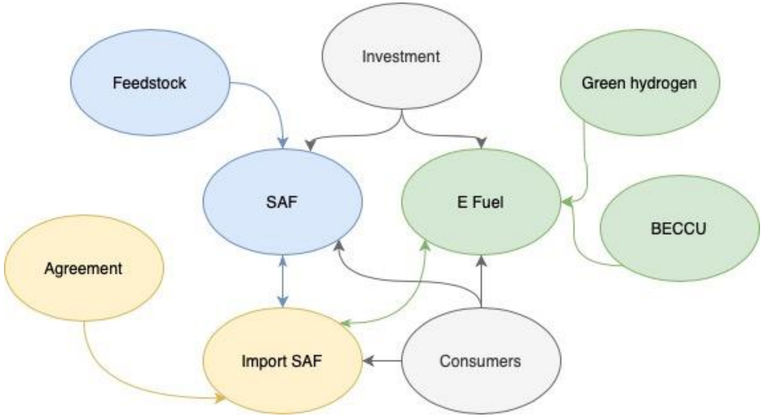
- Inventory analysis – sub-scenarios, influencing parameters & internal consistency check

Sub-scenario 1 – Long distance travel (100% SAF)

- Local production of wood based SAF
- Local production of electrofuel
- SAF production in Nordic countries
- Wooden material feedstock
- Investments to support large scaled deployment financially
- Consumers accept and willing to pay for SAF
- BECCU in place & green electricity allocated for green hydrogen production
- Nordic supply agreement

Assumptions

- ASTM approval for 100% SAF application in 2045
- Destination countries may not have SAF to support the return flight -> assume fossil fuel is used.



Two plausible consistent scenarios:
1) High volume of SAF & electrofuel production with low import of SAF;
2) High import of SAF with low local production

Preliminary findings

- Revised LCA scope and data collection:

Sub-scenario 1: Environmental impact per MJ of an average long haul return flight			
Well to pump	Pump to wake		Well to wake
Large scaled local SAF / electrofuel[1]	100% SAF trip	VS	Fossil fuel production + 100% fossil fuel trip
OR	OR		
Large scaled imported SAF	50% SAF + 50% fossil fuel		

	Foreground data highlights		Background data highlights
Sub-scenario 1			
• SAF production in Sweden & other Nordic countries	• Upscaling of both production and underlying technologies based on either experiences or learning curves	• Environmental impact of biogenic carbon based on projected EU policies , strategies and IPCC recommendations (SAF feedstock & BECCU)	• Electricity production or consumption mix in Sweden 2045 • Road and oceanic transport of SAF & fossil fuel in 2045 • Global average electricity production mix in 2045

[1] Assume there are high volume of feedstock available, high level of investment & policy support and high consumer acceptance of SAF production

Expected outcomes

- By integrating LCA and socio-technical scenario methods, it is expected to gain better understanding of
  - Sustainability of transitions by capturing
    - *Impact of the underlying technological processes (e.g. LH infrastructure, BECCU)*
    - *Potential burden shifting*
    - *Impact of technological process up-scaling*

  - Influences of other regimes or sector development
  - Potential impacts of alternative solutions than a particular technology in focus
  - Potential impacts of a system that depends on multiple emerging technologies

Thank you for your attention!

Any feedback, comments, questions are welcomed!

References

- Elzen, B. and Hofman, P., 2007. Exploring Future Transition Pathways-The Socio-Technical Scenario Approach.
- Ritchey, T., 2015. Principles of cross-consistency assessment in general morphological modelling. *Acta Morphologica Generalis*, *4*(2).