University of BRISTOL

AVDASI-3: Sustainable Aviation & Ethics

Lecture-3: Aircraft life cycle assessment (LCA) & circularity

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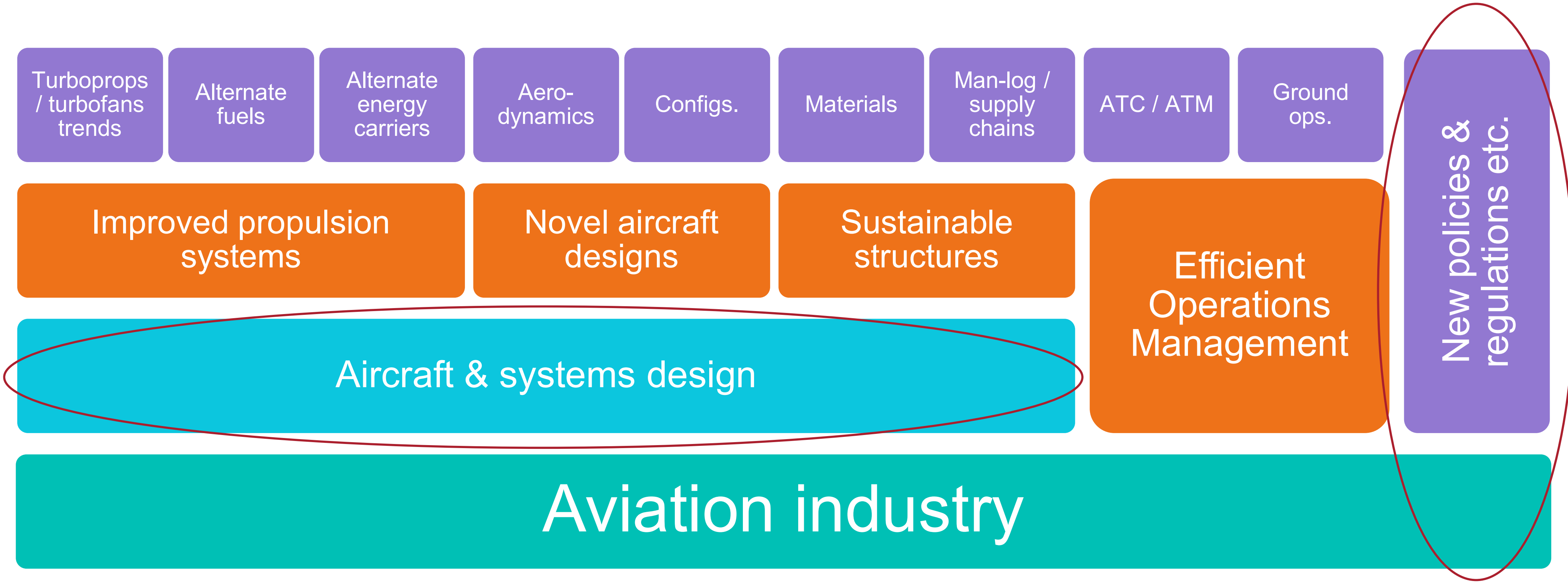
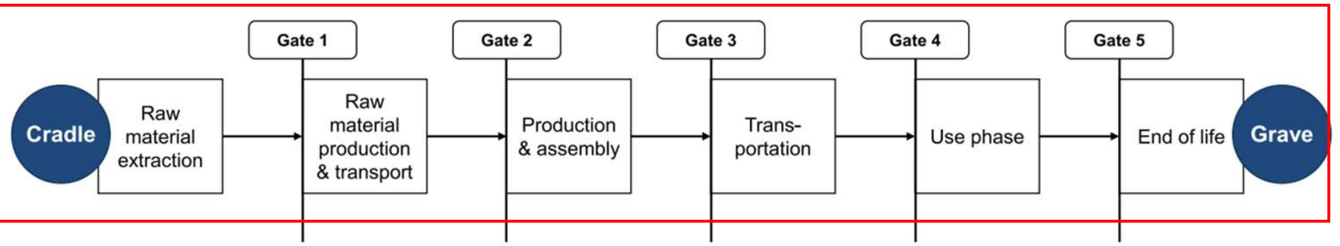
Building blocks for sustainable aviation



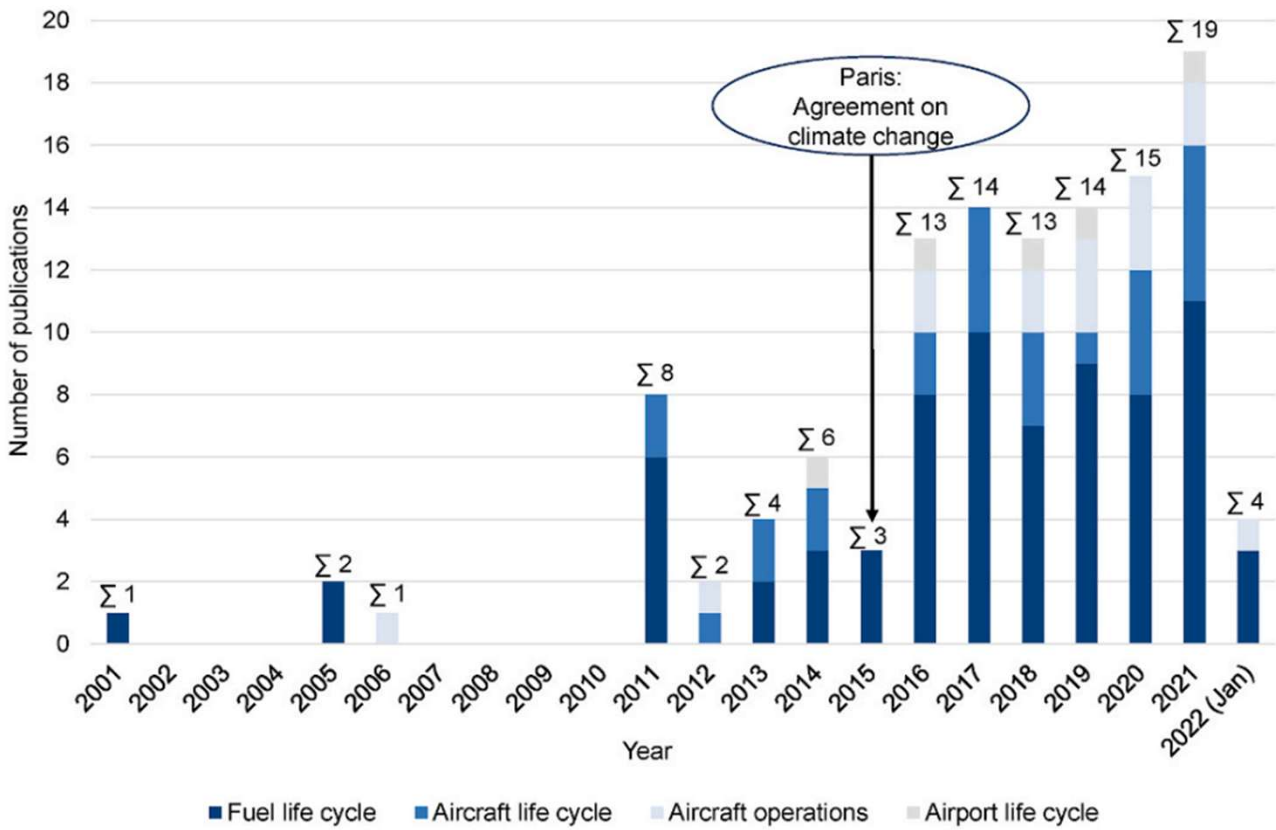
Aircraft lifecycle assessment

- Standardised method for quantifying environmental impacts - can be used to identify the most impactful stages of an aircraft's life cycle
- Phases
  - Goal and scope definition: Define the product system, boundaries, assumptions, and limitations
  - Inventory analysis: Compile and quantify inputs and outputs for the product throughout its life cycle
  - Impact assessment: Quantify the environmental impacts of the product
  - Interpretation: Interpret the results of the assessment
- LCA definitions
  - Cradle to grave / womb to tomb
  - Cradle to gate
  - Economic input-output (EIO) etc.



- Very less information available - very difficult to collect data, very few publication till recent times

LCA studies for aviation industry



[Life cycle assessment in aviation: A systematic literature review of applications, methodological approaches and challenges]

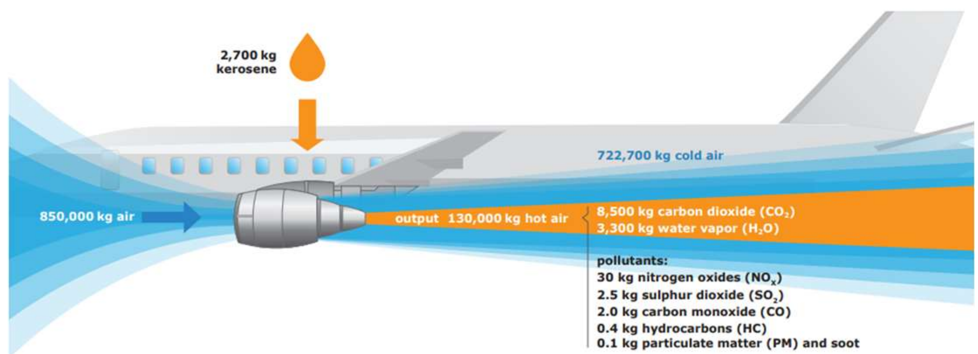
LCA basics

- Embodied energy
  - Energy spent to create 1 kg of finished product across all phases of it's lifecycle (MJ/kg)
- CO_2 footprint
  - Associated release of CO_2 or it's equivalent (kg/kg)
  - Global warming potential (GWP) for non-CO_2 products (approx.) with CO_2 as baseline
    - ➢ H_2O = 0.0005
    - ➢ CO_2 = 1
    - ➢ CH_4 = 25
    - ➢ N_2O = 280
    - ➢ Hydro fluoro carbons (HFC) = 14,000
    - ➢ Sulphur hexa fluorides (SF_6) = 23,000
    - ➢ SO_2 = no GWP assigned (precursor to aerosols & cooling)
  - Net GWP = $\Sigma(CO_2$ eqv. x mass)

GWP of flight

- Approx. GWPs
  - CO_2 = 1
  - H_2O = 0.0005
  - N_2O = 280
  - Rest: ignore
- GWP per hour of flight
  - GWP (CO_2) = 1 x 8,500
  - GWP (H_2O) = 0.0005 x 3,300
  - GWP (N_2O) = 280 x 30
  - Total GWP ~ 16,900 Kg CO_2 eqv. / h (in range of 110 kg CO_2 eqv. / pax-h)

Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers (Source: FOCA)



Contd…

GWP of flight (contd.)

- This CO_2 is generally emitted in higher atmosphere, and this is thought to have a greater greenhouse effect
- The emissions are therefore adjusted by a factor of 2 (**radiative forcing**) to give about 220 kg CO_2 equivalent / pax-h.
- Further allowance is needed for fossil fuel energy used in extraction, transport & processing of crude oil, aircraft manufacture and maintenance, staff training, airport construction, maintenance, heating, lighting etc.
- **The CO_2 emissions are rounded up to 250 kg CO_2 equivalent / pax-h**

Radiative forcing (RF) is the difference between the amount of energy entering the Earth's atmosphere and the amount leaving it.
[Radiative Forcing | MIT Climate Portal]

CO_2 released at higher altitudes has a higher radiative forcing because:
- Stronger IR absorption
- Greater direct impact on the Stratosphere
- Prolonged atmospheric lifetime due to delay in mixing & removal processes
- Feedback Mechanisms leading to contrails and cirrus clouds

Balance global CO_2 budget for 1.5°C limit is 400 bn tons from 2020 $\Rightarrow$ 50 tons CO_2 per person in lifetime
- Average emission country: will run out at by 2030
- High-emission countries like UK: by 2025!!!
- Is aviation sustainable???

Few popular LCA calculators

- OpenLCA
  - Free and open-source LCA tool, community-driven support
  - Compatible with major lifecycle inventory (LCI) databases like Ecoinvent
  - www.openlca.org
- SimaPro
  - Professional LCA software widely used for products
  - Comprehensive databases like Ecoinvent and Agri-footprint
  - Ideal for industries and academic research
  - www.simapro.com
- Sphera GaBi
  - Robust LCA tool for complex sustainability analyses
  - Sector-specific modules, scenario modeling and comparative analysis
  - Suitable for corporate sustainability strategies
  - www.gabi-software.com

Case Study using Ecoinvent 3.6

List is not exhaustive;
there are many other competitive LCA tools

CORSIA life-cycle assessment for SAF

- [CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels]

Core LCA [gCO_2e/MJ] =

$$e_{fc} + e_{fhc} + e_{fp} + e_{ft} + e_{fc} + e_{fut} + e_{fuc}$$

e_{fc} = feedstock cultivation
e_{fhc} = feedstock harvesting and collection
e_{fp} = feedstock processing
e_{ft} = feedstock transportation
e_{fc} = feedstock to-fuel conversion
e_{fut} = fuel transportation and distribution
e_{fuc} = fuel combustion in an aircraft engine

Any regional / seasonal variations up to 8 gCO_2e/MJ (10% of jet fuel baseline) is ignored, otherwise reasons investigated and harmonised

Contents lists available at ScienceDirect
Renewable and Sustainable Energy Reviews
journal homepage: www.elsevier.com/locate/rser
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CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels

Matteo Prussi[a], Uisung Lee[b,*], Michael Wang[b], Robert Malina[c], Hugo Valin[d], Farzad Taheripour[e], César Velarde[f], Mark D. Staples[g], Laura Lonza[h], James I. Hileman[i]

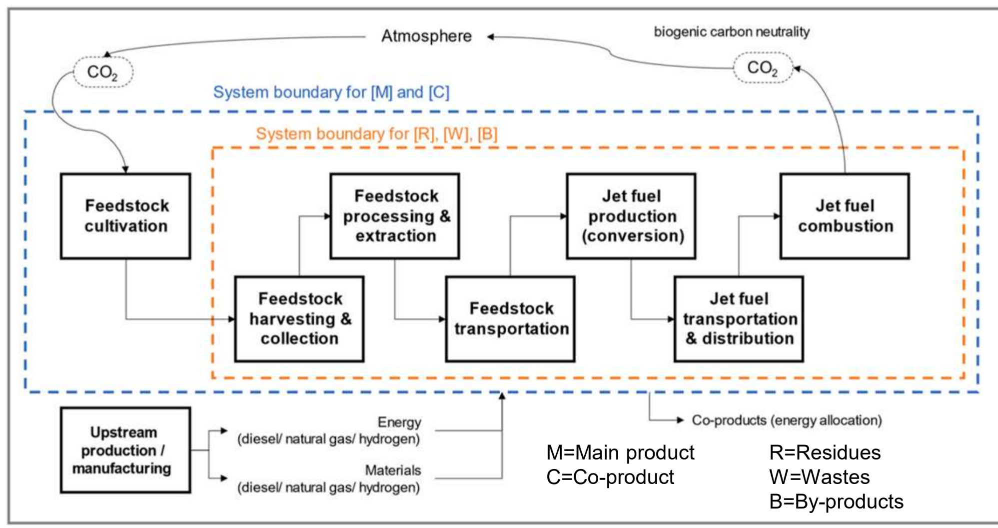


Fig. 1. The system boundary for core LCA of CORSIA SAFs.

Aircraft life(cycle?)

Carbon footprint of
HPC based designs
Design

Emissions from
aircraft & airport
operations
Operations

Manufacturing

Environmental
impacts from mining,
supply chains,
processing etc.

End-of-life

Waste dumps

Life Cycle Assessment
(LCA) impact
categories

LCA impact categories & examples

Environmental impacts

- Global warming (GHG)
- Air pollution
- Human toxicity
- Noise pollution

Used natural resources

- Fossil fuels (coal, petroleum etc.)
- Fresh water
- Mineral reserves

Waste types

- Hazardous
- Non-hazardous
- Radioactive

Output flows

- Components for reuse
- Materials for recycling
- Materials for energy recovery
- Waste incineration & landfill

Impact assessment framework for aviation

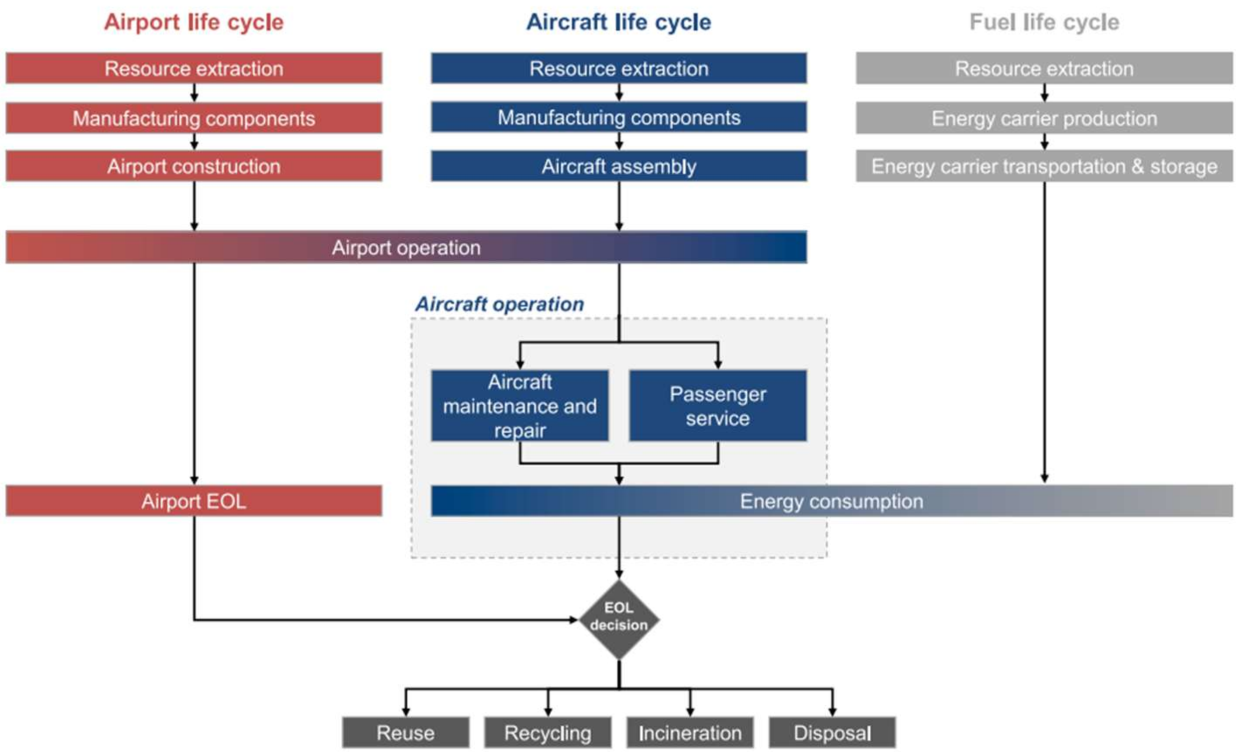
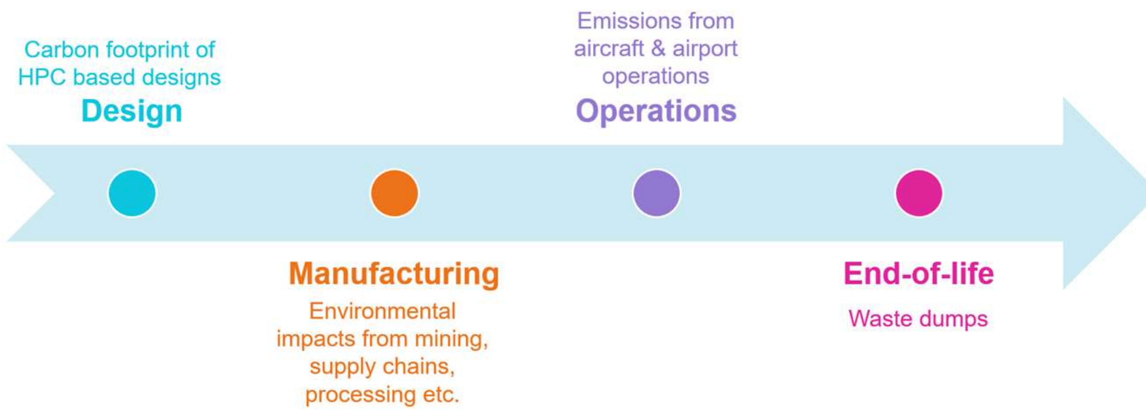


Fig. 2. Life cycles and system boundaries of the aviation industry for environmental impact assessment (adapted from Melo et al., 2020).

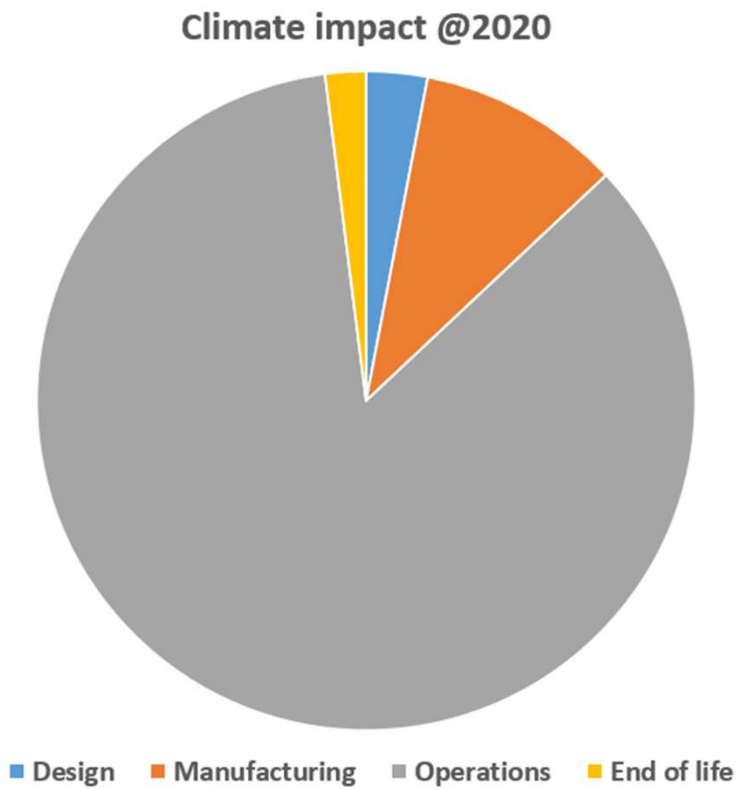
[Life cycle assessment in aviation: A systematic literature review of applications, methodological approaches and challenges]

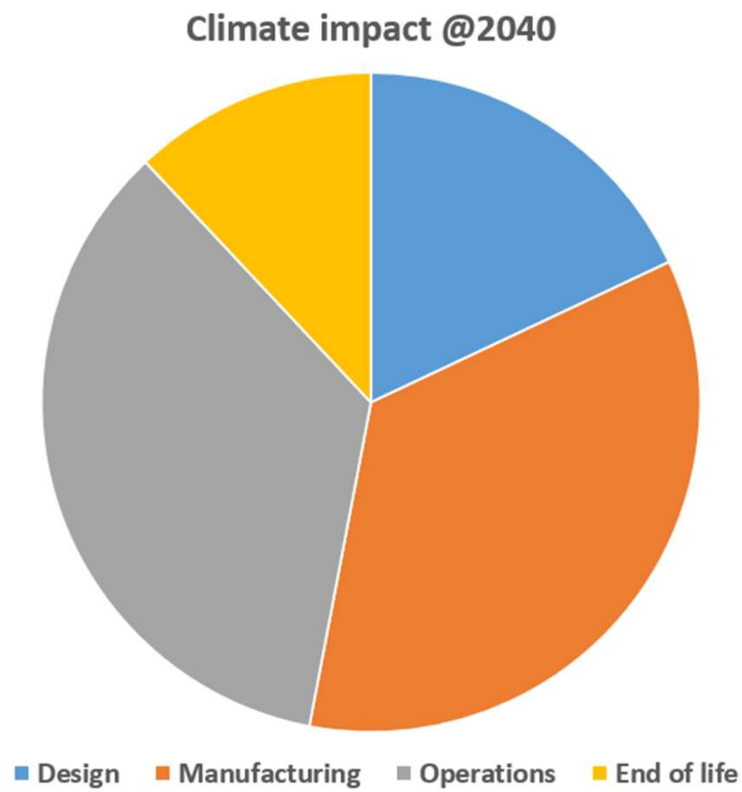
Conventional aircraft lifecycle design

- Linear (take-make-use-dispose)
- About 30-50 years from idea to end of life waste
- Main design drivers
  - ✓Weight
  - ✓Cost
  - ✓Performance
  - ✓Safety
  - X Environmental impact



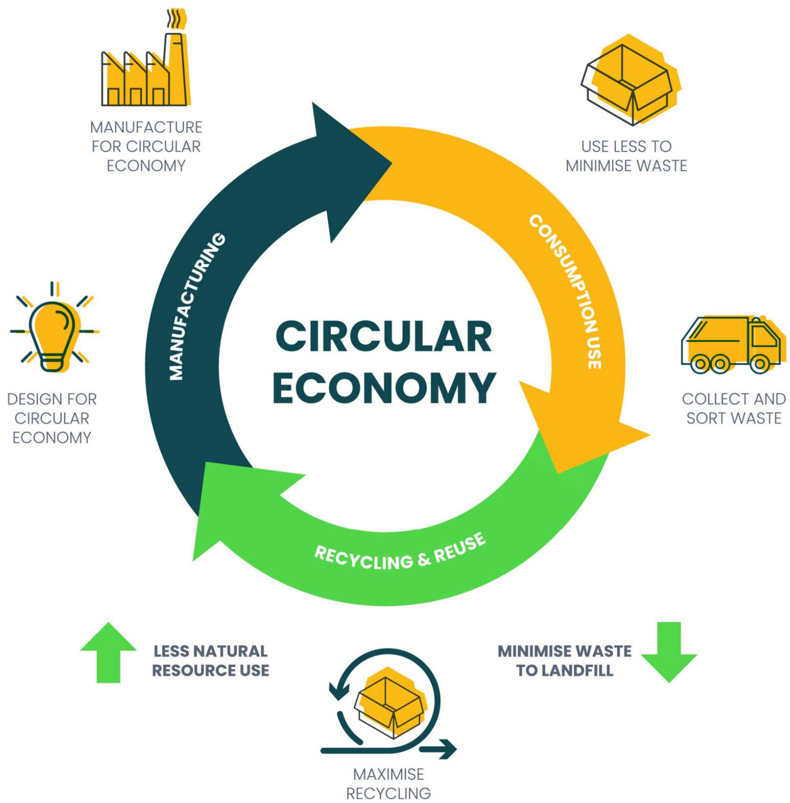
Rough Estimates of Climate Impacts of Aviation





- If currently planned measures are successful
- Larger share for manufacturing – needs attention
- Circularity?

Circular economy



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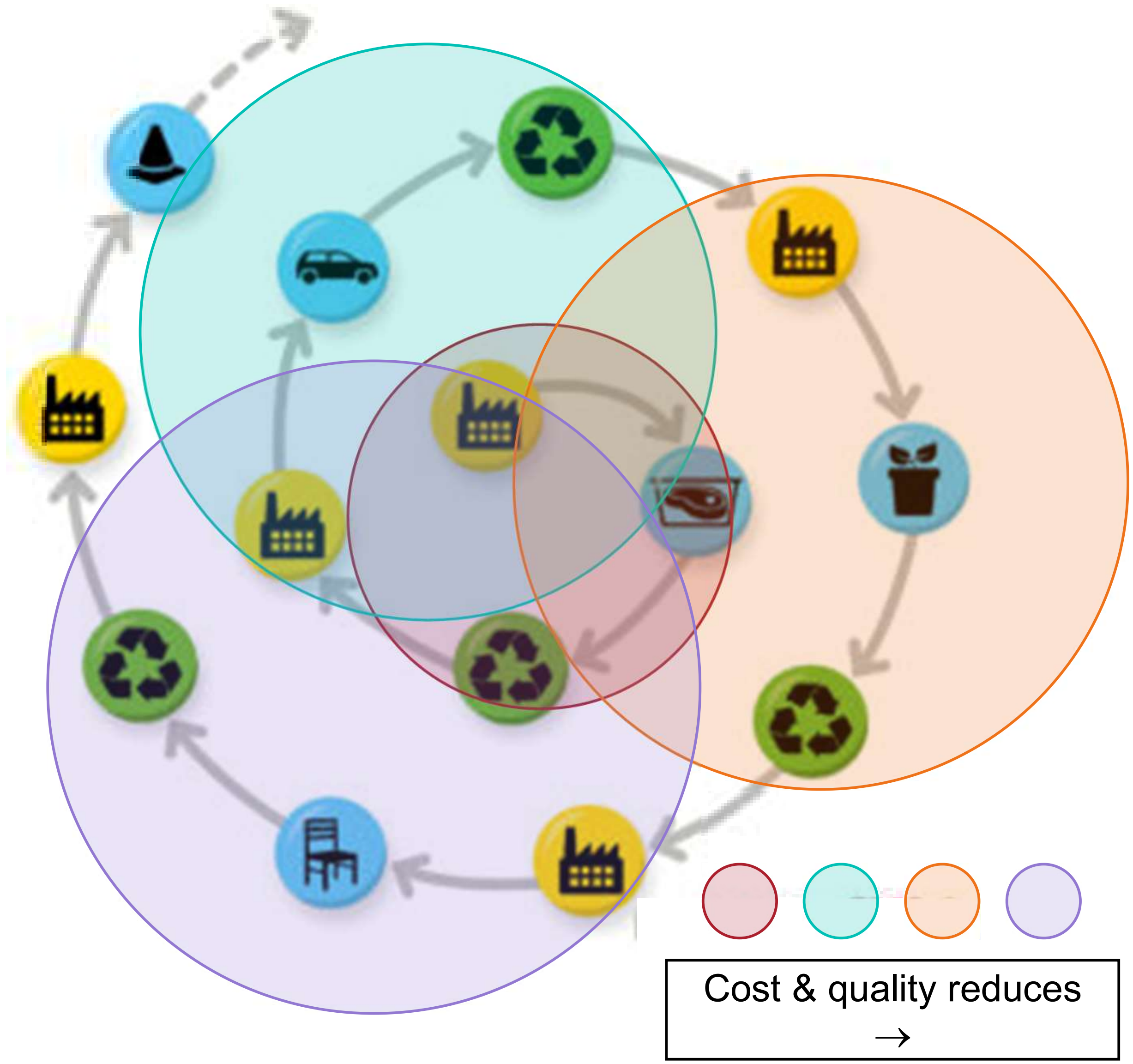
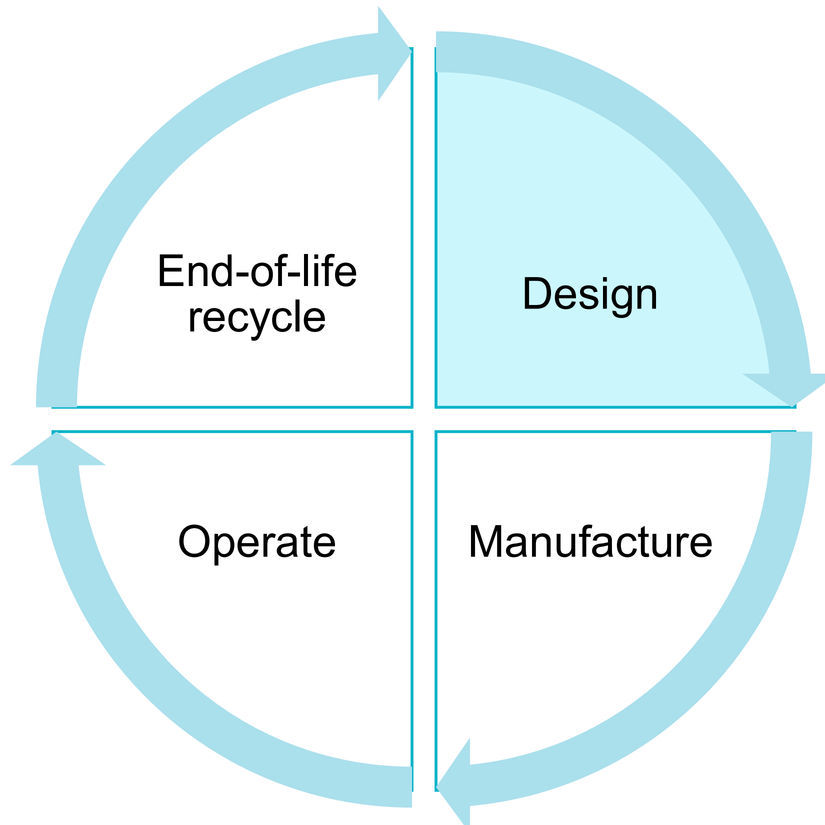


Circular lifecycle design

- Environmentally sound design of products
- Based on whole lifecycle
  - Design
  - Exploitation & processing of raw materials, pre-production, production, distribution, use and return back to the industrial cycle
  - Reduce the environmental impact of the whole lifecycle
- Design effects are relatively minor & not proportional
- Environmental impacts from:
  - High power computers & servers (max)
  - R&D equipment
  - Material qualification
  - Market exploration
  - Meetings (online & physical) etc.



Weight spiral – the nemesis of aircraft design

To maintain speed, T/O & landing distances, RoC etc.

Need to increase thrust

Weight increases

From larger surface area, bigger engines, more fuel etc.

Need to increase Lift

To balance the additional weight

Drag increases

Both lift induced (for higher lift) and skin friction (for higher surface area)

The inverse snowball promise

To maintain speed, T/O & landing distances, RoC etc.

Can reduce thrust

Weight decreases

From smaller surface area, smaller engines, less fuel etc.

Can reduce Lift

Enough to balance the reduced weight

Drag reduces

Both lift induced (for lower lift) and skin friction (for lower surface area)

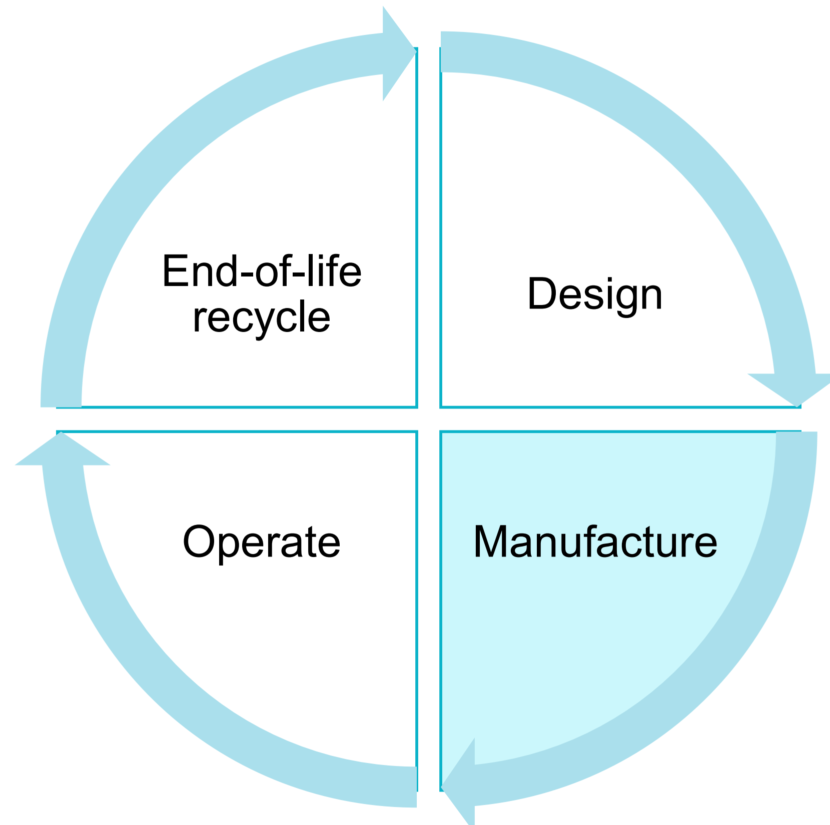
For each kg reduction of aircraft mass, about 372 kg less CO_2 is produced every year

Design drivers for sustainability

Will be covered later as part of Lectures (Configuration, aerodynamics, propulsion, structures / materials) on Sustainable Aircraft Design

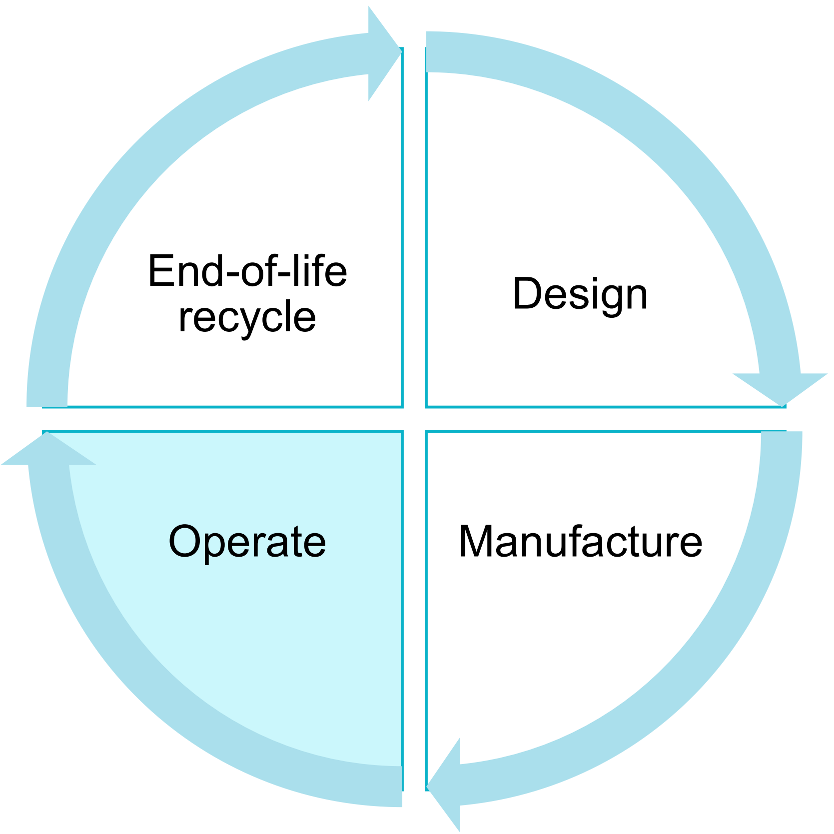
Materials & manufacturing for circularity

Will be covered later as part of Lecture on sustainable structures



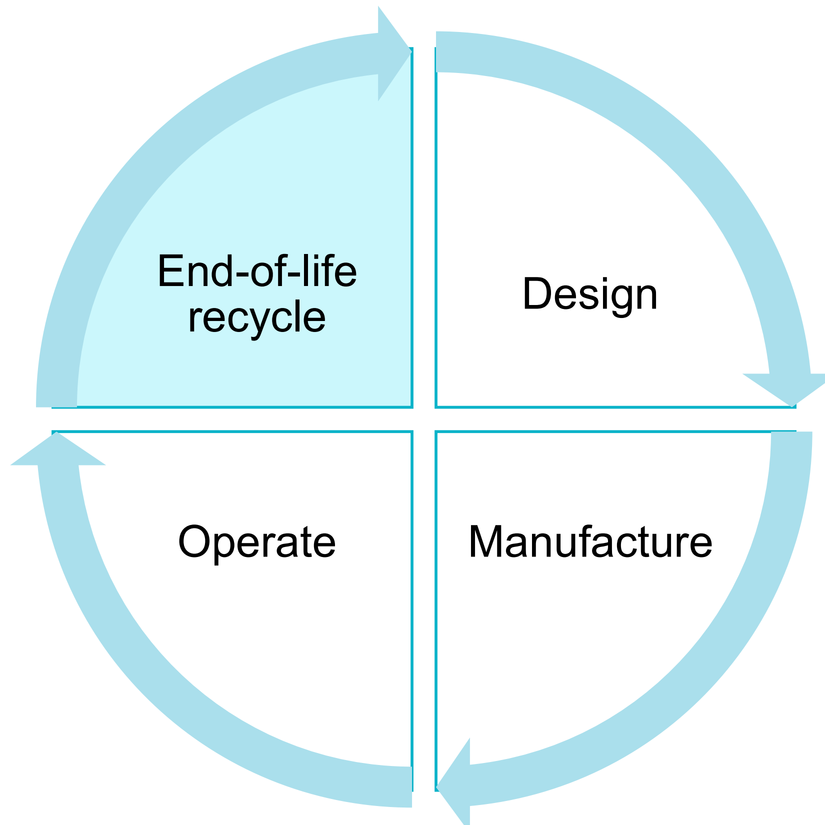
Aircraft operations for sustainability

Will be covered later as part of Lecture on Air Traffic Management & ground operations

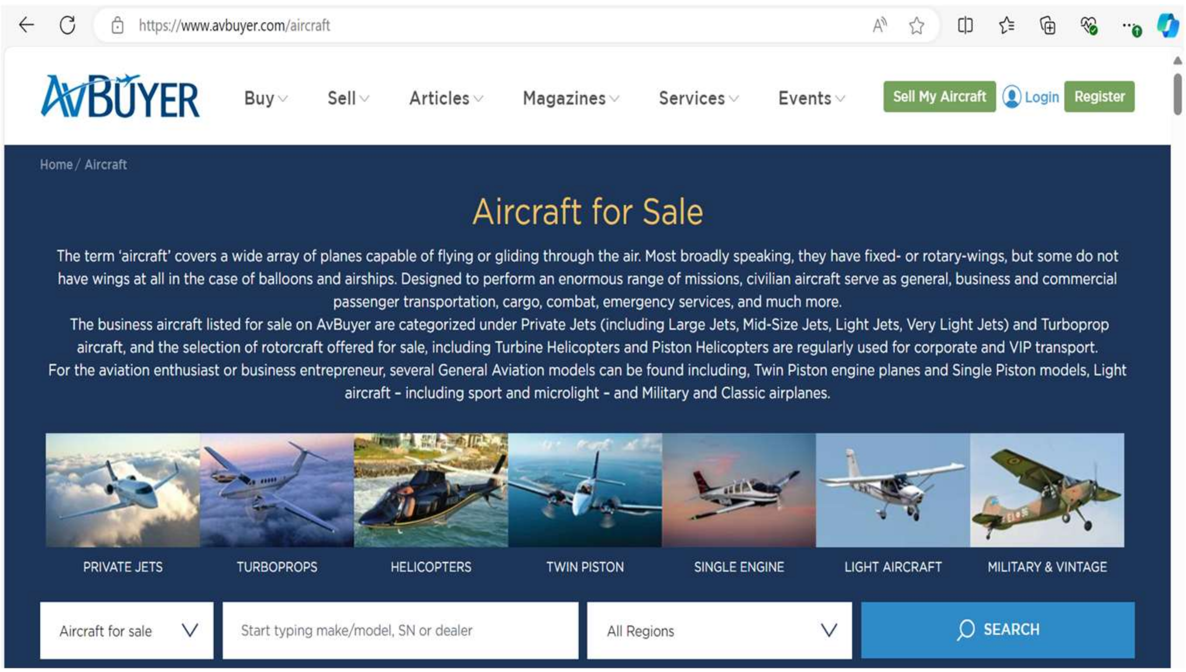


End-of-life management for circularity

- Average life of aircraft
  - Passenger aircraft: 25 years
  - Cargo aircraft: 32 years
  - Military aircraft: 20 years
- Disposal options
  - Sold as 2nd hand
  - Stored in yard (long term)
  - Decommissioned & recycled
    - Approx. 700 per year
    - Approx. 15000 for next 20 years



Disposal options



[A Guide to Sustainable Aircraft Decommissioning - Antala Ltd.]()

Recycling steps

- Step-1: Remove all hazardous materials
  - Fuel, hydraulic oil, waste-water etc.
- Step-2: Disassemble valuable parts (~50% wt.), repair (if needed) and re-use in the aviation market (components for re-use)
  - Undercarriage, engines, avionics, seats etc.
- Step-3: Dismantle parts (~ 35-40% wt.) and recycle for non-aviation market (materials for re-cycling / energy recovery)
  - Metallic parts, plastic interiors etc.
- Step-4: Incinerate / landfill with non-recyclable wastes (~10-15% wt.)
  - Carbon composites, insulation blankets, carpets, cushions, flame retardant panels etc.

AIR-International-Dec-21-aircraft-disassembly.pdf (wingborn.com)

Recycling challenges & mitigations

- Challenges
  - Increased use of thermoset composites & Li alloys
  - Lack of standardised legislations & regulations
  - Lack of business case in recycling
- Possible solutions
  - More use of thermoplastics
  - Industry scale recycling processes for composites & Li alloys
  - Design for end of life (fewer material combinations?)
  - Manufacture for dismantling (use fewer part counts, more traceability, joining processes like welding etc.)
  - Upcycling value stream creation

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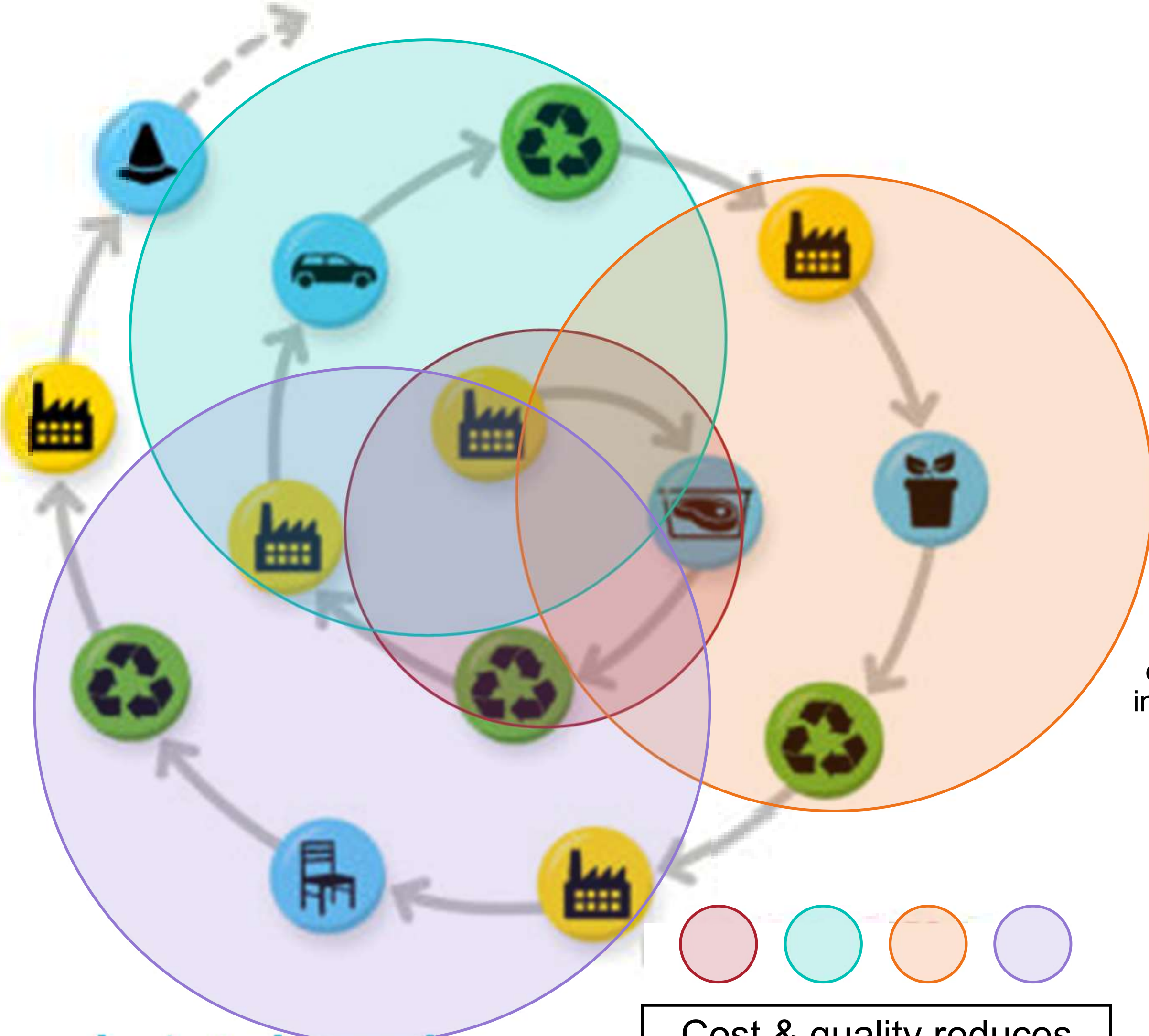
Towards a sustainable & circular aviation economy



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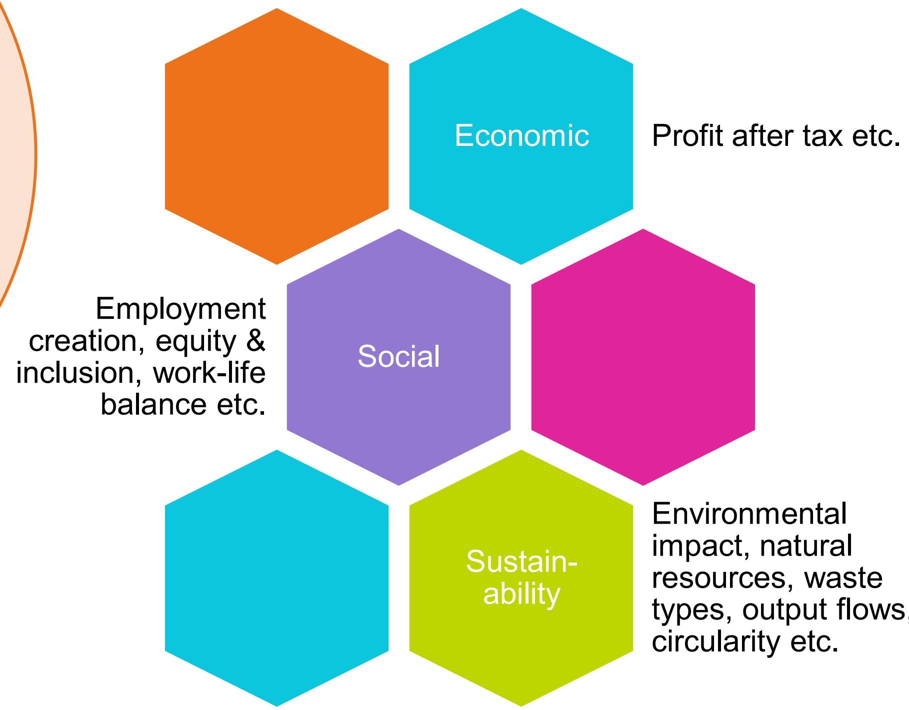
Cost & quality reduces
→



Multi-dimensional / triple bottom line (TBL)

Thank you

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