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H2 SOLUTIONS IN AIRPORT GROUND POWER EQUIPMENT

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AGENDA

1. Managerial Summary
2. Stakeholder Collaboration in an Airport Hydrogen Ecosystem: Investigation of Barriers and Design Advice- Case study at Groningen Airport Eelde
3. Replacing diesel-powered GPUs with hydrogen-powered GPUs - A study investigating the environmental impact of those GPUs and their supply chains
4. Economic Effects of Sustainable Energy Supply at Regional Airports: The Transformation Towards Hydrogen Ground Power Units (h-GPUs) at Groningen Airport Eelde

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1. MANAGERIAL SUMMARY

- Sustainable and zero-emission practices
- The ground power unit (GPU) is one of the ground support equipment that can be considered as a significant source of carbon emissions in airports since they are responsible for about 10% of the total emissions (Dube & Nhamo, 2019; Balli & Calliskan, 2022).
- Hydrogen transition
- Alongside analyzing the environmental impacts of this transition, it is important to evaluate its economic impact since hydrogen technology deployment in GPUs necessitates establishing a robust infrastructure, substantial investments, and operating costs.

SUSTAINABLE DEVELOPMENT GOALS

7 AFFORDABLE AND CLEAN ENERGY
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
17 PARTNERSHIPS FOR THE GOALS

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1. MANAGERIAL SUMMARY (CONT.)

- Benefits and barriers of h-GPUs
- This project aims to explore the feasibility and the grounds for the implementation of hydrogen solutions for GPUs

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THE SPECIFIC TASKS AND OBJECTIVES OF THE PROJECT

- Conducting a LCA to analyze CO_2 gains of h-GPUs.
- Development of a cost-benefits model to evaluate the economic impact of the transition to h-GPUs.
- Analysis of operational, economic, legal and regulatory, technical, safety barriers for the transformation.
- Determining the learning points in the transformation to h-GPUs for regional airports here and beyond to facilitate replicability in other regions.
- Proposing recommendations to support policy, stakeholders enhancing knowledge, and facilitating further research.

Stakeholder Collaboration in an Airport Hydrogen Ecosystem: Investigation of Barriers and Design Advice

Case study at Groningen Airport Eelde

CONTENT

Objective

- ❑ What are stakeholder cooperation possibilities for an airport hydrogen ecosystem?
- ❑ What are the barriers and design recommendations?

Summary

- ❑ Investigation of stakeholder roles, expectation and barriers
- ❑ Design advice of managers and policy makers

Methodology

- Case study at Groningen Airport Eelde
  - 16 interviews

- 22 stakeholder categories
  - Technology providers, politics, industry, society etc.
  - Validity and triangulation: various categories

Findings

- Hydrogen economy
  - Promising but uncertain
  - Applications?
    - Batteries or electricity not possible
- Business model
    - Economies of scale
    - Refueling station
    - Transport and heating
- Collaboration
  - Entire supply chain realisation
  - Subsidies on supply chain level
- Decentralized or centralized system
  - Grid regulations

Findings

- Economic barriers
  - High investment and operational costs
  - Feasible business model
- Technical barriers
  - Lack of infrastructure, skills and applications
  - Not enough people and manufacturers
- Political barriers
  - Lack of regulations and standards
  - Government knowledge —> Municipality level
  - Complicated procedures
- Social and environmental barriers
  - Lack of public knowledge
  - High acceptance hydrogen
  - Airport resistance
    - Financial, noice, pollution

Discussion

- Economic
  - Decreasing costs future
  - By 2040, FCEVs feasible
- Technical
  - Strong dependence on economic barriers
- Political and regulatory
  - More government support needed
    - Foster market development and mitigate uncertainty
  - Municipality level
- Social and environmental
  - Social acceptance controversial
  - Sustainability helps to gain support
  - Communication, openness, transparency, participation

Conclusions and Advice

- Hydrogen is promising, but there are significant challenges
  - Various interdependent barriers

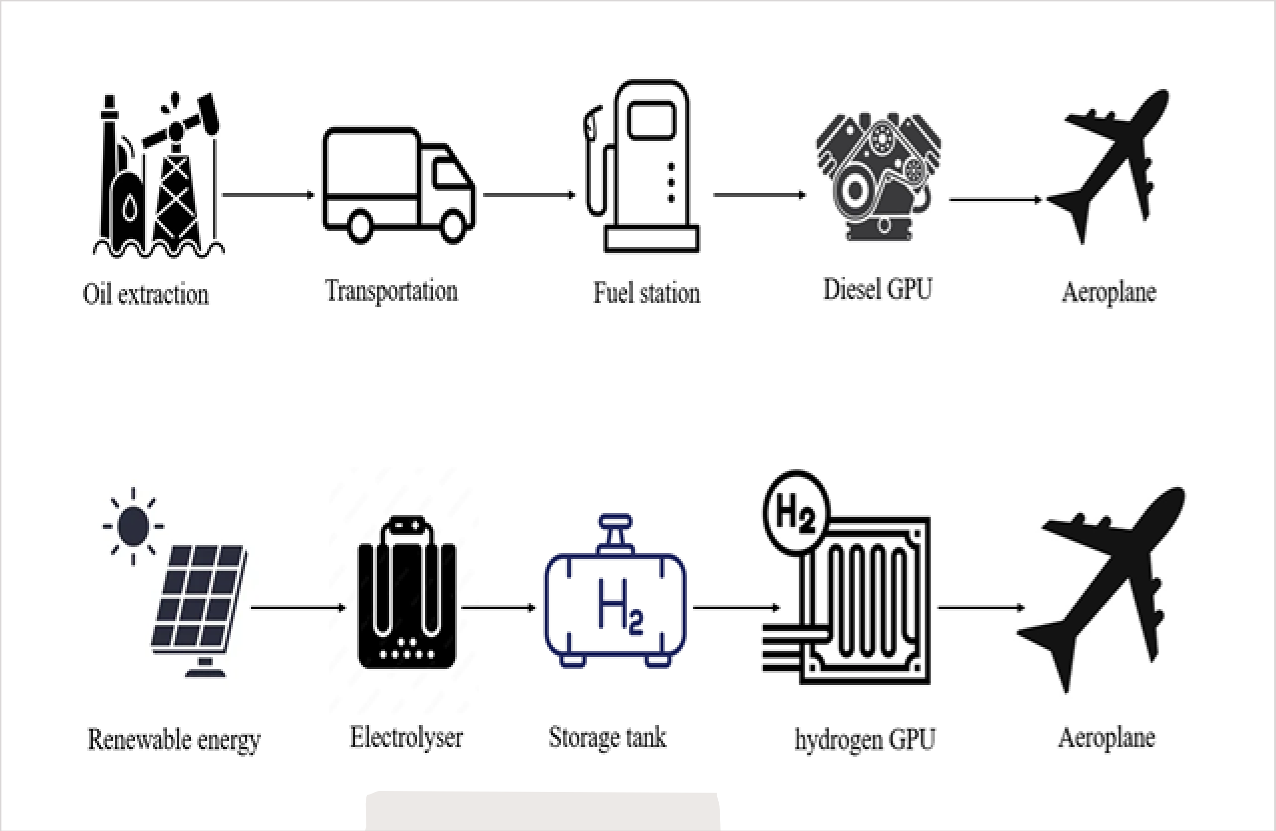
- Until 2030
  - Focus battery electric GSE
  - Infrastructure development
  - Subsidies and government support
  - Clear regulations
  - Communication and social acceptance
- Until 2050
  - More FCEVs
  - Electricity and hydrogen flying
  - Hydrogen grid pipelines
  - Social acceptance

Replacing diesel-powered GPUs with hydrogen-powered GPUs

A study investigating the environmental impact of those GPUs and their supply chains

CONTENT

OBJECTIVE



What is the environmental impact of a hydrogen or diesel GPU and their supply chains?

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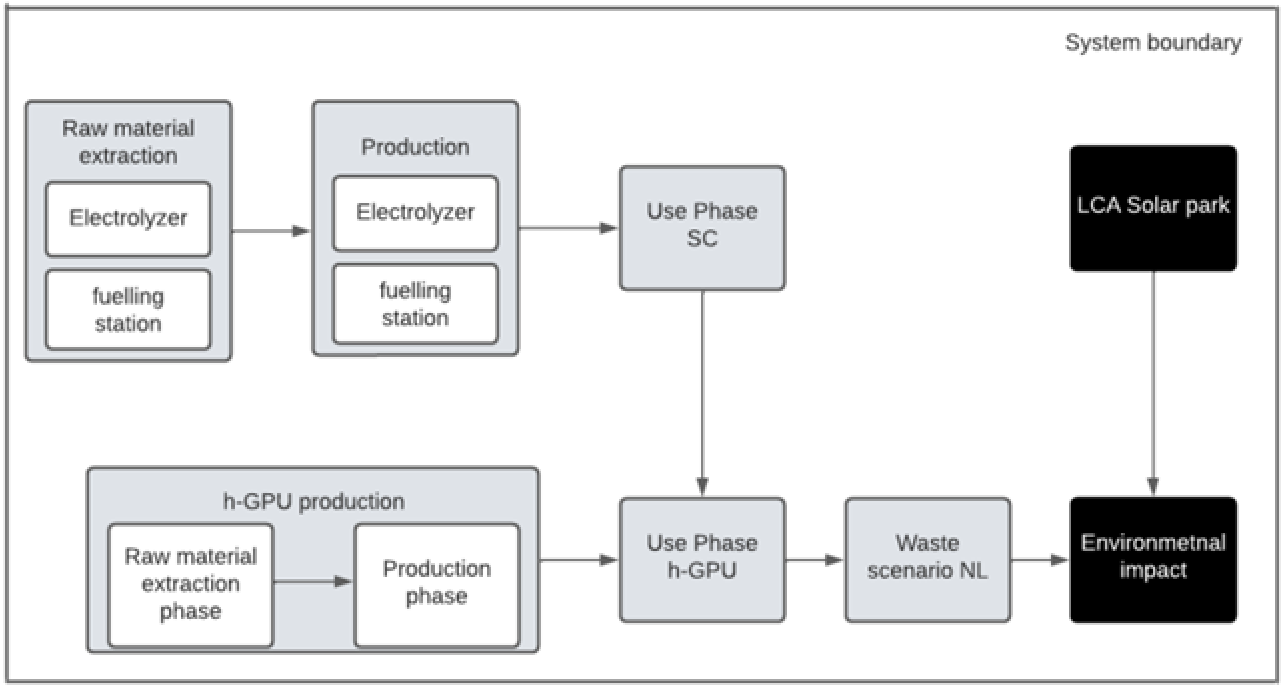
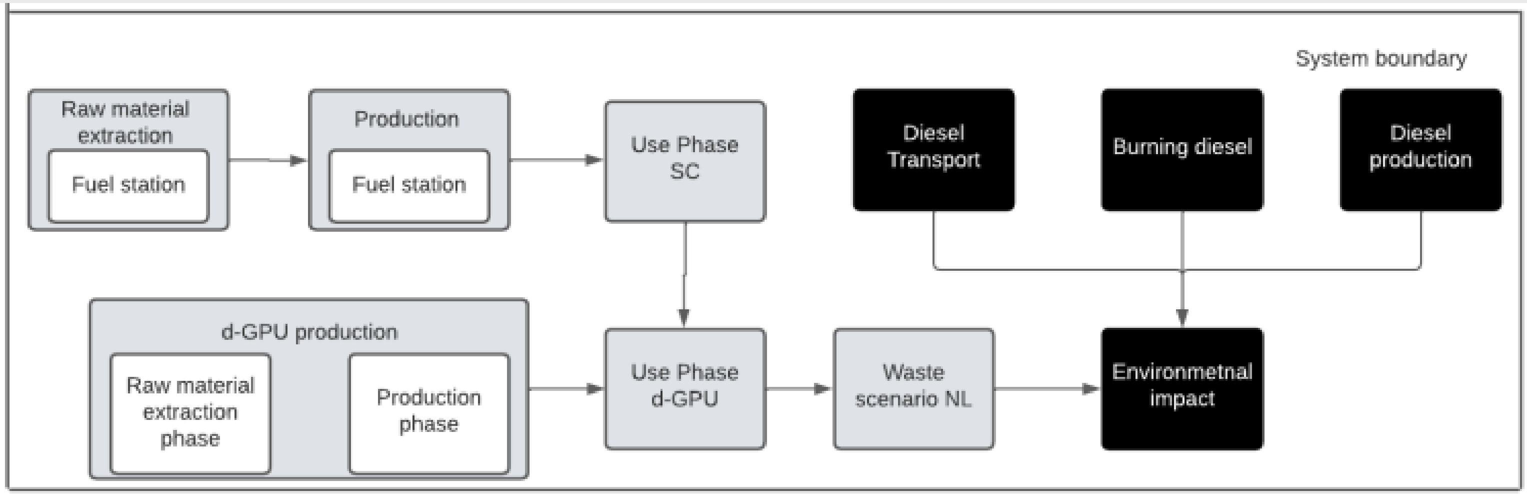
METHODOLOGY

LIFE CYCLE ASSESSMENT



LCA Diesel Supply Chain



LCA Hydrogen Supply Chain

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METHODOLOGY

SCENARIO DEVELOPMENT

Scenario:	Diesel per day	Diesel per year	Diesel per year (MJ)	Capacity storage	Transport per year
1 flight a day	42 kg	15330 kg	654591 MJ	294 kg	2981,16 tkm
3 flights a day	126 kg	45990 kg	1963773 MJ	882 kg	8963,76 tkm
5 flights a day	210 kg	76650 kg	3272955 MJ	1470 kg	14905,8 tkm
10 flights a day	420 kg	153300 kg	6545910 MJ	2940 kg	14905,8 tkm
15 flights a day	630 kg	229950 kg	9818865 MJ	4410 kg	44717,4 tkm

Scenario's Diesel Supply Chain

Scenario's Hydrogen Supply Chain

Scenario:	H2 per day	Capacity electrolyser	Electricity needed from the grid	Capacity solar panels	Percentage of the solar farm GAE	Capacity Storage
1 flight a day	15 kg	37.5 kW	864 kW	200 kW	1.1 %	31 kg
3 flights a day	45 kg	112,5 kW	2592 kW	599 kW	3.2 %	92 kg
5 flights a day	75 kg	187,5 kW	4321 kW	999 kW	5.4 %	153 kg
10 flights a day	150 kg	375 kW	8641 kW	1998 kW	10.7 %	305 kg
15 flights a day	225 kg	562.5 kW	12962 kW	2998 kW	16.1 %	457 kg

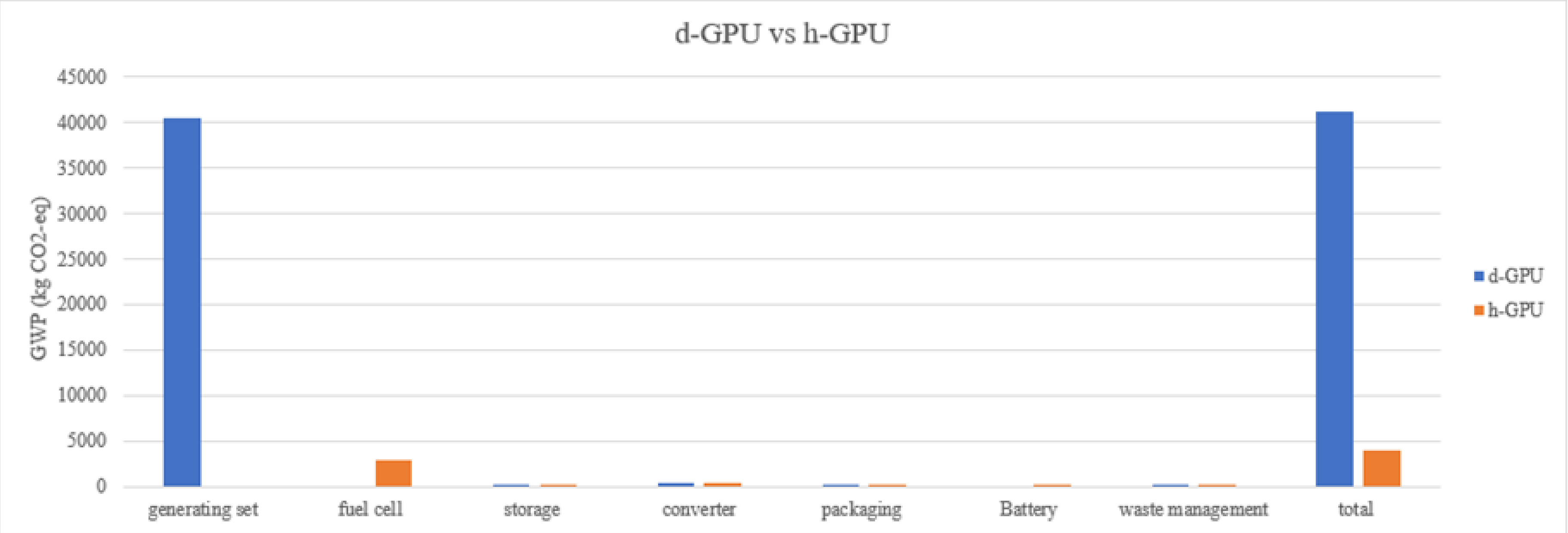
FINDINGS

GPUs COMPARISON

- One year d-GPU: 41,170 kg CO_2-eq
- Generating set contributes the most

- One year h-GPU: 3,900 kg CO_2-eq
- Fuel cell contributes the most
- Hydrogen storage higher GWP than diesel storage

d-GPU			h-GPU		
	Unit	GWP (x1000)		Unit	GWP (x1000)
generating set	kg CO_2-eq	40.47	fuel cell	kg CO_2-eq	2.89
diesel storage	kg CO_2-eq	0.06	storage	kg CO_2-eq	0.19
converter	kg CO_2-eq	0.40	converter	kg CO_2-eq	0.40
packaging	kg CO_2-eq	0.20	packaging	kg CO_2-eq	0.20
waste management	kg CO_2-eq	0.04	battery	kg CO_2-eq	0.12
total	kg CO_2-eq	41,17	waste management	kg CO_2-eq	0.11
			total	kg CO_2-eq	3.90



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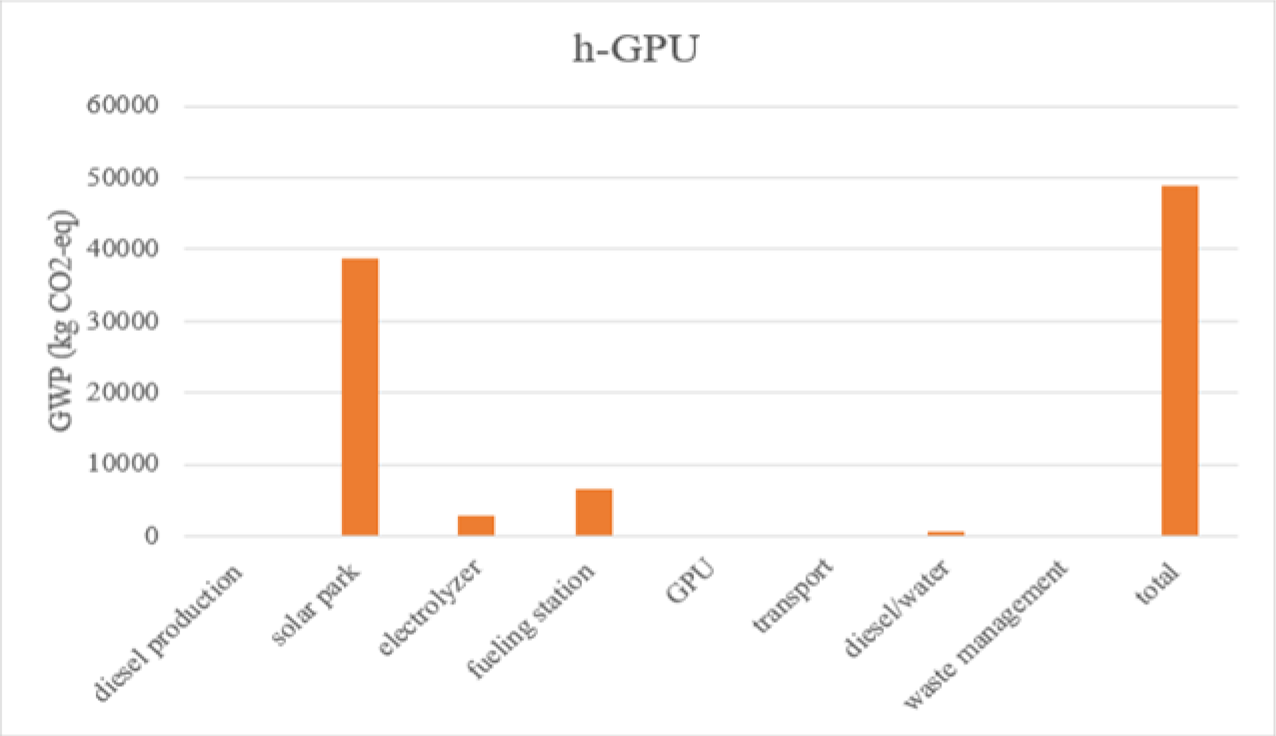
FINDINGS

SUPPLY CHAIN COMPARISON

- d-SC: Transport highest GWP
- Production of diesel and burning of diesel also significantly contributing to the GWP
- h-SC: Solar park highest GWP (79% of the GWP of the entire supply chain)
- Electrolyser and fuelling station also significantly contributing to the GWP

d-GPU	Unit	GWP (x10.000)	h-GPU	Unit	GWP (x10.000)
diesel production	kg CO_2-eq	3.45	solar park	kg CO_2-eq	3.88
fueling station	kg CO_2-eq	0.004	electrolyser	kg CO_2-eq	0.29
d-GPU	kg CO_2-eq	0.16	fueling station	kg CO_2-eq	0.65
transport	kg CO_2-eq	143.23	h-GPU	kg CO_2-eq	0.02
burning diesel	kg CO_2-eq	31.33	Water usage	kg CO_2-eq	0.06
waste management	kg CO_2-eq	4.00	waste management	kg CO_2-eq	0.01
total	kg CO_2-eq	182.43	total	kg CO_2-eq	4.90



DISCUSSION

- The GWP of the d-GPU is 10.4 times larger than the GWP of the h-GPU. The supply chain of the h-GPU is favoured over the supply chain of the h-GPU. Additionally, the more flight leaving the more favourable the h-SC becomes.
- Improvement points h-SC: electrolyser, solar park and storage facilities.
- Electrolyser: Large scale production
- Storage facilities: centralised storage. However, this lead to extra GWP due to transport
- Solar park: Reconsidering material choice. Literature proposes organic PV panels instead of multi-junction silicon panels
- Other ways to reduce the GWP per year: increasing lifetime and performance of the supply chain components
- Take a closer look at the recycling of the components. Keep the recycling in mind while designing products.

Economic Effects of Sustainable Energy Supply at Regional Airports:

The Transformation Towards Hydrogen Ground Power Units (HGPUs) at Groningen Airport Eelde

CONTENT

- Objective
- Methodology
- Findings
- Discussion
- Conclusion

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OBJECTIVE

What are the costs and benefits of transforming towards a h-GPU for airports?

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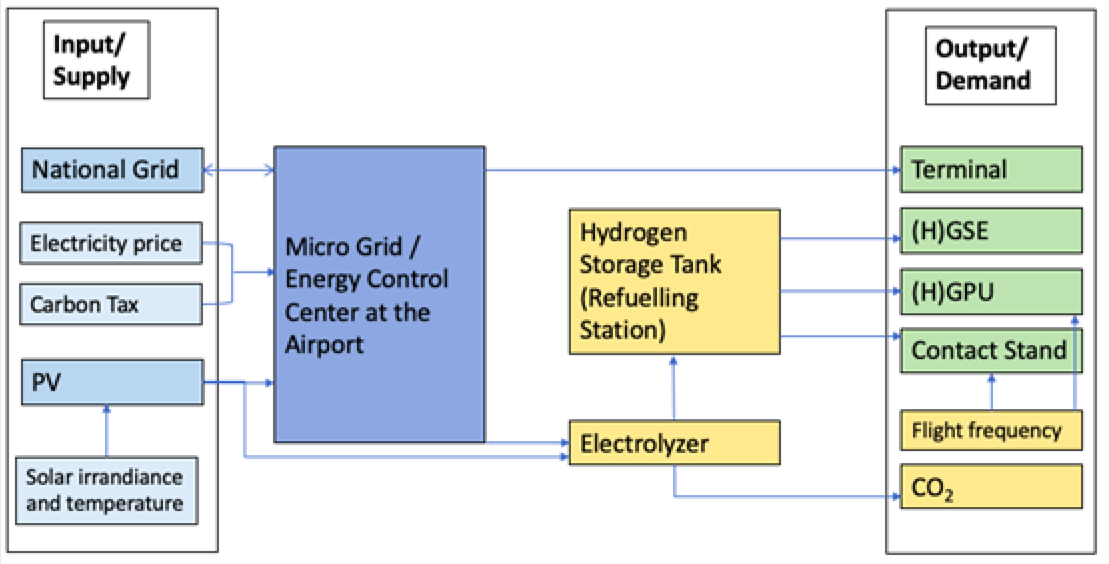
METHODOLOGY

COST AND BENEFIT ANALYSIS + SIMULATION MODEL

- $TC_y = \sum_{y=0}^{N} \frac{CapEx_{y,i}}{(1+r)^y} + OpEx_{y,i} + COE_y$
- $REV_y = R_y^{electricity} + R_y^{hydrogen}$
- $NPV = -\mathrm{CapEx} + \sum_{y=0}^{N} \left(\frac{REV_y - OpEx_y}{(1+r)^y}\right)$



Parameters	Descriptions
TC_y	Annual total cost in year y
REV_y	Annual generated revenues in year y
NPV	Net present value of the investments
N	Project life cycle and service time of the energy devices (25 years)
y	Year in the life cycle
r	Discount rate
i	Energy devices: GPU, HGPU, HST, electrolyzer, and PV
$CapEx_{y,i}$	Annual capital expenditures for the energy device i, excluding PV, in year y
$OpEx_{y,i}$	Annual operational expenditures for energy device i, in year y
COE_y	Annual cost of energy for hydrogen, electricity, and diesel in year y
$R_y^{electricity}$	Annual revenue generated from selling excess of solar energy in year y
$R_y^{hydrogen}$	Annual revenue generated from selling excess of hydrogen in year y

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METHODOLOGY

SIMULATION AND COST MODEL

In scenario A, demand has doubled in size.

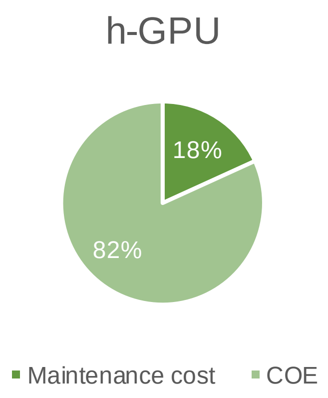
In scenario B, a carbon tax is introduced on the emitted carbon.

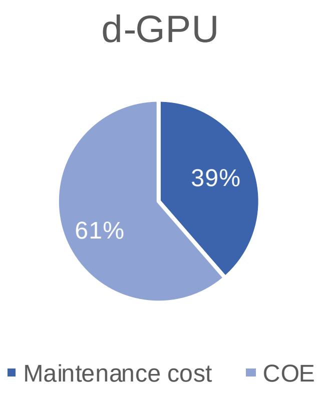
In scenario C, demand has doubled, and a carbon tax is implemented on the emitted carbon.

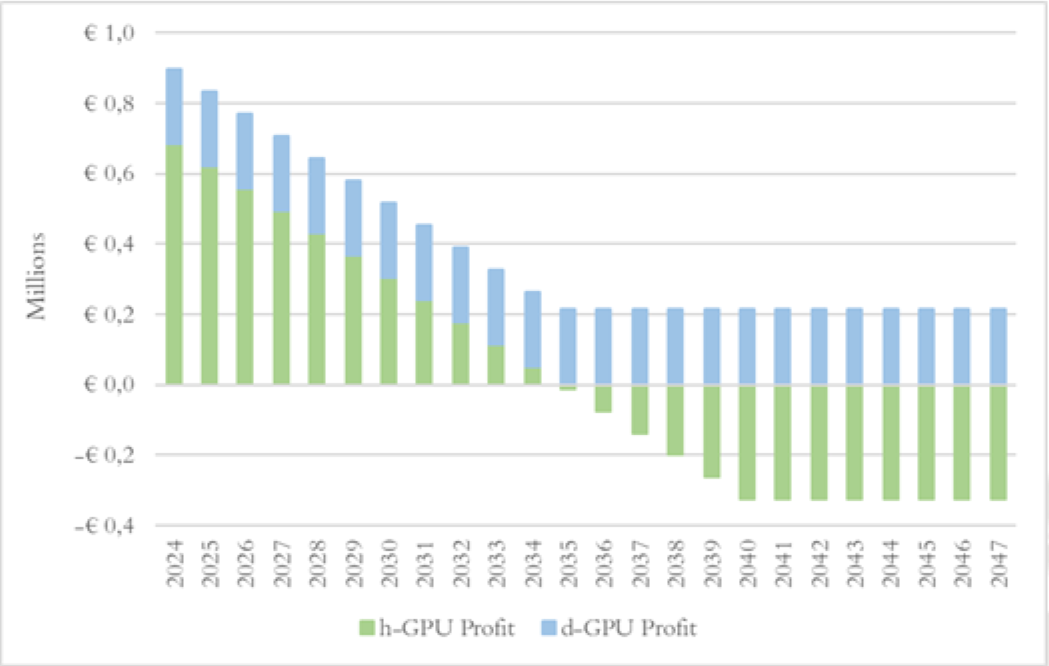
FINDINGS

BASELINE

- Total capital investment required for the h-GPU is €200.000, whereas this stands at €85,000 for the d-GPU. If we consider the entire hydrogen infrastructure equipment, the total capital investment amounts to €1.2 million.
- The h-GPU may have higher energy costs, but it requires less maintenance costs during its lifetime than the d-GPU.
- The COE for the h-GPU is €143000, whereas this is €79,000 for the d-GPU since the per unit cost of hydrogen is higher than the per unit cost of diesel at the infancy stages of hydrogen economy.
- Hydrogen sales make up 46% of the overall revenue, while electricity sales constitute the remaining 54% for the h-GPU. The hydrogen production cost is predicted to be €5.97 per kg.







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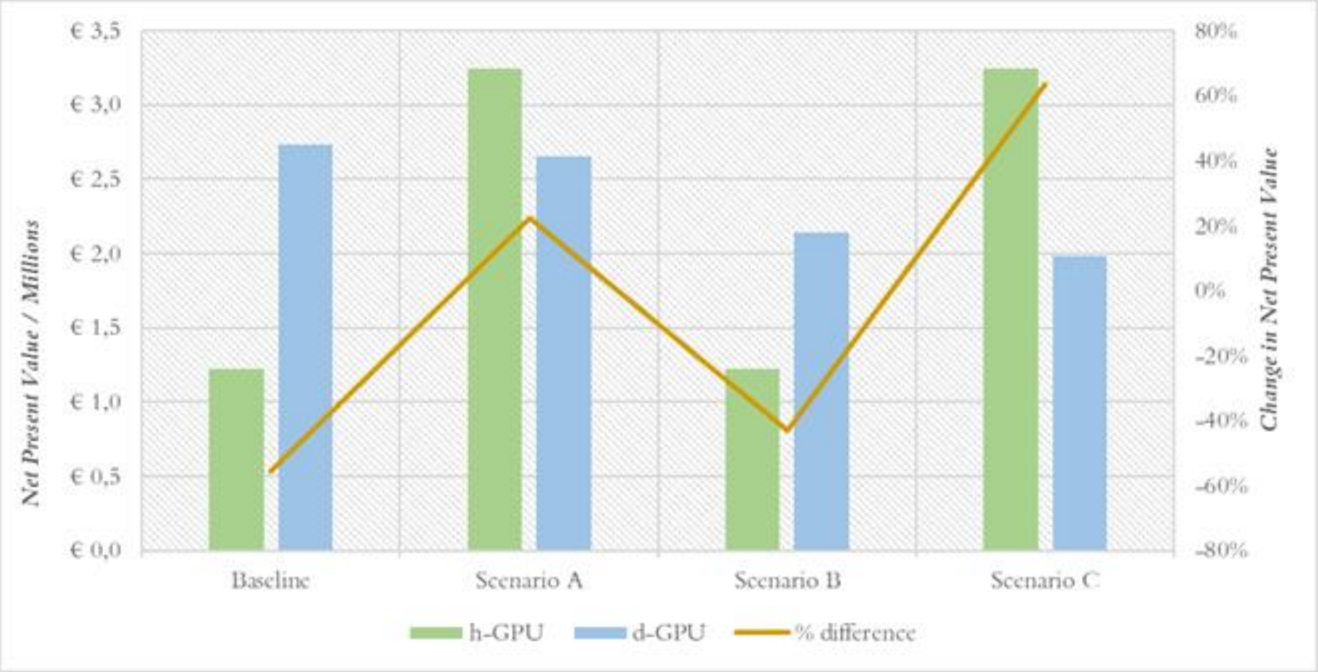
FINDINGS

Scenarios

Scenario A: Doubled Demand
Scenario B: Carbon Emission Tax
Scenario C: Doubled Demand and Carbon Emission Tax



The total cumulative revenue for the h-GPU and d-GPU is €8.3 million and €5.5 million, respectively.
Specifically, the NPVs of the h-GPU and d-GPU are approximately €1.2 million and €2.7 million, respectively, indicating a difference of 55%.

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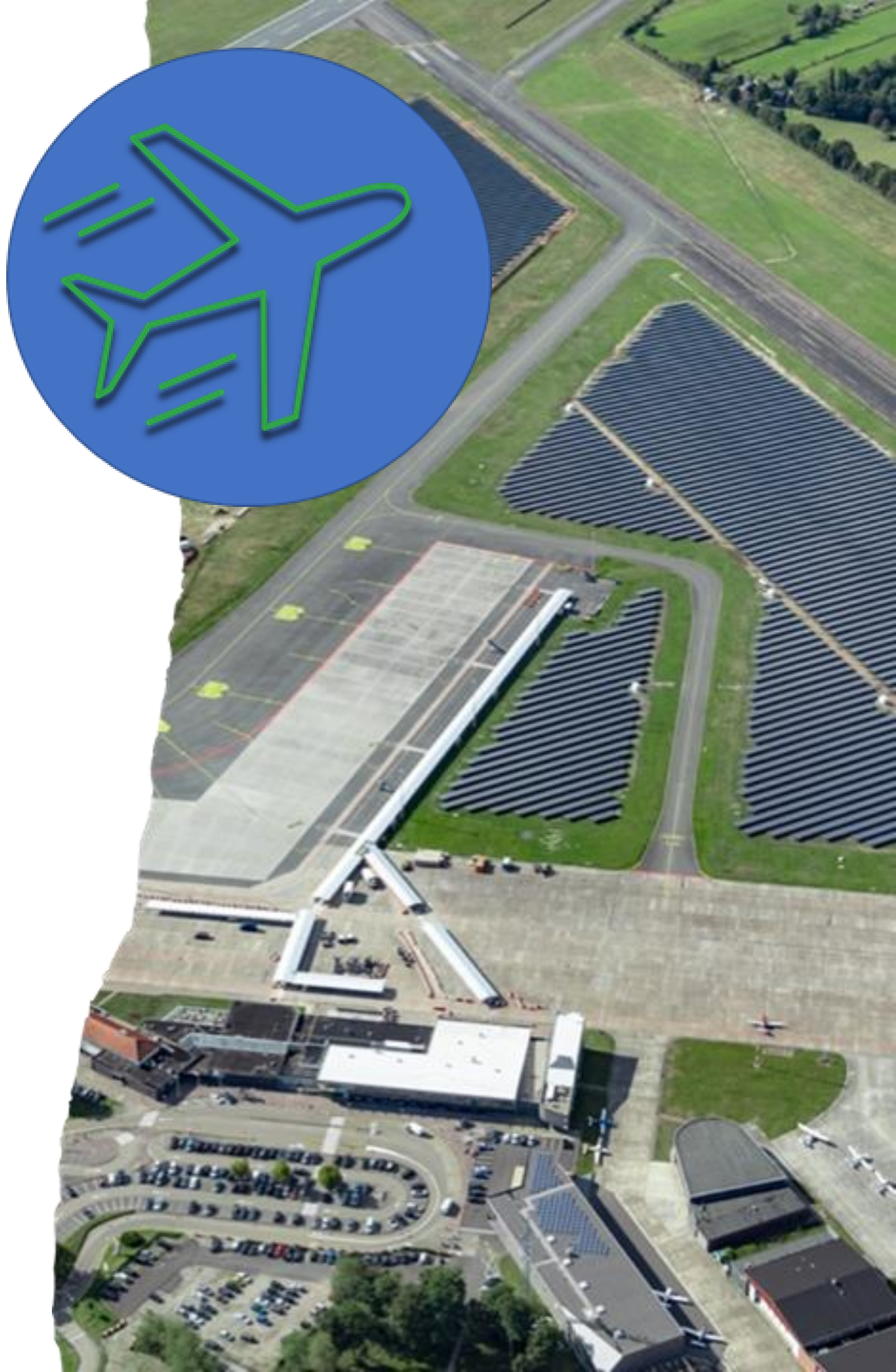
FINDINGS

- The advantages of economics of scale, by doubling demand, leads to a drop in the unit cost of hydrogen from €5.97 per kg to €3.80 per kg.

- The cost for the d-GPU increases due to the implementation of the carbon emission, causing for a lower NPV.

- H-GPU gains a market opportunity when demand is doubled as the NPV is a 22% higher than the d-GPU. Additionally, when carbon emission tax is implemented and demand is doubled the difference NPV increases to 63%.



DISCUSSION

- Sensitivity analyses

  -electricity price,

  -carbon tax,

  -the diesel price.

- In conclusion, the results show that deploying a h-GPU system at an airport can lead the path to important market opportunities, particularly when considering increased flight frequencies and the adaptation of the carbon emission tax regulations.

- Transitioning to h-GPUs can be considered under adequate hydrogen demand that can stem from both airside and landside operations.

DISCUSSION:

RECOMMENDATION

- Technological advancements in hydrogen to reduce the high investment costs associated with this technology, by implementing tax incentives, subsidies, loans, and grant programs.

- Training programs to provide the necessary skills and knowledge

- Provide supportive policies to facilitate the formation of hydrogen hubs

- Ensure the generated hydrogen is carbon-neutral and minimize conversion loss.

- Electrolyzer efficiency

REFERENCES

- ACI, S. (2019). What is net zero? Airports Council International Europe. Accessed by August 25, 2022, retrieved from https://www.aci-europe.org/netzero.
- Balli, O., & Caliskan, H. (2022). Environmental impact assessments of different auxiliary power units used for commercial aircraft by using global warming potential approach. *Environmental Science and Pollution Research*, 29(58), 87334-87346.
- Barke, A., Thies, C., Melo, S. P., Cerdas, F., Herrmann, C., & Spengler, T. S. (2020). Socio-economic life cycle assessment of future aircraft systems. *Procedia CIRP*, 90, 262-267.
- Baroutaji, A., Wilberforce, T., Ramadan, M., & Olabi, A. G. (2019). Comprehensive investigation of hydrogen and fuel cell technology in the aviation and aerospace sectors. *Renewable and sustainable energy reviews*, 106, 31-40.
- Cetinkaya, E., Dincer, I., & Naterer, G. F. (2012). Life cycle assessment of various hydrogen production methods. *International journal of hydrogen energy*, *37*(3), 2071-2080.
- Curran, M., 2015. Life Cycle Assessment Student Handbook. United Stated of America: Scrievener Publishing LCC.
- Dube, K., & Nhamo, G. (2019). Climate change and the aviation sector: A focus on the Victoria Falls tourism route. *Environmental Development*, 29, 5-15.
- Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and sustainable energy reviews*, 39, 748-764.
- GAE (2022) Development of hydrogen Ground Power Unit at Groningen Airport Eelde. Available at: https://www.groningenairport.nl/en/news/development-of-hydrogen-ground-power-unit-at-groningen-airport-eelde (Accessed: 5 February 2023).
- Glanz, S., & Schönauer, A. L. (2021). Towards a low-carbon society via hydrogen and carbon capture and storage: Social acceptance from a stakeholder perspective. Journal of *Sustainable Development of Energy, Water and Environment Systems*, 9(1), 1–18.
- Goedkoop, M., Oele, M., de Schryver, A., Vieira, M., & Hegger, S. (2008). SimaPro database manual methods library. *PRé Consultants, The Netherlands*, 22-25.
- Helmers, E., Leitão, J., Tietge, U., & Butler, T. (2019). CO2-equivalent emissions from European passenger vehicles in the years 1995–2015 based on real-world use: Assessing the climate benefit of the European "diesel boom". *Atmospheric Environment*, 198, 122-132.
- IRENA (2022) Global hydrogen trade to meet the 1.5°C climate goal: Part I – Trade outlook for 2050 and way forward. Abu Dhabi: International Renewable Energy Agency. Available at: www.irena.org/publications.
- Nielsen, E. (2020). In house production drastically reduces CO2 emissions. Retrieved from: https://blog.alpla.com/en/blog/company-economy/house-production-drastically-reduces-co2-emissions/10-20 Accessed on: 19th of January 2023.
- Papadis, E., & Tsatsaronis, G. (2020). Challenges in the decarbonization of the energy sector. *Energy*, 205, 118025.
- Qyyum, M. A., Dickson, R., Shah, S. F. A., Niaz, H., Khan, A., Liu, J. J., & Lee, M. (2021). Availability, versatility, and viability of feedstocks for hydrogen production: Product space perspective. *Renewable and Sustainable Energy Reviews*, 145, 110843.
- Statista. (2022). Hours of sunshine in the Netherlands 1990-2021. https://www.statista.com/statistics/1012949/hours-of-sunshine-in-the-netherlands/ Accessed on 10-11-2022 https://www.statista.com/statistics/276629/global-co2-emissions/ Accessed on 1st of January 2022.
- Testa, E., Giammusso, C., Bruno, M., & Maggiore, P. (2014). Analysis of environmental benefits resulting from use of hydrogen technology in handling operations at airports. *Clean Technologies and Environmental Policy*, 16(5), 875-890.
- Wu, M., Wu, Y., He, J., Xu, M., & Zhang, T. (2022). ScienceDirect Barrier identification , analysis and solutions of hydrogen energy storage application in multiple power scenarios based on improved DEMATAL- ISM approach. *International Journal of Hydrogen Energy*, 47(71), 30329–30346.
- Wulf, C., & Kaltschmitt, M. (2018). Hydrogen supply chains for mobility—environmental and economic assessment. *Sustainability*, 10(6), 1699.
- Wulf, C., Reuß, M., Grube, T., Zapp, P., Robinius, M., Hake, J. F., & Stolten, D. (2018). Life Cycle Assessment of hydrogen transport and distribution options. *Journal of cleaner production*, 199, 431-443.
- Xiang, Y., Cai, H., Liu, J., & Zhang, X. (2021). Techno-economic design of energy systems for airport electrification: A hydrogen-solar-storage integrated microgrid solution. *Applied energy*, 283, 116374.

“Thank You”