UNIVERSITY OF GÄVLE

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Come Fly with Me (Sustainably)

Pathways to Sustainable General Aviation and Private Pilot Training

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Preface

"Come fly with me, we'll fly, we'll fly away …"

–

Come Fly with Me (1958): Jimmy Van Heusen (music), Sammy Cahn (lyrics)

Aviation and the old human dream of flying are fascinating topics, reflected, for instance, in Frank Sinatra's famous 1958 rendition of the song "Come Fly with Me" which inspired the title of this thesis.

This thesis was written for my master's degree in Sustainability Science at the University of Gävle. First and foremost, I would like to express my sincere gratitude to my supervisor Dr. Shveta Soam whose valuable feedback has greatly contributed to the quality of this thesis. I want to thank all the outstanding educators at the University of Gävle who broadened my horizons and gave me the opportunity to critically reflect upon the ever-more important subject of sustainability.

I could not have conducted this study without my survey respondents and interview partners who shared their valuable knowledge, opinions, and concerns about sustainable development in general aviation and private pilot training with me. My special thanks and appreciation go to Motorflug-Verband der Schweiz (MFVS) which distributed my online survey to a broad bandwidth of GA stakeholders and therefore vastly contributed to the representativeness of this research. I want to express my thanks to AlpinAirPlanes GmbH for the generous invitation to Écuvillens and for providing me with the opportunity to gather first-hand experience in electric general aviation.

Lastly, my sincerest thanks go to all people who believe in the sustainable transformation of general aviation and actively contribute to sustainable development in this field so that future generations of private pilots can pursue their dream of flying without negative impacts on the environment and society.

Abstract

Whereas commercial aviation is attempting to achieve the reduction of its substantial carbon footprint, general aviation's (GA) climate change contribution is negligibly small, which is why the sector is facing other sustainability challenges mainly entailing the operation of dated technology and aircraft, increasing regulatory constraints, rising costs, noise emissions, and popular discontent, as well as remaining the last mobility sector in the world to still use leaded fuels. Throughout recent years, there have been remarkable sustainability trends in GA as well as heightened efforts to improve its emissions profile (noise, pollutants, CO_2) and environmental reputation, for instance by the increased use of electric aircraft, especially for private pilot training. From a sociotechnical perspective, this mixed-methods study highlights current sustainability challenges and trends in GA as well as potential pathways towards more sustainable GA and private pilot training. Eight in-depth semi-structured interviews with Swiss and international GA stakeholders were complemented with a bilingual representative quantitative online survey (N=427) among Swiss GA stakeholders, a comparative CO_2 analysis showing the emissions advantages and feasibility limits of supplementing private pilot training with lessons using electric aircraft, as well as participant observation. The data show that most Swiss GA stakeholders have increased environmental awareness and are concerned about sustainability and the environment both, in flight and other activities. Although the majority advocates for sustainable development in GA there are not one but many challenges and obstacles to a more sustainable GA. The largest challenges are the abatement of noise emissions and the facilitation of the leaded aviation gasoline (AVGAS 100LL) phaseout. The most pertinent obstacles towards sustainable GA innovation are said to be bureaucracy, overregulation and reluctance in the civil aviation authorities, high costs, averseness to risk and innovation, as well as a trend of decline in GA activity due to continuous demographic change. No single sustainability pathway but rather a mix of immediate and long-term sustainability measures was identified. Despite its current limitations, electric aviation proves to be one of the most feasible pathways to sustainable private pilot training. For more sustainable GA, the use of more fuel-efficient planes and available unleaded fuels, propeller, and muffler retrofits, as well as is feasible short- and midterm measures. In the long run, electric and hybrid aviation as well as bio- and synfuels are likely to become attractive options for GA. The study shows the importance of sustainable development in GA and private pilot training, not because it will majorly contribute to climate change mitigation, but because it will ensure the improvement of its negative environmental reputation and societal acceptance, which will be vital to ensuring the survival of the GA sector.

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List of Abbreviations

Abbreviation	Meaning
AVGAS 100LL	Aviation Gasoline 100 Octane Low Lead
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EASA	European Union Aviation Safety Agency
EDB	Ethylene Dibromide (Scavenger Chemical in leaded AVGAS)
EET	Estimated Elapsed Time = The estimated time required to proceed from one significant point to another (ICAO definition)
FAA	Federal Aviation Administration (USA)
FL	Flight Level (e.g., FL110 = altitude 11,000 feet)
FOCA	Federal Office of Civil Aviation (Switzerland)
GA	General Aviation
GHG	Greenhouse Gases, e.g., carbon dioxide
ICAO	International Civil Aviation Organization
LAPL(A)	Light Aircraft Pilot License (only EASA territory)
MTOW	Maximum Take-Off Weight
PPL(A)	Private Pilot License (Airplane)
SEP	Single Engine Piston
STC	Supplemental Type Certificate
TEL	Tetraethyl Lead

1 Introduction

Humankind's dream of flying is an old and fascinating one. It is associated with many great thinkers, inventors, and engineers who have pursued its realization ranging from Leonardo da Vinci, the Montgolfier Brothers, Otto Lilienthal, and the founding fathers of modern aviation, the Wright Brothers (Anderson, 2004; Cassidy, 2019; Jakab, 1997). Having undergone a rapid technological evolution throughout the 20th century, aviation has become a core element of our established global socioeconomic structures as it connects cultures and significantly contributes to global economic performance (Müller et al., 2022).

However, aviation is a fast-growing high-energy sector coined by a great degree of unsustainability as it makes substantial contributions to anthropogenic climate change (Paddon, 2022). Despite a seemingly small global annual contribution of 2.4% CO_2 emissions (Klöwer et al., 2021), the current global share of CO_2 emissions from commercial flight activities is estimated at 5-8% and total emissions (from commercial aviation) are projected to triple by 2050 (Gössling & Humpe, 2020; Paddon, 2022). Klöwer et al. (2021) estimate that aviation has contributed roughly 4% to observed human-induced global warming to date. According to Gössling and Humpe (2020), while less than 5% of the world population is flying internationally, 1% of the world population accounts for about 50% of CO_2 emissions from commercial flights. Noticeably, throughout recent years, aviation has started to play an increasingly central role in the political and societal discourse regarding climate change and sustainability. Some of the most pertinent phenomena regarding this were the emergence and popularization of *flygskam* (Swedish: *Flight Shame*) as well as its counterpart *tågskryt* (Swedish: *Train Brag*) (Gunziger et al., 2022; Trespeuch et al., 2020).

The Covid-19 pandemic and associated drastic drops in global air travel passenger numbers have given food for thought in the industry, politics, society, and the scholarly community regarding global dependencies and unsustainability in our sociotechnical transport systems (e.g., Gettelman et al. (2021); Gössling (2020)). Scholars, such as Müller (2020), even saw the pandemic disruption in global aviation as a chance or favorable condition for redirecting transport systems towards sustainability. In contrast to major reductions in passenger numbers during Covid-19, two sectors of aviation flourished, i.e. cargo and private aviation (Sahoo et al., 2021; Sobieralski & Mumbower, 2022).

Private aviation, more correctly *General Aviation* (GA), is defined by the International Civil Aviation Organization (ICAO) as "all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire". This includes, among other activities, business aviation, sightseeing and tours, recreational flying, and private pilot training. Commercial aviation has received much scholarly, political, and societal attention and demonstrated noteworthy engineering and management efforts to increase energy efficiency and reduce noise and carbon emissions (e.g., sustainable aviation fuels, improved turbine engines). GA has not received the same amount of consideration, but this does not mean that there are no sustainable development efforts in GA. Yet, the challenges, possibilities, and available options for sustainable development are different from those in commercial aviation.

Although at first GA seems to play only a minor role regarding economic and environmental aspects compared to other sectors of aviation, it is a highly important component of the whole picture, and its significance becomes greater "(..) when it is realized that every airline and military pilot must begin their journey to professional competence in the cockpit of a general aviation aircraft" (IAOPA Europe, 2022).

1.1 Aim of the Study

This research seeks to explore and evaluate currently available and potentially feasible options to foster sustainable development in GA and private pilot training (single-engine piston airplane) considering the three dimensions of Elkington's *Triple Bottom Line*, i.e., environmental, economic, and social aspects. However, the main emphasis shall lie on the environmental dimension. An analysis of contemporary sustainability challenges in GA precedes the investigation of pertinent GA stakeholders' measures (e.g., student pilots, flight instructors, flight school operators, airfield operators, electric aircraft manufacturers, etc.) perceptions, views, acceptance, and attitudes toward current and potential sustainable development trends. The research asks the overarching question:

What are feasible pathways to sustainability in general aviation and private pilot training?

The following sub-research questions shall help guide the research project:

RQ1: What are the current and most pertinent challenges in the transition toward sustainable GA and private pilot training?

RQ2: What are the environmental advantages and disadvantages of using currently available electric aircraft in private pilot training compared to commonly used single-engine piston aircraft?

RQ3: How can flight school syllabi be adjusted to foster sustainability in private pilot training?

RQ4: What are the attitudes, opinions, and concerns of GA stakeholders regarding the sustainability transition in GA and private pilot training?

1.2 Limitations and Applicability of the Study

This section elaborates on the limitations of this study and the applicability of its results.

1.2.1 Geographic Limitations, Representativeness, and Applicability

Although GA is a widespread activity around the world, certain trends, regulations, policies, and attitudes may vary from country to country and between different cultures. Most of the research was carried out in Switzerland and mostly involved Swiss stakeholders. However, Switzerland is one of the 31 member states of EASA (European Union Aviation Safety Agency) so the results presented in this thesis may be applicable to the vastly standardized European and even international context since there is a very high degree of standardization in GA pertaining to used technologies, rules, and regulation.

Given that the current Swiss private pilot population is currently between 4000 and 5000, the survey sample of N=427 is statistically representative, per Taro Yamane's formula (Israel, 2013) for a representative sample size *n*:

$n = \frac{N}{1+N(e)^2}$, where *N* = Total Population, *e* = Precision Level

Thus, aiming for a Precision Level of 5% with a 95% Confidence Level and P = .5, we calculate as follows: $\frac{5000}{1+5000(0.05)^2} = n = \mathbf{370}$

370 < 427 → survey sample representative under stated conditions

To the author's best knowledge, this study is the first representative empirical study of its kind applying a sociotechnical perspective on the issue of sustainable development in GA and private pilot training. The empirical findings can be used by various stakeholders and drivers (e.g., regulators, administrators, manufacturers, researchers, et cetera) striving toward the goal of advancing sustainable development in this area of aviation.

1.2.2 Scope, Scale, Time, and Funding

This research project was facilitated within a ten-week research period and depended exclusively on private funds (e.g., software licenses, transportation, work hours). The thesis was subject to restrictions in scope, i.e., a maximum of 8,000 words.

2 Background

This chapter outlines and explains concepts crucial to the context of this research. Secondly, it reflects on the state of the art in research regarding the issues of sustainability in GA and private pilot training.

2.1 General Aviation Concepts and Statistics

2.1.1 Defining General Aviation

GA, often misinterpreted by the public as 'aviation in general', sparks mental images in people of small single-engine piston-powered airplanes in the context of recreational flying at small airfields. This only applies to approx. 25% of GA (IAOPA Europe, 2022). The remaining 75% of the approximately 40m annual GA flight hours stem from GA activities such as flight instruction, business travel, agricultural application, and emergency medical services (IAOPA Europe, 2022).

The spectrum of GA activities is very broad. Thus, ICAO defines GA as "**those flight activities not involving commercial air transportation or aerial work**" (IAOPA Europe, 2022). A detailed typological overview based on the ICAO definitional frame is provided by IAOPA Europe (2022)[1] visible in Table 1.

TABLE 1: TYPOLOGICAL OVERVIEW OF AVIATION SECTORS AND ACTIVITIES, FROM IAOPA EUROPE (2022)

AVIATION			
CIVIL AVIATION			STATE AIRCRAFT
GENERAL AVIATION (GA)	**AERIAL WORK (AW)**	**COMMERCIAL AIR TRANSPORT (CAT)**	
includes •**Corporate Aviation** Company own-use flight operations •**Fractional Ownership Operations** aircraft operated by a specialized company on behalf of two or more co-owners •**Business Aviation (or Travel)** self-flown for business purposes •**Personal/ Private Travel** travel for personal reasons/ personal transport •**Air Tourism** self-flown incoming/ outgoing tourism •**Recreational Flying** powered/ powerless leisure flying activities •**Air Sports** Aerobatics, Air Races, Competitions, Rallies etc.	*includes* •**Aerial Crane Operations** •**Aerial Survey and Charting** •**Agricultural Flights (Crop Dusting) Aircraft Sales Demonstra-tions** •**Banner Towing/ Advertising Flights** •**Environment Surveillance and Enforcement** •**Ferry Flights/ Delivery Flights** •**Flight Demonstra-tions (Air Shows)**	*includes* •**Scheduled Air Services** •**Non-Scheduled Air Transport** •**Air Cargo Service** •**Air Taxi Operations** (see note) The criteria to determine "commercial" or "non-commercial" (general aviation) is the fact of **paying for the purpose of transportation** from A to B, not of paying or not, nor of being flown by paid (employed) crew. NOTE: Aircraft types used and the operational similarity of Air Taxi are much closer to General	*includes* •**State VIP Transports** •**Police/ Customs Aircraft** •**General Air Traffic (MIL)** (not to be confused with General Aviation) Transport, Civil Support or Ferry missions where airspace and ATC of mainly civil air traffic is used. •**Operational Air Traffic (MIL)** Operations within the States' defined Missions of the Air Force, including surveillance/ identification, air superiority

[1] IAOPA is cited as a main source since it is the only General Aviation and Aerial Work Representative recognized by ICAO

	•**Fire Fighting (Forest Fires etc.)** •**Glider Towing** •**Medical Evacuations** •**Nostalgy Flights in Historic Aircraft** •**Pilot Training (from private to airline pilots)** •**Research and Development Flights** •**Search and Rescue** •**Sight Seeing Flights** •**Skydiver Hoisting** •**Supplies Dropping** •**Test Flights** •**Traffic Surveillance** •**Transplant Organ Transports** •**TV-Live Reporting** •**Weather Research** The list is not exhaustive. As a general rule: All commercial and non-commercial civil flight operations of which the primary goal is NOT the transportation of persons or goods from one point to another, including ALL flight operations for the benefit of third parties (public benefits), are Aerial Work Operations.	Aviation than to Commercial Air Transport. Therefore albeit not being GA&AW according to ICAO definitions, in some countries it is considered part of GA&AW and thus represented by the national AOPA).	defence, tactical intelligence/ photography, ground troops support, etc., including training for such operations. NOTE: State aircraft (VIP, Police etc.) may be General Aviation/Aerial Work if aircraft are on the civil register but may benefit from State Aircraft status.

2.1.2 Relevance of General Aviation

Haygood (2021) estimates that there are approximately 1.5 to 2.3 million pilots around the globe (GA, commercial, airline, and military). The European branch of the *International Council of Aircraft Owner and Pilot Associations* (IAOPA Europe, 2022) estimates that there are approximately 350,000 aircraft and 700,000 pilots involved in GA activities. In comparison, only 60,000 aircraft and 400,000 pilots are active in commercial air transportation (incl. charter and cargo aviation) (IAOPA Europe, 2022). The largest player in GA is the USA, where California, Florida, and Texas feature the highest GA activity (Haygood, 2021). GA is the smallest niche in aviation accounting for "only" 4% of the global aviation fuel use compared to military aviation (8%), commercial aviation (freight) (17%), and commercial aviation (passengers) (71%) as depicted in Figure 1 (Gössling & Humpe, 2020).

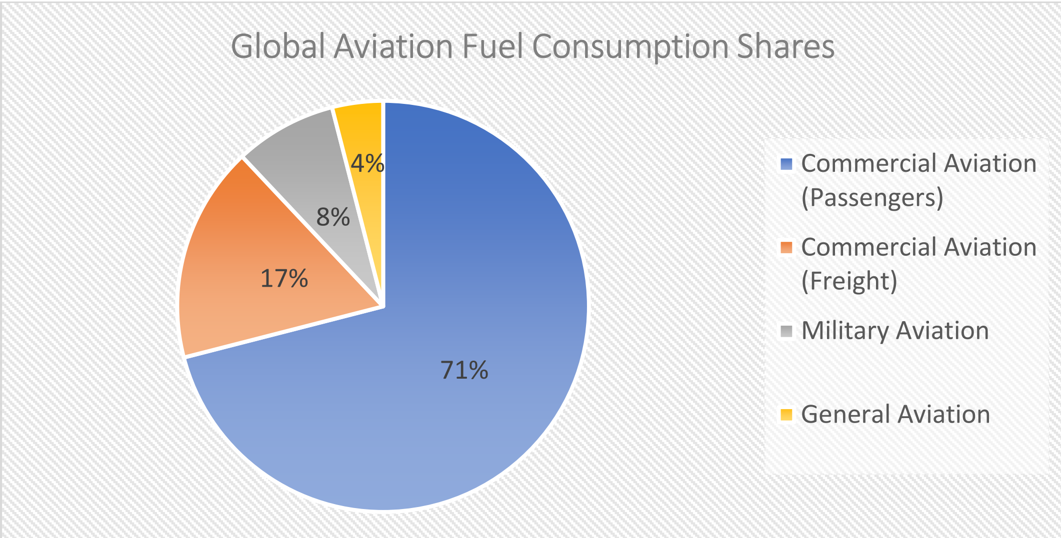

FIGURE 1: GLOBAL AVIATION FUEL (ALL TYPES) CONSUMPTION SHARES, BASED ON DATA FROM GÖSSLING AND HUMPE, 2020

2.1.2.1 Relevance of General Aviation in Switzerland

Switzerland features one of the most densely populated airspaces in entire Europe featuring more than 1.1m flight movements in 2020 (24% less compared to pre-Covid19) of which 84% were GA flight movements, according to the Federal Statistical Office (FSO, 2021). Figure 3 presents an overview of the quantitative importance of GA flight movements in Switzerland at regional and national airports (smaller aerodromes not shown). Even though GA is popular in Switzerland, the number of private pilots has steadily declined from 6,792 in 2000 to 4,369 (-35%) private pilot license holders in 2020 (see Figure 2). Part of this development is due to the demographic change, an aging pilot population, and ever-increasing complexity of rules and regulations in GA (Schlittler, 2018). In Switzerland, as of May 2022, there are 55 registered flight schools within the category Declared Training Organization (DTO) and 46 within the category of Approved Training Organization (ATO) (FOCA, 2022b).

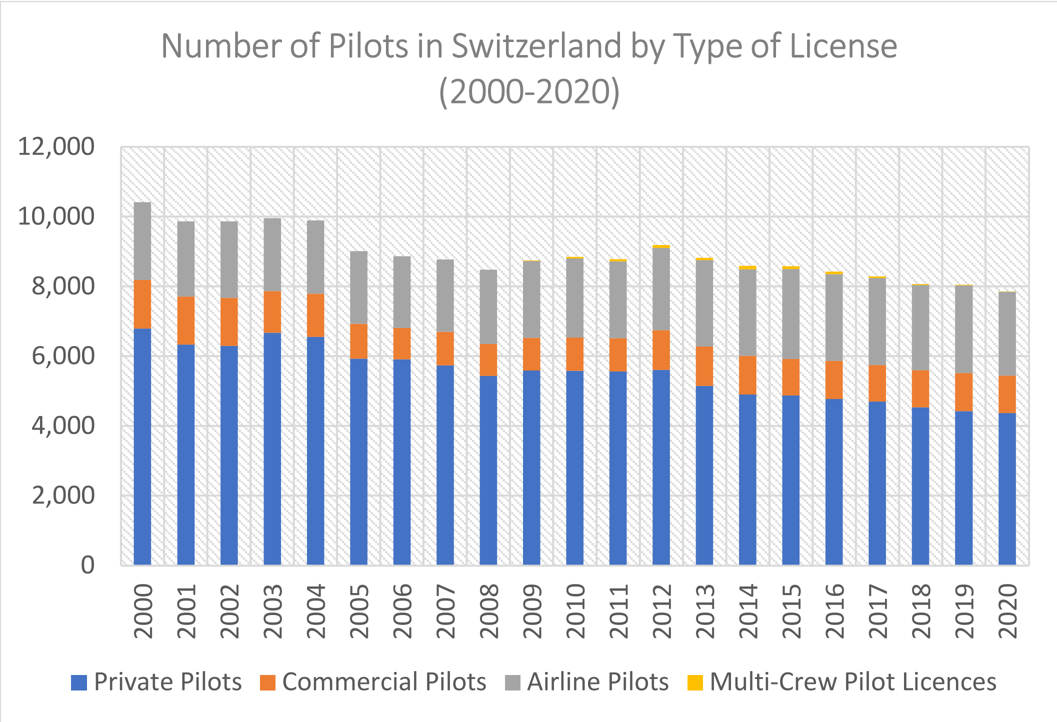

Figure 2: Number of Pilots in Switzerland by type of License 2000-2020, Source Data: Swiss Federal Statistical Office (2021)

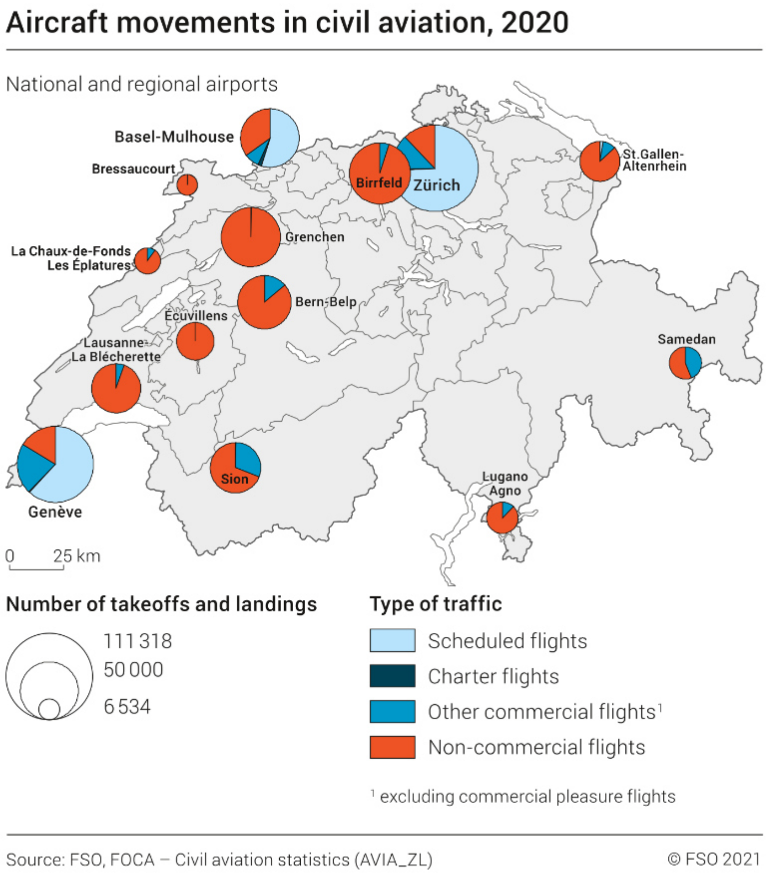

FIGURE 3: AIRCRAFT MOVEMENTS IN CIVIL AVIATION IN SWITZERLAND 2020, ADOPTED FROM FSO (2021)

2.1.3 Private Pilot Training

To become an active airplane pilot in GA the obtainment of a Private Pilot License (PPL) (United States: Private Pilot Certificate) according to the standards of ICAO is essential. Also, there exists the (EASA-exclusive) LAPL (Light Aircraft Pilot License) that can usually not be used in states outside the EASA territory (European Commission, 2022b). Both license types permit the non-commercial transport of passengers (PPL: as many as the aircraft legally permits; LAPL: max. 4 people on board incl. pilot) (FlyGA, 2022). The PPL(A) is usually acquired for the operation of single-engine piston (SEP) airplanes up to 5700kg MTOW (Maximum Take-Off Weight) (LAPL(A): 2000kg MTOW) (FlyGA, 2022; Rozenberg et al., 2017). Obtaining a PPL requires a Medical Certificate of Class 1 or 2, theoretical and practical training (45h total including 10h solo flights) and examinations, and a radiotelephony license (Rozenberg et al., 2017).

2.2 Sustainability Aspects and Sustainable Development in General Aviation

This section provides an overview of sustainability-related aspects and sustainable development efforts in GA and Private Pilot Training.

2.2.1 General Aviation's Environmental Impacts and Problems

2.2.1.1 Climate Change Impacts

In global terms, the *Aircraft Owners and Pilots Association* AOPA (2008) estimates the GHG contribution of GA to be less than one percent. Furthermore, AOPA (2008) estimates the global GHG share of small piston-powered GA aircraft to be around 0.13%. For Switzerland, FOCA (2007) argues that AVGAS-related CO_2 emissions from piston-engine GA aircraft can be nearly neglected as they comprise less than one percent of total civil aviation GHG emissions. However, there is great potential in the optimization of the energy consumption of GA considering that the average GA aircraft is approximately 50 years old (Luebbers, 2019).

2.2.1.2 Noise Pollution

Noise pollution is one of the most prominent environmental problems and socially relevant topics regarding aviation (FOCA, 2022d; Homola et al., 2019; Sobotta et al., 2007). The impacts of excessive noise pollution exposure can range from pure discomfort to negative effects on mental and physical health. Having become the focus of a fierce social debate, the abatement of noise and prevention of unnecessary exposure of people to loud noise from aircraft have become a top priority for aviation stakeholders (FOCA, 2022d; Min et al., 2015). Aviation noise mitigation measures as well as the definition of maximum legal noise levels (near aerodromes or airports) vary from country to country and are subject to national and regional legislation. In Switzerland, for instance, complex assessments incorporating the local topography and settlement structures near aerodromes and airports are used to determine the maximum number of permitted annual flight movements. GA aircraft, per se, are however loosely regulated apart from being classified in noise categories which may impact where they can start/land and how high the applicable landing fees will be (see *Section 2.2.2.1*).

2.2.1.3 Health Impacts

Lead and Bromide Emissions from Leaded Aviation Gasoline

In July 2021, roughly 100 years after its introduction, leaded car gasoline was finally phased out globally with Algeria having been the last country to stop selling leaded car gasoline (Angrand et al., 2022). AVGAS 100LL is the only fuel left in the world containing lead, more specifically *tetraethyl lead* (TEL) (see also Figure 4).

TEL increases fuel octane and thereby mitigates engine knocking, i.e., uncontrolled fuel detonation, which can cause engine damage and thus compromise flight safety (Kessler, 2013). Typically, aircraft piston engines are designed to have high performance at as little weight as possible so that they rely on high-octane fuels (Kessler, 2013). According to Kessler (2013), AVGAS 100LL would be equivalent to 105 octane car gasoline.

Thus, AVGAS 100LL is responsible for a large share of the atmospheric lead and bromide emissions (from scavenger *ethylene dibromide, EDB)* that have negative effects on human health (e.g., on the human nervous system, body development, reproduction, carcinogenetic properties) (Angrand et al., 2022; FOCA, 2007; Kumar et al., 2018; Levin et al., 2021; Zahran et al., 2017). Whereas the American Environmental Protection Agency (EPA) estimates the share of AVGAS-related atmospheric lead emissions to be around 45% in the U.S. (Levin et al., 2021), FOCA (2007) attributes 100% of atmospheric lead and bromide emissions (5t per annum each) in civil aviation to leaded AVGAS. While the FAA aims for a phaseout until 2030, the *European Chemicals Agency* (ECHA) has, on April 11, 2022, added TEL (classified as *toxic for reproduction, category 1A*) to the European authorization list, which means that companies who want to continue using TEL after Fall 2024 are obliged to file a special application (ECHA, 2022). This is effective as of May 1, 2022 (European Commission, 2022a) and could mean a *de facto* phaseout of AVGAS100LL in Europe until 2025.

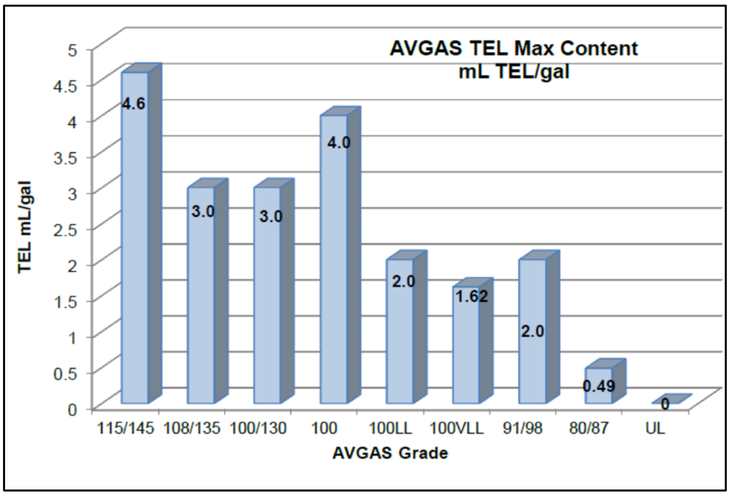

FIGURE 4: TETRAETHYL LEAD CONTENT IN DIFFERENT (HISTORICAL) GRADES OF AVGAS, ADOPTED FROM FAA (2011, P. 14)

<u>Hearing Impairment/Loss</u>

Pilots and airfield staff are also exposed to substantial noise emissions. Hearing loss among pilots is quite common and studies show that there is a strong correlation between flight hours/overall noise exposure time and increased risk of hearing loss (Antuñano & Spanyers, 2006; Atalay et al., 2015; Beringer & Harris Jr, 2005; Nie et al., 1997).

2.2.2 Sustainable Development in General Aviation

2.2.2.1 Noise Reduction

Noise abatement as a topic is especially pertinent in Switzerland being subject to both high population density as well as one of the most complex and most frequented airspaces on the European continent (DETEC, 2022). There are various ways to efficiently abate and deal with noise emissions.

Propeller and Muffler Modifications

In 1917 Frederick Lancaster concluded that the suction and pressure surfaces of rotating propeller blades generate sound waves that increase in intensity along with the tip speed of the propeller (Berton & Nark, 2019). Research and experiments have successfully demonstrated that noise reduction without decreasing the performance of the aircraft is possible through propeller modifications (Berton & Nark, 2019; Humpert et al., 2015). A good example in GA is Lars Hjelmberg's (Hjelmco Oil AB) modification for a Piper PA28 Warrior entailing an efficient setup of a Hoffmann[2] 4-blade propeller in combined use with a Liese[3] muffler system which achieved a certified noise reduction by 7-8 dB, or approximately 65%, and an increase in manifold pressure by 1.8 inches mercury allowing the aircraft to maintain 75% power up to FL120 yielding a fuel reduction of 8% at 120kt TAS, and even lower consumption of 5 USG/h at 100kt TAS (regularly 8.5-9.5 USG/h) (Hjelmco Oil AB, 2022). Prior to the privatization of Swedish airport and airfield operations in 2009 (taken over by then newly-formed *Swedavia AB*), this noise-reducing modification allowed a 50%[4] discount on landing fees in Sweden. The modification received an STC[5] (Supplemental Type Certificate) from the Swedish *Luftfartsverket* in 2000 and is thus EASA compatible.

Continuous Descent Approach

Being of a purely operational nature, applying the Continuous Descent Approach (CDA) instead of a conventional Step-Down Approach (cf. Figure 5) is a very effective way of reducing noise. The CDA is a steady decrease in altitude after leaving cruising altitude using reduced engine power and does therefore also decrease fuel consumption, CO_2 as well as other local atmospheric emissions (Jin et al., 2013; Scheelhaase et al., 2015).

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[2] German Propeller Manufacturer: HOFFMANN PROPELLER GmbH & Co. KG | Kuepferlingstraße 9 | D-83022 Rosenheim, https://hoffmann-prop.com/, accessed April 26, 2022
[3] German GA Aircraft Muffler Specialist: Bitz GmbH, Ulrichsmahd 22-30, D-86179 Augsburg, http://www.hliese.de/Info/info.html, accessed April 26, 2022
[4] Information from private conversation with Lars Hjelmberg, April 22, 2022
[5] https://www.hjelmco.com/upl/files/2430.pdf, accessed April 26, 2022

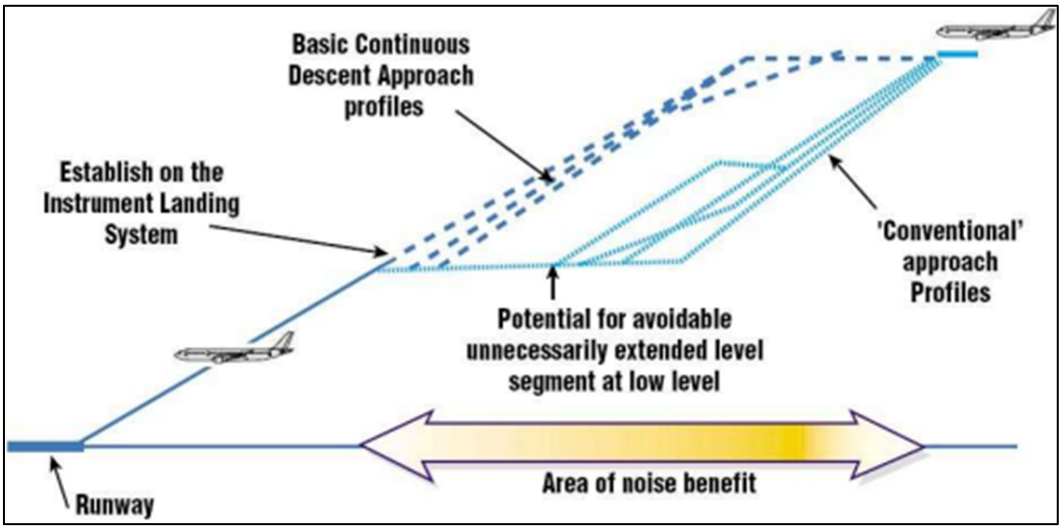

FIGURE 5: VISUALIZATION OF CDA VS NON-CDA (CONVENTIONAL STEP BASED APPROACH), ADOPTED FROM HULLAH ET AL. (2008, P. 61)

Noise-Based Landing Fees

In many countries landing fees at airports are composed of different components such as aircraft MTOW, nitrogen dioxide emission profile (Sweden and Switzerland were the first in Europe to introduce this pricing component, cf. FOCA (2022a)), and, indeed, noise. All aircraft registered in Switzerland and their respective noise charge classes are publicly accessible (FOCA, 2022c). This measure, however, provides aircraft owners with the possibility of benefitting from technological retrofits with evident noise reduction since those aircraft "(..) may be classified in a lower noise emission category" (FOCA, 2022c).

Noise Reduction Training

While technological noise abatement solutions have their limitations, it is not only important to reduce noise at its source but also to reduce the subjective impact of it which is heavily dependent on where and when it is emitted. In theory and practice, private pilots are trained to reduce noise and the impact of it on people that could be negatively affected by it (e.g., residents near airfields/airports). For instance, pilots are asked to avoid flying low and slow over noise-sensitive areas and furthermore asked to run the engine at low rpm.

Besides mandatory theory classes in various subjects and obligatory flight lessons according to the national syllabus, there are other ways of obtaining more detailed knowledge about noise pollution and reduction techniques provided by various institutions, for instance, FOCA's freely downloadable computer-based training, i.e., *Fluglärmminderung Computer Based Training*, that offers interested pilots the possibility of familiarizing themselves with this complex subject (FOCA, 2022d).

There are also airports such as Bern Airport that work with voluntary computer-based training and even offer pilots who have taken the online lessons and passed the online noise abatement test a discount on the landing fees (Bern Airport, 2022).

<u>Airport/Airfield Operations and Restrictions</u>

The significance of noise pollution becomes very clear when one looks at the geometry of airfield traffic patterns ('circuits') in Switzerland compared to the standard circuit which is a fixed rectangular pattern. A typical example is provided below depicting the air traffic pattern (black lines with arrows) of Gstaad Airport (LSGK) in Saanen, Switzerland (Figure 6) and the standard left-hand circuit that is flown in a simple rectangular shape (Figure 7). The yellow noise-sensitive areas in the visual approach chart in Figure 6 shall be circumvented via such a deviant geometric pattern.

Furthermore, certain measures regarding flight operations can, and must usually be taken by aerodromes/airports to reduce the impact of noise pollution on noise-sensitive residential areas in their vicinity. These measures usually entail adjustments to circuit geometry and altitudes, prescribed departure and arrival sectors and routes, flight day and time (e.g., no departures on Sundays, national holidays, before 10 am LT, during lunchtime, no landings past 8 pm, etc.) and flight type/movement restrictions (no training flights, circuit training, touch & go's on Sundays, etc.).

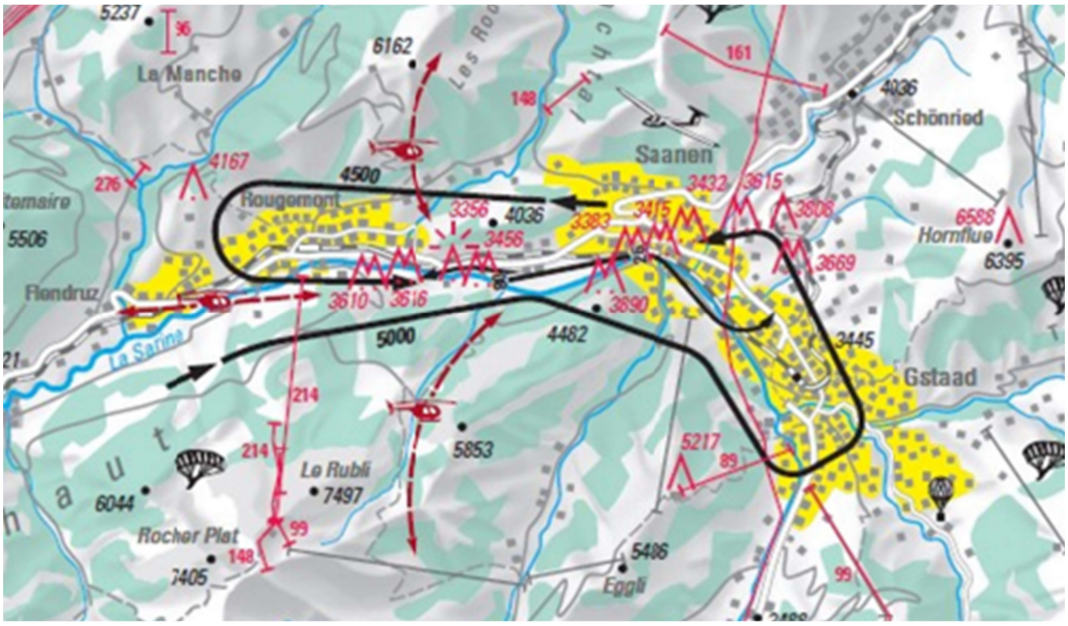

FIGURE 6: EXCERPT OF VISUAL APPROACH CHART FOR GSTAAD AIRPORT, FROM GSTAAD AIRPORT (2020)

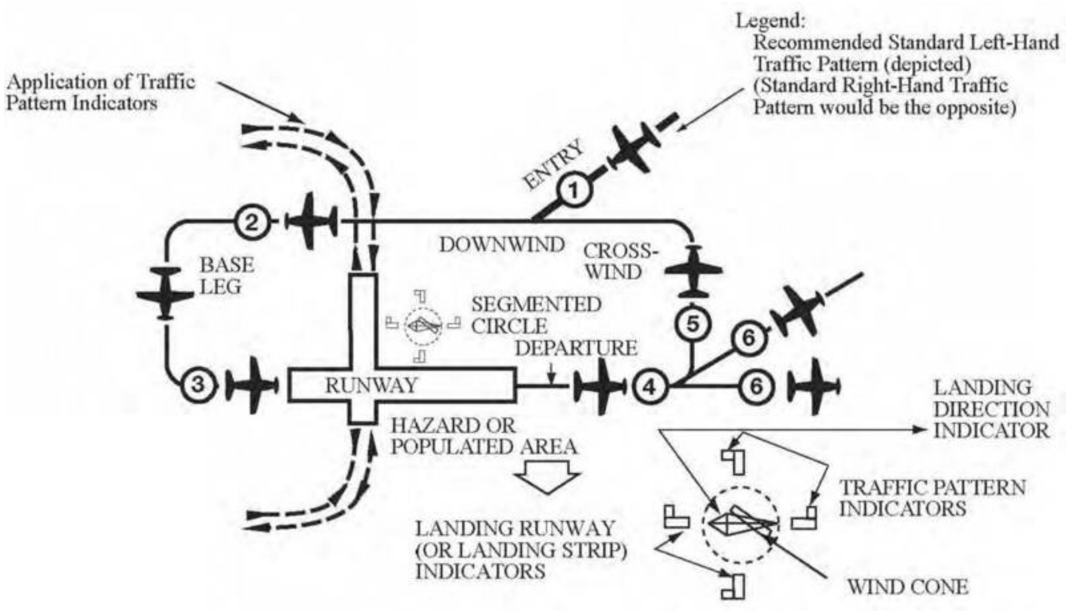

Figure 7: Standard Left-Hand Circuit, adopted from FAA (2022a)

2.2.2.2 Fuel Solutions

AVGAS 100LL Phaseout

Hirschman (2009, cited in Cloche (2010, p. 65)) described the leaded **AVGAS dilemma** as "**one of the most pressing problems in aviation** right now … an unleaded avgas replacement that will run across the entire piston-engine fleet". There have been several attempts and transdisciplinary research projects in various countries to find suitable alternatives for AVGAS 100LL, e.g., the research initiative of FOCA, DLR, and Swedish *Hjelmco Oil* in the first decade of the 2000s (FOCA, 2007), or the FAA driven *Piston Aviation Fuels Initiative* (PAFI) that has thus far not yielded the desired replacement solutions (FAA, 2014, 2019). Kumar et al. (2020) summarize that FAA's "(..) twenty years of research with two-hundred unleaded blends has not found a drop-in' unleaded replacement for aviation gasoline 100 low lead (..)". At the beginning of 2022, the FAA and EPA established a new program, a private-public partnership framework called EAGLE (**E**liminate **A**viation **G**asoline **L**ead **E**missions), that has the objective of paving the way toward the ambitious goal of a lead-free GA by 2030 (FAA, 2022b).

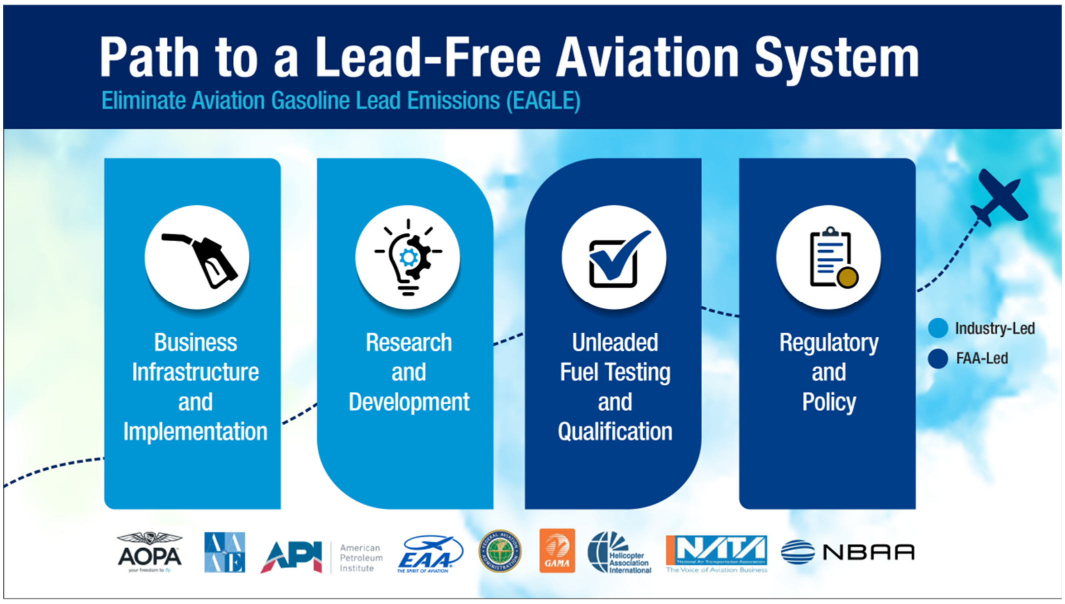

FIGURE 8: CONCEPTUAL OVERVIEW OF FAA'S EAGLE PROGRAM (ELIMINATE AVIATION GASOLINE LEAD EMISSIONS), ADOPTED FROM FAA (2022B)

The phaseout of leaded AVGAS in Europe is just a question of time. This uncertainty including the recent decision of the European Commission to ban TEL from 2025 as well as the uncertain future fuel supply situation[6] has been putting GA in Europe under high pressure. A production stop of AVGAS 100LL in Europe would mean that European GA stakeholders, such as flight clubs and airports, would have to import AVGAS 100LL from suppliers in the United States, which is expected to increase the average price of one liter AVGAS 100LL by approx. 1€ (AOPA Germany, 2022). In recent time, there have been noteworthy technological developments that have sparked noticeable optimism. Millner (2022) assures "100UL avgas is coming. Pricing shouldn't be dramatically different than today. (..) The relative ease of blending unleaded avgas compared to leaded avgas may lead to more market competition, and we will all benefit from that". Furthermore, there are very recent advances in the development and testing of synthetic unleaded aviation gasoline that would both cut lead and carbon emissions.

[6] As has been discussed fiercely at the general assembly of Fluggruppe Sarnen-Kägiswil (FGSK) on the 6th of May, there are only two AVGAS 100LL producing refineries left in Europe, one in Poland and one in the Czech Republic

AVGAS 100LL Alternatives, Biofuels, and Synthetic Fuels

One of the most feasible and readily available alternatives to using leaded AVGAS is the use of MOGAS (unleaded car gasoline) (Kumar, 2019). This can be done if the aircraft engine is certified for its use or an STC has been obtained. In fact, some sources suggest that using MOGAS instead of AVGAS 100LL is better for the internal engine parts and fuel systems (Cloche, 2010). Nevertheless, some GA stakeholders, such as Cessna Textron Aviation, have uttered serious concerns regarding the use of MOGAS in GA aircraft. These concerns regard mostly material incompatibility of the fuel system, risk of phase separation, vapor lock due to increased vapor pressure, carburetor icing because of raised enthalpy of evaporation, reduced energy content and the ethanol content in MOGAS, which eventually "(..) red-flagged the issue" (Kumar, 2019, pp. 5-6). In addition, there is also a minor market for retrofitting GA aircraft, e.g., Piper PA28 or Cessna 172, with diesel engines from *Continental Diesel* (Continental Aerospace Technologies, 2022).

Despite the still widespread use of leaded AVGAS, there are some available (not in every geographic region, or regulatory territory) older and newer lead-free fuel alternatives to this fuel. Some of these are 82 UL, 91/96 UL (Hjelmco Oil AB), 94 UL (Swift Fuels), G100 UL (General Aviation Modifications, Inc.), and UL 102 (Swift Fuels) (Cloche, 2010; Wikipedia, 2022). While in commercial aviation synthetic and biofuels, or SAF (Sustainable Aviation Fuels) have found their way into regular use, these types of fuels have not penetrated GA (yet).

However, the British company *Zero Petroleum* announced the completion of the world's first flight (November 2, 2021, Ikarus C42 aircraft at Cotswold Airport) using 100% net-zero synthetic fuel within the framework of their recent partnership with the Royal Airforce (Zero Petroleum, 2021).

2.2.2.3 Electric Aircraft

In its *2021 Aviation Climate Action Plan*, the FAA (2021, p. 8) argues that while the electrification in GA "(..) would only have a small impact on GHG emissions, the use of electrification as a means to power general aviation could have considerable air quality benefits as many small, short-haul aircraft are powered by leaded aviation gasoline". Riboldi et al. (2020, p. 35) argue that "the reduction of noise pollution in areas close to airfields is among the most significant improvements promised by a transition to fully-electric or hybrid-electric propulsion in aviation".

Since 2020, the use of electric aircraft in both military and private pilot training has gained much popularity across Europe, especially Switzerland featuring the currently highest rate of electric planes per capita. There are currently twelve DTOs in Switzerland with an electric plane (see Appendix A). Specifically, this relates to the still only certified electric aircraft *Pipistrel Velis Electro* (certified in 2020). For instance, the *Royal Danish Airforce*, and the *Royal British Airforce* and the *U.K. Ministry of Defence* has been using the *Velis Electro* for parts of their military pilot training (Airforce Technology, 2022; Royal Danish Air Force, 2021).

It is expected that the technology will improve steadily, promising shorter charging times and longer endurance as well as even economic advantages compared to ever-increasing AVGAS costs, which could lead to increased adoption by flight schools and other GA stakeholders (Hospodka et al., 2020; Peciak & Skarka, 2022).

In a recent survey study on the perceptions and attitudes of GA stakeholders in flight schools in India and Canada toward electric planes for private pilot training, Edwards and Parker (2022, p. 11) found strongly positive perceptions "indicating great excitement about the potential of the new electric aviation technology (..) " and that " (..) the flight school community is clearly in favor of introducing electric propulsion technology and reducing the environmental impacts of their industry". However, none of the flight schools surveyed in their study were in the possession of an electric plane at that time.

3 Theoretical Perspective and Methodology

This chapter gives an account of the applied theoretical perspective, and the research paradigm, and describes the employed methodology and methods.

3.1 Theoretical Perspective

This study investigated the sustainability transition in GA and private pilot training from a sociotechnical perspective suitable for the multidimensional nature of sustainable development and GA involving an array of interrelating environmental, social, and economic aspects that require consideration for a holistic sustainability transition in this aviation niche. The overarching research paradigm for this study is *Pragmatism* which implies that there is not just one solitary reality but rather truth and reality being under constant renegotiation and subject to behavior, social norms, and beliefs (Kivunja & Kuyini, 2017). Furthermore, the pragmatic paradigm has value-laden axiology seeking positive change and allowing research to be flexible without having to position the study within a paradigm such as positivism, post-positivism, interpretivism, or constructivism (Kivunja & Kuyini, 2017; Stiebe, 2021). Pragmatic research is especially suitable for sociotechnical sustainable mobility research, embraces the plurality of methods and involves a mixed-methods research approach drawing on both quantitative and qualitative methods with the fundamental notion that the choice of methods should be such a one that aids in the targeted knowledge discovery (Kaushik & Walsh, 2019; Kivunja & Kuyini, 2017; Maxcy, 2003; Morgan, 2013; Stiebe, 2021).

3.2 Methodological Approach

Corresponding with the chosen pragmatic research paradigm, this research has been carried out as a mixed-methods study including secondary as well as empirical research involving quantitative and qualitative methods.

3.2.1 Secondary Research

Research seeks to expand existing scientific knowledge and fill so-called *research gaps* that can be defined as " (..) areas that have not been covered in past studies" (Rehan et al., 2019, p. 119). In the case of this study, secondary research has been carried out in various forms and assisted in 1) determining the status quo of research and technological developments concerning the topic, 2) identifying the research gap, and 3) creating a brief (non-exhaustive) stakeholder overview mainly focused on the Swiss and European GA landscape (see Appendix A) for later empirical research. To obtain a comprehensive overview, several types of sources have been consulted and systematically analyzed using striking search queries using combinations of keywords such as "AVGAS", "Sustainable", "Sustainability", "General Aviation", "Private Pilot Training", "Electric Aircraft", etc. The consulted sources were mostly (online) newspaper articles, grey literature, academic literature (mostly via Google Scholar, Scopus, Science Direct, Google Internet Search), national and supranational statistics (e.g., FOCA, FAA, AOPA), and other online sources (e.g., info pages of GA stakeholder organizations).

3.2.2 Empirical Research

This section describes the methodological foundation of the empirical research part of this project. Being active in GA in central Switzerland the author had 1) practical insights and an extensive stakeholder network in GA, and 2) favorable access to the research field due to professional engagement with sustainable mobility research.

3.2.2.1 Qualitative Research

The field research part of this study has primarily drawn on semi-structured in-depth expert interviews. Some qualitative statements by GA stakeholders have also been available for analysis from responses to the open-ended questions in the survey. Furthermore, the author was able to complement an on-site interview with some participant observation.

Expert Interviews

Expert interviews are a popular method in social and sociotechnical research, especially during exploratory phases to scope and identify certain social issues (Bogner et al., 2009; Littig, 2009).In this case, sustainability in GA and private pilot training is analyzed using expert interviews However, the quality of the results is highly dependent on the quality of the chosen experts (Gläser & Laudel, 2009).

The interviewees were identified and recruited via different methods, namely 1) via non-probability/convenience sampling (author's personal network), 2) based on the preceding stakeholder overview (see Appendix A), and 3) via snowball sampling. A total of eleven invitations via WhatsApp messages, phone calls, or e-mail was sent out of which only three interview candidates and stakeholder organizations did not reply. Eight interviews, six in German and two in English, were conducted between April 16 and May 13, 2022, both, online (7) and face-to-face (1) (see Table 2).

The interviews followed a bilingual (English and German) interview guide comprising thirteen main questions and eight potential follow-up questions (see Appendix C). Semi-structured interviews, in comparison to structured interviews, are an ideal means to allow for more flexibility during the process, e.g. follow-up questions (Wengraf, 2001). During the interviews, some notes were taken, and consensual video and audio recordings were made for later evaluation.

The evaluation of the interviews was guided by the research questions and the de facto a priori assigned codes from the interview guide. This allowed a time- and resource-efficient partial/sectional transcription of the interviews. The interviews were not transcribed in entirety, but a pragmatic partial/sectional transcription approach has been used. It should be noted that since most interviews were held in German, the English quotations used in Chapter 4 are literal translations.

Qualitative Statements from Open-Ended Survey Questions

The survey contained some open-ended questions where users could comment in their own words. Some of these statements proved to be of good quality and provided further insights into the opinions, attitudes, and concerns of GA stakeholders.

Participant Observation

The author was able to complement the on-site interview with some participant observation following the generous invitation of Marc Corpataux of Alpin Airplanes GmbH at Aérodrome Régional Fribourg-Ecuvillens, which permitted exploring the infrastructure (e.g., plane materials, charging infrastructure, etc.), get a guided tour of the Pipistrel Velis Electro, adjacent facilities (e.g., solar-powered charging station) and the possibility to take the plane himself (dual control) on a free test flight May 13, 2022. Some notes and pictures have been taken in the field, e.g., Figure 9.

FIGURE 9: AUTHOR TAKING THE PIPISTREL VELIS ELECTRO FOR A TEST RIDE IN THE VICINITY OF ECUVILLENS, FR, MAY 13, 2022, PILOT IN COMMAND: MARC CORPATAUX OF ALPIN AIRPLANES GMBH

Table 2: Interview Participant Description

#	Date	Time (CET)	Duration (hh:mm)	First Name	Last Name	Role	Organization	Location	Mode	Language	Remarks
1	16.04.	12:00	00:46	Martin	Wälti	CEO	Aviathor GmbH	Oberdorf (Nidwalden)	Online (Zoom)	German	
2	20.04.	13:30	00:52	Jan	Spycher	CEO	Buochs International Airport LSZC	Buochs (Nidwalden)	Online (Zoom)	German	Also Certified Flight Instructor
3	21.04.	14:00	01:01	Andreas	Ryser	Head of Environmental Department	AeroClub Suisse	Luzern	Online (Zoom)	German	
4	21.04.	09:00	01:01	Damian	Hischier	Experimental Test Pilot; consultant and project manager for different organizations and individuals in Europe, Africa and Australia; Certified Flight Instructor	Freelance	Oberwald im Goms (VS)	Online (Zoom)	German	Main Test Pilot for Volocopter; Pilot with most experience of eVTOL's (electric vertical take-off and landing aircraft)
5	22.04.	12:30	01:12	Lars	Hjelmberg	CEO and Founder	Hjelmco Oil AB	Sollentuna, Sweden	Online (Zoom)	English	Unleaded and Sustainable AVGAS Pioneer
6	24.04.	20:30	01:35	Hermann	Spring	PPL(A) Course Coordinator	Flug Betriebs AG	Sarnen-Kägiswil	Online (Zoom)	German	
7	04.05.	10:00	00:36	Axel	Doffey	Business Development Manager	H55	Sion, VS, Switzerland	Online (Zoom)	English	H55 is the legacy of Solar Impulse (see Bertrand Piccard and André Borschberg famous for their solar airplane 'solar impulse' flying around the entire globe 2015-2016)
8	13.05.	15:00	00:25	Marc	Corpataux	CEO and Founder	Alpin Airplanes GmbH	Ecuvillens Airport	On-Site (Ecuvillens)	German	Pipistrel Velis Electro Test Flight in Ecuvillens + Interview; Sole distributor/representative for Pipistrel Velis Electro planes in Switzerland and Pipistrel Velis Electro supplier to Swiss flight schools

3.2.2.2 Quantitative Research

The quantitative part of this research covered two different methods. First, a PPL(A) syllabus-based CO_2 Analysis ("Carbon Footprinting") comparing two conventional flight school planes with internal combustion engines to the currently only EASA-certified electric plane (Pipistrel Velis Electro) was made. Second, a quantitative online survey among GA stakeholders in Switzerland was conducted.

CO$_2$ Analysis/Carbon Footprinting

Aviation does not only have a climate impact through its direct CO_2 emissions but also via climate-relevant non-CO_2 emissions including first and foremost NO_x, SO_x, water vapor, soot, and contrail-related cirrus clouds (Scheelhaase et al., 2015). Altitude plays a substantial role in the climate impacts of the non-CO_2 emissions from aviation (Azar & Johansson, 2012). However, most GA and private pilot training activities are conducted at relatively low altitudes (mostly <10,000ft), and commercial aviation cruising usually between 33,000ft and 42,000ft (Pilot Institute, 2021). On the one hand, small planes in GA do not produce contrails or cirrus clouds. On the other hand, the altitude effects increasing the climate impact of non-CO_2 emissions are not present to any significant extent at said GA altitude range. Thus, no EWF must be applied for the low altitude GA calculations (see also, Hospodka et al. (2020)). For the analysis, the syllabus was first digitized in Microsoft Excel. Then, the flights with more than 45 minutes of estimated elapsed time (EET) were marked as unfeasible (see Figure 10/Appendix E) for replacing them with flights using the Pipistrel Velis Electro due to endurance limitations (max. 40-50min including VFR reserve time).

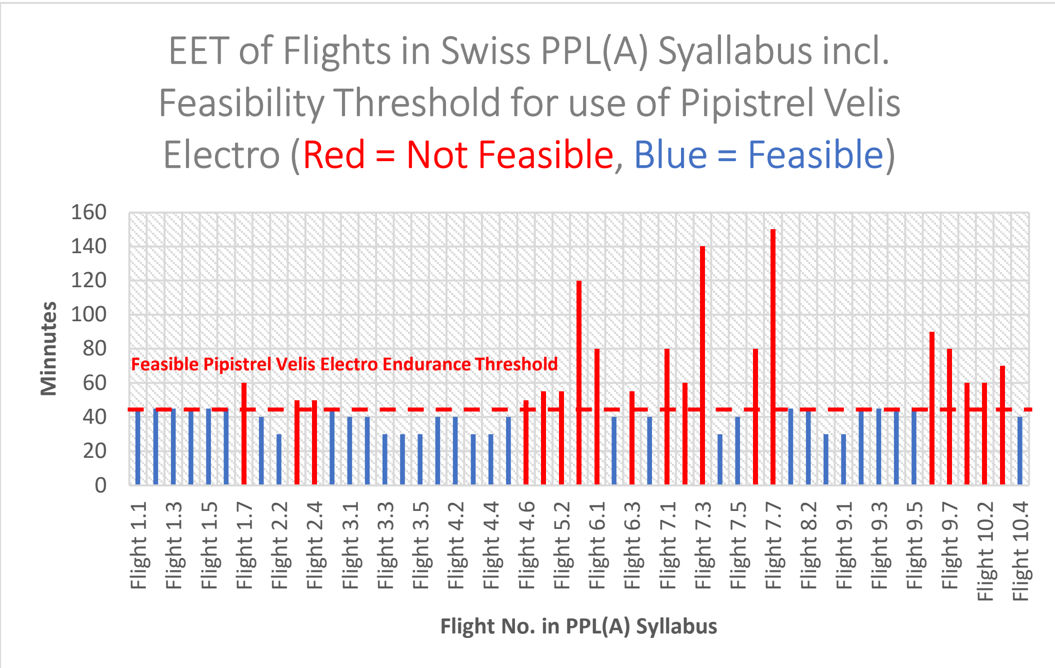

Figure 10: Syllabus Analysis with Regard to Replaceability of Flights with Pipistrel Velis Electro

Since the fuel consumption for GA aircraft can vary from plane to plane, even if it is the same type (e.g., modifications), an average fuel consumption rate was assumed. The following typical GA aircraft have been used as examples in the calculation: 1) Piper PA28-161 Warrior II, 2) Diamond DA20i Katana. The AVGAS 100LL fuel consumption rates were set at 9.25USG/h[7] and 3USG/h[8], respectively (fuel consumption differences due to substantial size, weight, and engine efficiency differences). For the electric plane, average electric power consumption of 26kWh[9] per hour was assumed. As Hospodka et al. (2020) already remarked, there are not too many data sources with exact emission data for AVGAS 100LL in comparison to other fuel types. Thus, to compare the use-phase emissions the scientific emissions report from FOCA (2007) served as a comprehensive and reliable data source for the CO_2 analysis. The value stated there is 3.17kg CO_2 per 1kg AVGAS 100LL. The density of AVGAS 100LL was assumed to be 0.72kg/l whereas one USG equals 3.785l. The comparison also involved the consumption of electric energy which needed to be converted into CO_{2e} emissions. The Swiss consumer electricity mix value was used in the analysis, i.e., 0.128kg CO_{2e}/kWh[10]. Because the average age of GA aircraft, as well as their mileage/flight hours, are quite high the production phase of the aircraft is not considered in the analysis.

Quantitative Survey

The centerpiece of this research has been a quantitative bilingual (English and German) online survey among pertinent GA stakeholders in Switzerland. The questionnaire, which was designed using *Microsoft Forms*, comprised 24 questions divided into two parts, i.e., a) questions about the respondents flying activity/flight training as well as sustainability and environmental topics (17), and b) sociodemographic questions (7) (see Appendix D). Some questions built on the insights from the preceding expert interviews. The survey was distributed on May 10, 2022, through the official newsletter e-mail of *Motorflug-Verband der Schweiz* (MVFS) (Motor Flight Association of Switzerland) (see Appendix D). The responses were exported as *Microsoft Excel* files for further processing and statistical analysis. The German and English survey responses were translated and merged into one file. The datasets (free text answers, e.g., age, residential canton, etc.) have been cleaned wherever obvious typographical errors or unambiguity permitted manual corrections. The following software has been used for the treatment and processing of the survey data: *Microsoft Excel*, *IBM SPSS*, *Tableau*.

[7] Author's current training plane
[8] https://www.diamondaircraft.com/en/flight-school-solution/aircraft/da20/tech-specs/, accessed May 28, 2022
[9] https://velis.virus-grenchen.ch/flugzeug/, accessed May 28, 2022
[10] https://www.bafu.admin.ch/bafu/de/home/themen/klima/fragen-antworten.html#-1202736887, accessed May 28, 2022

Sample Description

From May 10 to May 27, 2022, 425 responses were received on the German survey and another two responses on the English survey. The sample was composed of predominantly middle-aged (Ø=50 years), above-average[11] income (79% > 90,000 CHF p.a.), highly educated (70% tertiary education background), male (94%) participants. The most prominent respondent groups (multiple selections/functions were possible for each respondent) were private pilots (79%), active and former commercial pilots (19%), and flight instructors (11%). Though only comprising a little more than six percent each, important further respondent groups were student pilots (6.6%) as well as people active in flight school administration and operations (6.1%). About one-eighth of the sample has already come in contact, i.e., flown on an electric aircraft. Most respondents resided in the cantons Zurich (36%), Aargau (18%), and Bern (12%). Three respondents resided outside Switzerland, namely Germany (2) and Liechtenstein (1). For detailed information, please see Table 3 and Figure 11.

Table 3: Sociodemographic Survey Sample Composition

SOCIODEMOGRAPHIC ASPECT	CATEGORY	VALUE
RESPONDENT TYPE (N=427)	Private Pilot	78.92%
	Commercial Pilot (Active + Retired)	19.20%
	Flight Instructor (PPL(A)/LAPL(A))	11.24%
	Other Functions	6.79%
	Student Pilot (PPL(A)/LAPL(A))	6.56%
	Flight School Operation/Administration	6.09%
	Aerodrome or Airport Operation/Administration	2.81%
	Aircraft Manufacturing/Maintenance	1.87%
	Supervision/Regulation/Government	0.70%
	Student Pilot (Other)	0.23%
	Military Pilot	0.23%
	Test Pilot	0.23%
GENDER (N=427)	Female	6%
	Male	94%
AGE (N=421)	Average	50
	Median	51
	Std. Dev.	14.6
	Min	17
	Max	81
INCOME (N=325)	< 30,000 CHF	2.8%
	30,000 - 59,000 CHF	3.7%
	60,000 - 89,000 CHF	14.5%
	90,000 - 109,000 CHF	16.9%
	110,000 - 149,000 CHF	29.5%
	150,000 - 199,000 CHF	14.2%

[11] Median annual income per capita in Switzerland in 2020, 79,980 CHF; see https://www.bfs.admin.ch/bfs/de/home/statistiken/arbeit-erwerb/loehne-erwerbseinkommen-arbeitskosten.html

	200,000 - 249,000 CHF	7.1%
	> 250,000 CHF	11.4%
EDUCATION (N=421)	Tertiary Education (College, University, University of Applied Sciences, etc.)	70.3%
	Commercial/Military Pilot Training	1.2%
	Apprenticeship/Vocational Training	21.1%
	Secondary Education (A-Levels/Matura)	6.9%
	Secondary Education (Obligatory Level)	0.5%
AIRCRAFT OWNERSHIP (N=427)	Yes	22%
	No	78%
PREVIOUS EXPERIENCE WITH ELECTRIC AIRCRAFT (N=427)	Yes	12%
	No	88%

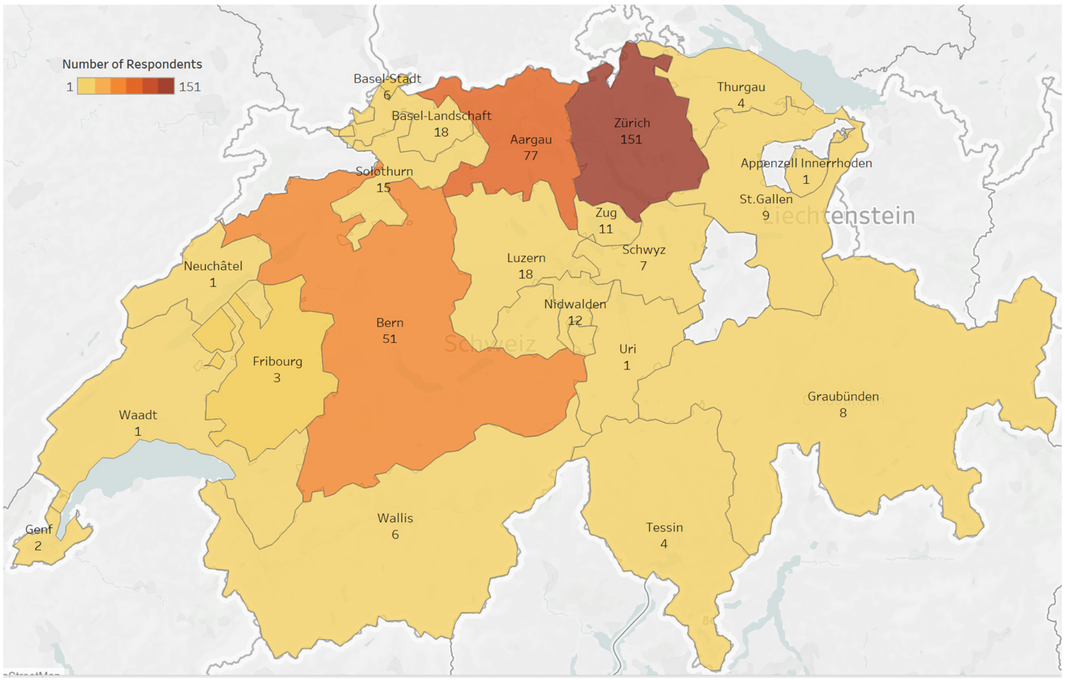

Figure 11: Map of respondents' residential cantons, N=420, Liechtenstein (1) and German (2) Respondents not visualized

3.2.2.3 Data Protection, Data Loss Risk Mitigation, and Data Management

The primary data were treated with utmost caution in line with common data protection guidelines. To avoid data loss, backups were made, and the principle of redundancy was applied by always making two simultaneous recordings on at least two devices (smartphone, tablet, and/or personal computer).

The author is dedicated to research following the FAIR guideline for scientific data management and stewardship embracing four core principles, namely **F**indability, **A**ccessibility, **I**nteroperability, and **R**eusability (Wilkinson et al., 2016). The meaning of the principles is described in Table 4. Thus, other researchers and interested stakeholders shall have access to a well-organized anonymized empirical survey dataset and are welcome to reuse and build on it.

Table 4: The FAIR Principles for Scientific Data Management and Stewardship, Adapted From Boeckhout et al. (2018, p. 932)

Principle	Explanation
Findability	Datasets should be described, identified, and registered or indexed in a clear and unequivocal manner
Accessibility	Datasets should be accessible through a clearly defined access procedure, ideally using automated means. Metadata should always remain accessible
Interoperability	Data and metadata are conceptualized, expressed, and structured using common, published standards
Reusability	Characteristics of data and their provenance are described in detail according to domain-relevant community standards, with clear and accessible conditions for use

3.2.2.4 Synthesis/Triangulation

According to Thurmond (2001, p. 253), triangulation increases research reliability and entails "(..) the combination of two or more data sources, investigators, methodologic approaches, theoretical perspectives or analytical methods within the same study". In this study, this was done in two ways, namely 1) matching qualitative responses to open-ended questions on the survey with qualitative statements obtained during the interviews, and 2) using quotes and interview insights to support quantitative findings from the survey, and vice versa.

3.2.2.5 Bias Risk

The author was aware that due to his personal involvement in GA the research could be exposed to some degree of bias which he tried to cautiously avoid by being as critical as possible.

3.2.3 Research Plan

This research project was conducted from March to June 2022. A detailed overview of the schedule and methodology can be obtained from Appendix B.

4 Results

This section presents the most relevant empirical findings in relation to the main research question as well as the related sub-questions.

4.1 Current Sustainability Challenges in Private Pilot Training

Whereas 79% of the survey respondents agree or strongly agree that sustainability and the environment are important topics in GA, there is no unanimous opinion on what the greatest sustainability challenges in GA are. When asked, Interviewee 7 elaborated:

> "Well, the largest challenge is CO_2 emissions. (..) In General Aviation it is actually a bigger problem than in commercial aviation. (..) There is a scenario where some politicians can just say: 'General Aviation? We don't care and we can close it because it pollutes and has no impact, it's a hobby basically'. There is a trend in this way. (..) **General Aviation should be at the forefront to propose alternatives in terms of CO2 reduction and noise reduction**."

However, throughout the interviews, it seemed that GA stakeholders are divided into two camps regarding the question of whether GHG emissions in GA are a substantial problem or not. This matches the survey answers, where about 39% categorized them as a major problem, and 39% did not.

Interviewee 5 remarked that the main problem in GA is the continued use of leaded AVGAS and the generation of bromide emissions but also emphasized that "(..) the second problem is noise". Interviewee 3 stated that "in Switzerland, we are extremely hyper sensitized against noise emissions". These concerns are also widely reflected in the survey results where 68% and 63% agreed or strongly agreed that the continued use of leaded AVGAS and noise emissions are major problems in GA, respectively. Although there are available technological solutions (e.g., propeller and muffler retrofits, cf. Chapter 2.2.2.1), there seems to be reluctance, especially in flight schools, to adopt such technologies due to high costs. Interviewee 5 stated that "the reason why nothing is happening is that no one wants to pay the 6,000€ to put the new propeller and muffler on the aircraft. If they don't see that they get the money back, and flight schools are usually not very rich institutions, nothing is happening".

Furthermore, besides the high costs of innovation in GA, the interviews unveiled further detrimental barriers to innovation, i.e., bureaucracy and (over)regulation as well as (predominantly American) nationalism. While the main drivers in sustainable GA are currently private entities, Interviewee 5 remarked that the facilitation of sustainable development in GA, especially sustainable fuel development, should be more supported by the governments "(..) because [they] have taken tens of millions of Euros during the years in fuel taxes and have given us nothing back (..) they should open their purse and give the money to the technical universities (..)". Likewise, Interviewee 8 commented that the civil aviation authorities, such as FOCA, FAA, and EASA, should take their role in sustainable development in GA more seriously and act against the continued use of leaded AVGAS. According to the survey results, bureaucracy, politics, and overregulation are the primary obstacle to sustainable development in GA, followed by high costs (see Figure 13).

One of the great hurdles on the route to sustainable GA and private pilot training is certainly the decreasing number and increasing age (demographic change) of active GA pilots and aircraft. A shrinking GA market and decreasing GA activity act as inhibitors to innovation. One survey participant (209) remarked „(..) unfortunately, GA activity keeps declining and therefore innovation is difficult". Nevertheless, there also seems to be hope in the younger generations and their increased awareness of the environment and sustainable development as Interviewee 8 remarked "I believe this helps (..) it is a generational question. It's not that I want to dismiss the older generation, but things are going to change, they will definitely change".

In terms of the need for fresh innovation in the market, Interviewee 6 argued "we are currently lacking an Elon Musk in aviation".

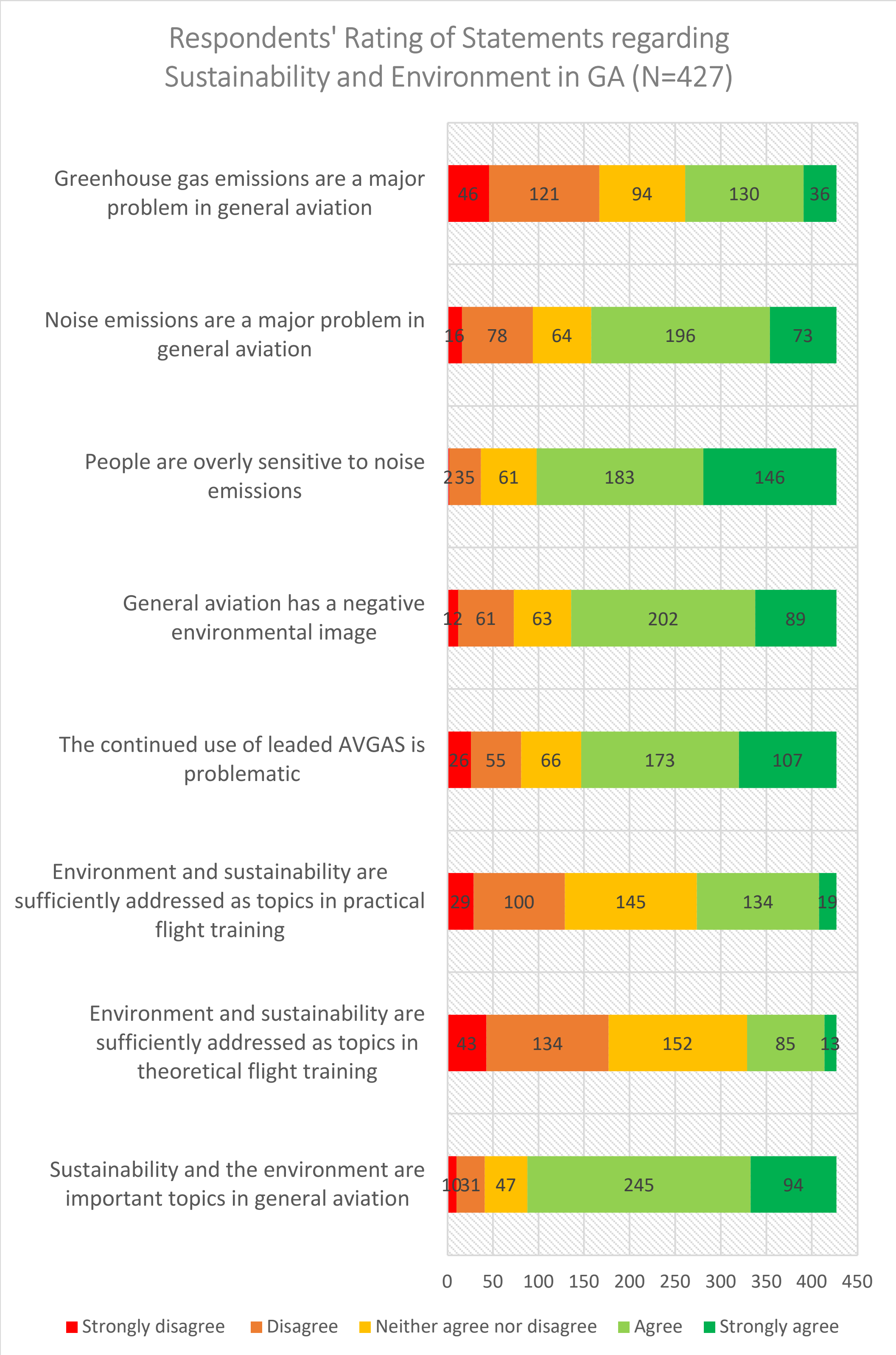

Figure 12: Respondents' Opinions on Sustainability and Environmental Aspects in GA, Survey Results

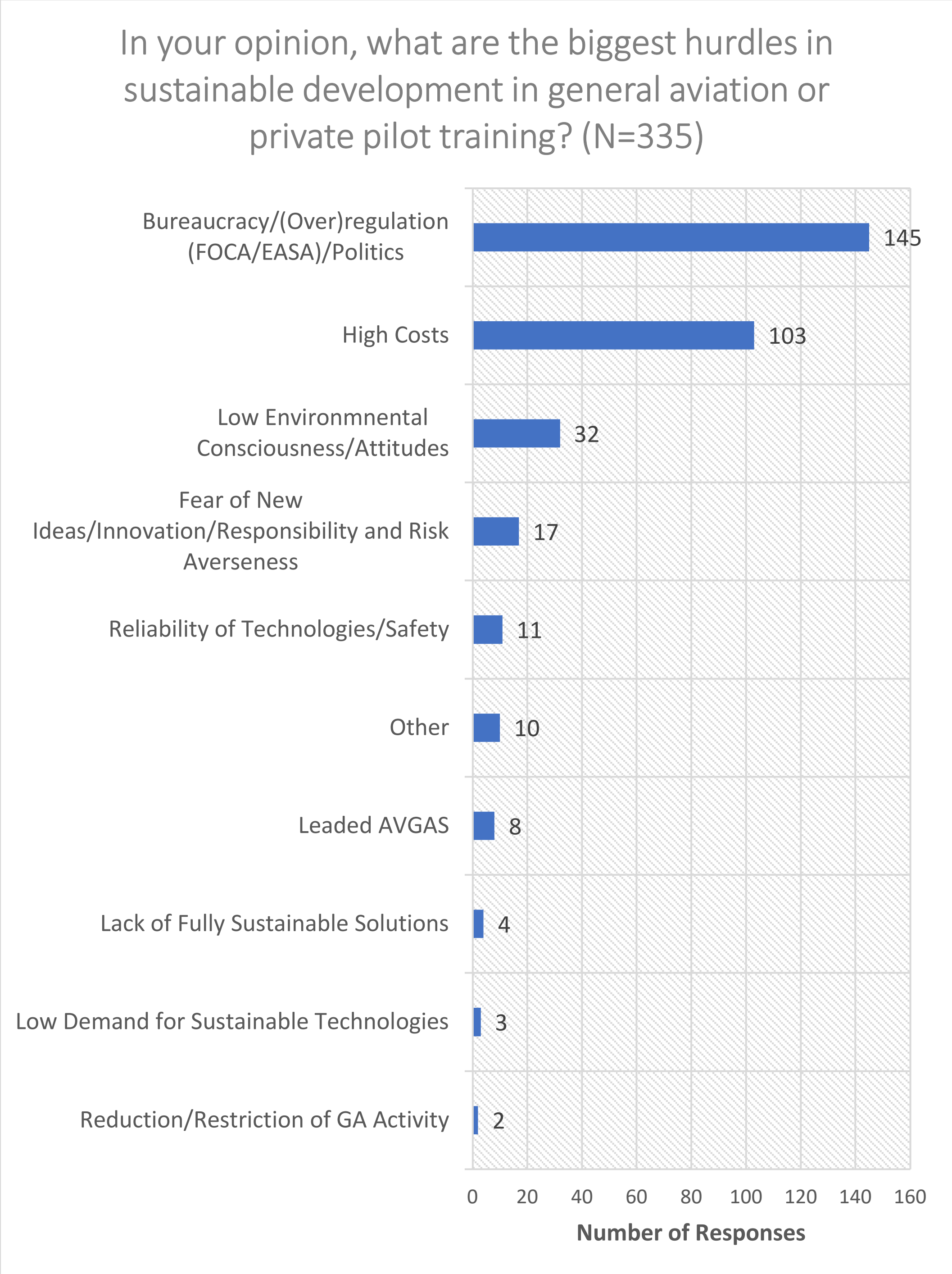

FIGURE 13: LARGEST OBSTACLES TO SUSTAINABLE DEVELOPMENT IN GA AND PPL/LAPL(A) TRAINING, SURVEY RESULTS

4.2 Electric Aircraft in Private Pilot Training

Electric aircraft, especially *Pipistrel Velis Electro*, have gained popularity in basic pilot training. According to Interviewee 8, Switzerland was the first country to adopt and register the Slovenian-built aircraft and is currently boasting the highest rate of electric aircraft per capita. Furthermore, the small country is home to more drivers of innovation in electric aviation, e.g., the Sion-based company *H55* that also electrified the first-ever commercial flights in the world (*Harbour Air* in the Pacific Northwest).

The interest in electric GA as well as its growing role in pilot training are reflected in the survey results. 12% of Swiss motor pilots and 18% of current student pilots have already flown an electric aircraft. The most frequent reasons stated for flying an electric aircraft were general interest in the technology and trial flights (51%), as well as flight training (teaching and learning) (38%) as can be seen in Figure 14. The majority (56%) of all respondents estimates the overall potential of electric planes for more sustainable GA and PPL(A)/LAPL(A) training to be high, whereas many (42%) expressed their doubts about the technology and rated its potential to be low or non-existent (see Figure 15). When asked to rate a range of aspects that are often mentioned as disadvantageous in relation to electric aircraft use, the respondents saw a *big problem* regarding the low range/endurance (79%), insufficient charging infrastructure at airfields/airports (52%), and long battery charging times (45%). The aspects considered the least problematic were high costs and fire hazard of the battery which 52% and 47% of the respondents considered being *no problem* or *rather no problem*, respectively. Except for the aspect of battery fire hazard, all listed aspects were predominantly assumed to be rather or fully problematic as is depicted in Figure 16.

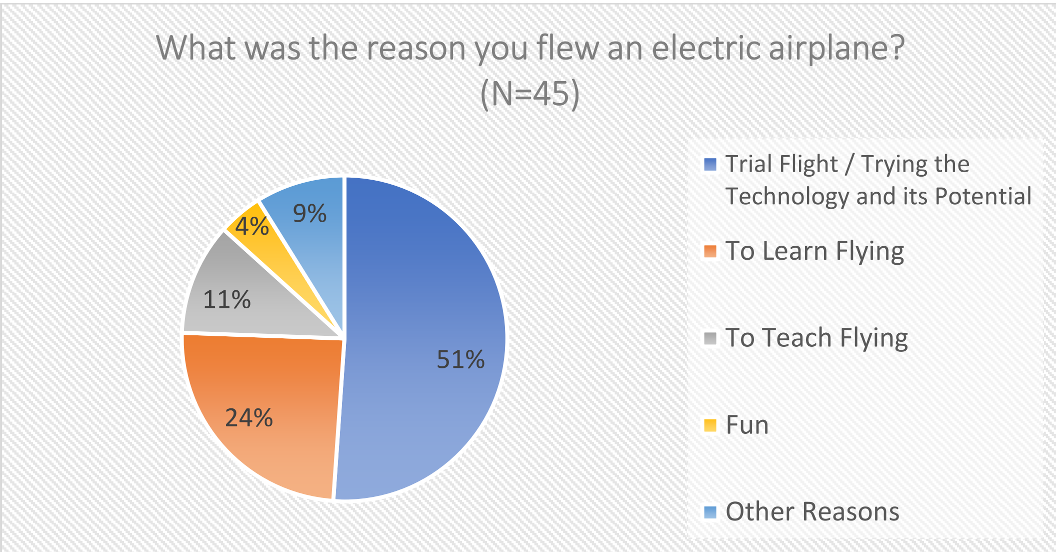

FIGURE 14: WHAT WAS THE REASON YOU HAVE FLOWN AN ELECTRIC AIRPLANE?, SURVEY RESULTS

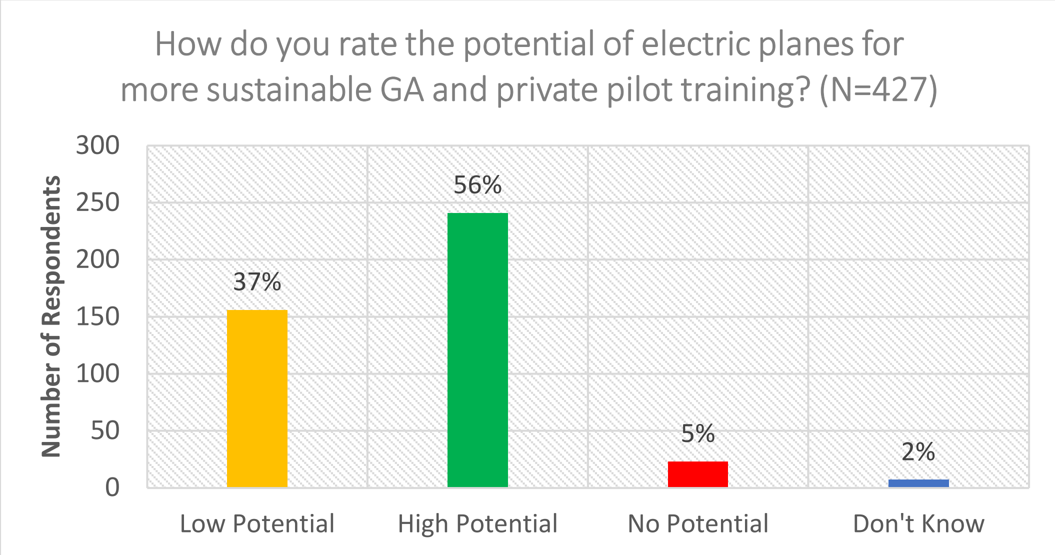

Figure 15: Respondents Assessment of Electric Aircraft Potential for Sustainable GA and PPL(A)/LAPL(A) Training, Survey Results

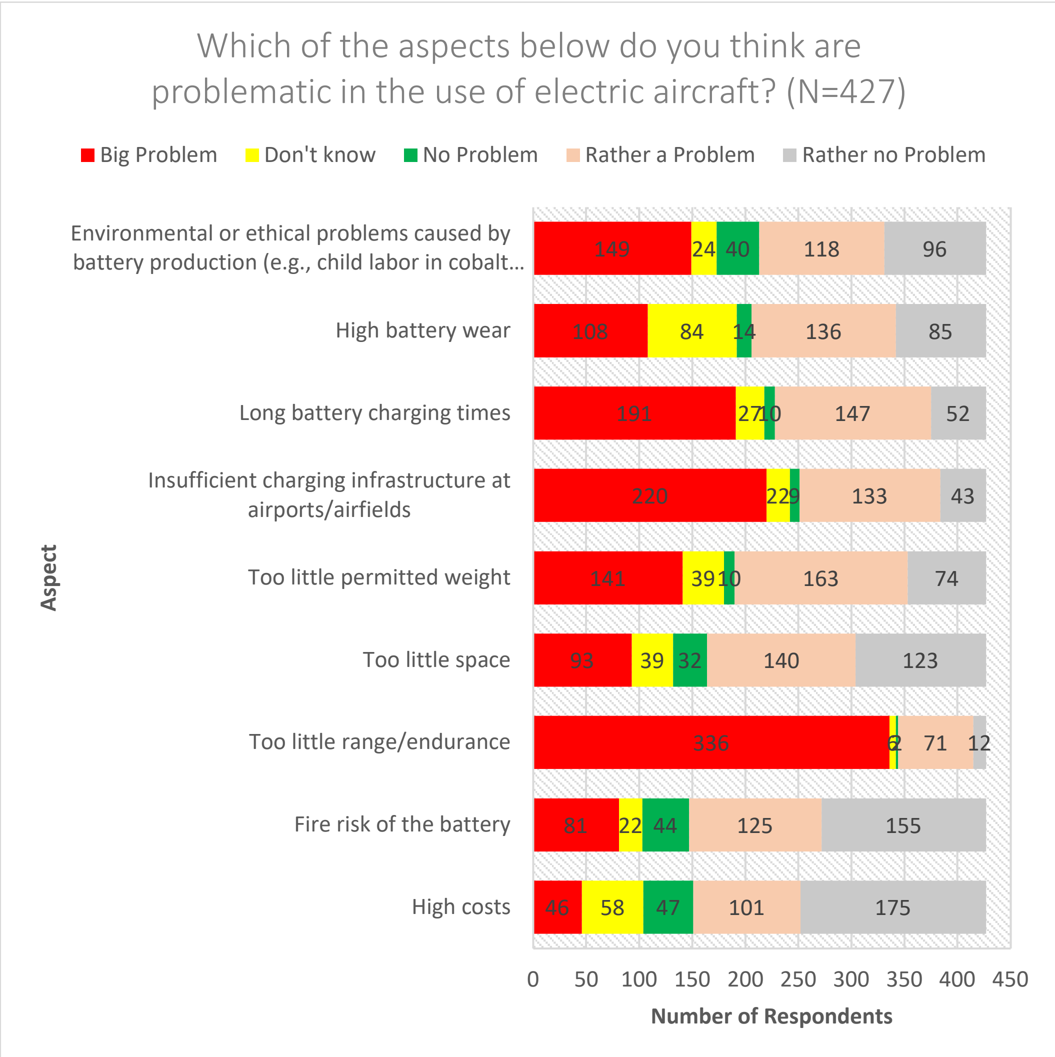

Figure 16: Respondents' Views on Problematic Aspects of Electric Aircraft Use, Survey Results

Interviewee 5, a Swedish pioneer in sustainable and unleaded GA fuels, remarked "I think that someday battery aircraft will come, but we are not there yet". Interviewee 2 argued that electric GA is currently not financially feasible "except we would highly subsidize this (..) but it is highly unlikely that the federal government will do this". Nevertheless, the introduction and efficient distribution of Pipistrel Velis Electro planes has been subsidized by FOCA and its subsidy fund *BV 87*[12] (Interviewee 8). Interviewee 2 remarked referring to non-existent subsidies in Germany: "That's why you don't see these electric planes in Germany". Despite the general discontent with the civil aviation authorities among GA stakeholders, FOCA has been praised by Interviewees 6 and 8 for its initiative in supporting the adoption of electric aviation.

Furthermore, Interviewee 2 commented that charging and ground times in combination with 40-50 minutes (incl. legal VFR reserve) endurance are still unfavorable for efficient flight school operations. Similar remarks were made by Interviewees 7 and 8. A further problem, rather a practical one, is that there is currently a lack of standardization in electric aviation. Like in the early days of electric automobility, there is now a "mess of various different power plugs and protocols", Interviewee 8 explained.

A few additional problems include, according to Interviewees 6 and 8, the currently high wear and depreciation (approx. 40 CHF per charging cycle) of the batteries in Pipistrel Velis Electro planes, the frequent battery mandatory battery changes at 80% battery life, as well as thermal management for charging, especially if it is too cold (e.g., during winter).

Nevertheless, according to interviewees 7 and 8, the thermal management, endurance as well as charging times are expected to improve with the newer generations of upcoming battery technology so that the utility of electric planes for private pilot training may soon increase. One of the current advantages for densely populated and noise-sensitive regions like Switzerland is the noise reduction potential of electric planes. Besides the reduction of direct pollutant emissions compared to single-engine piston aircraft (e.g., lead, bromides, hydrocarbons), greenhouse gas emissions can also be reduced using electric aircraft as can be seen in the PPL(A) syllabus-based CO2 analysis below that shows the possibilities of saving between 478kg CO2e and 1,591kg CO2e when conducting combined flight training with a Diamond DA20i Katana (assuming 3USG AVGAS per hour) or a Piper PA28-161 Warrior II (assuming 9.25USG AVGAS per hour) (see Figure 17). These figures apply when the flights that were marked as feasible (below the 45-minute threshold line) in the syllabus analysis are replaced with flights using the electric plane.

[12] https://www.bazl.admin.ch/bazl/de/home/fachleute/regulation-und-grundlagen/spezialfinanzierung-luftverkehr--wofuer-es-gelder-gibt/gesuch-um-finanzhilfe-.html, accessed May 28, 2022

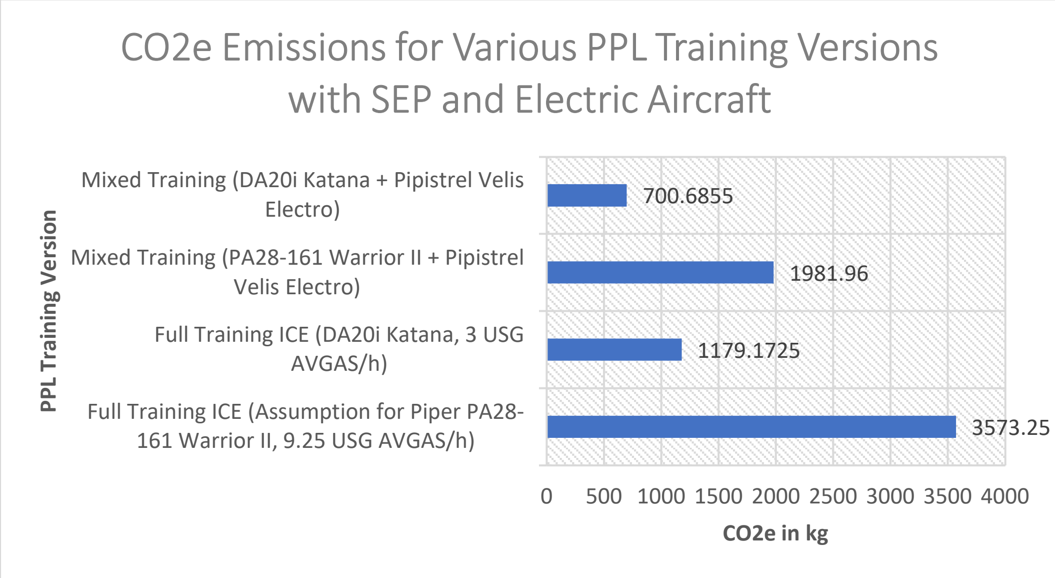

FIGURE 17: PPL(A) SYLLABUS-BASED CO2 ANALYSIS AVGAS VS ELECTRIC AIRCRAFT

4.3 Syllabus Adjustments for Sustainable Flight Training

Interviewee 3, a representative of the authority administering the Swiss PPL(A) syllabus, said that he keeps thinking about how one could implement sustainability into flight training but remarked that the question of how the syllabus could be amended to achieve this remains yet unanswered as there is a lack of concrete ideas. Interviewee 1 advocated for the adoption of more computer simulation-based training for pilots (VR/AR), whereas 59% of the survey respondents see no or only low potential in the increased use of simulation technology to foster sustainable development in private pilot training. Interviewee 7 remarked that "the syllabus will be adapted, definitely" and there is potential for a syllabus change to accommodate the capabilities of electric planes, but it will take time for the FOCA to approve. Thus, the recommendation was not to wait for the FOCA nor for the improved technology to come but to conduct complementary flight training (electric plane + same plane with internal combustion engine) to seize the potential of the already available technology.

4.4 Attitudes, Perceptions, and Visions of GA Stakeholders

While the interviews and survey showed well that most of the respondents consider environmental and sustainability topics to be very important topics in GA, the survey also showed that the majority of survey respondents does not have a bad environmental conscience concerning their flight-related GHG, pollutant, and noise emissions. Only 20 to 25% *often* or *always* have a bad environmental conscience regarding these aspects as can be seen in Figure 18. Many, however, as can be taken from Figure 19, act to make their flight operations more sustainable. The most common measure is to use noise abatement flying techniques and tactics (52%). 20% of the respondents already fly on unleaded fuels. About 4% fly electric planes and another 4% compensate their carbon emissions, whereas 10% stated to take no measures at all. Sustainability also plays an important role in most survey respondents' lives, especially regarding their nutrition (52%), personal mobility (69%), and energy consumption (83%) (see Figure 20).

As visible in Figure 21, most respondents see high potential in electric airplanes (56%), biofuels (50%), and synfuels (56%). The latter is interesting insofar as synfuels and especially the young company *Synhelion* (ETH Zurich spin-off) was mentioned fairly often during multiple interviews. The lowest potential (42%) for sustainable development in GA was assigned to an automatic CO_2 calculator connected to the digital flight logbook with instant CO_2 compensation offers.

Both, the interview and survey results, did not paint a black and white picture regarding the stakeholders' future visions for GA. While Interviewee 7 explained that he sees the future of GA as 100% electric, others were open to a larger variety of future scenarios including syn- and biofuels or hybrid aviation. Furthermore, some interviewees assume that it will become more complicated to enter GA, others believed in deregulation and simplification of GA activities in the future.

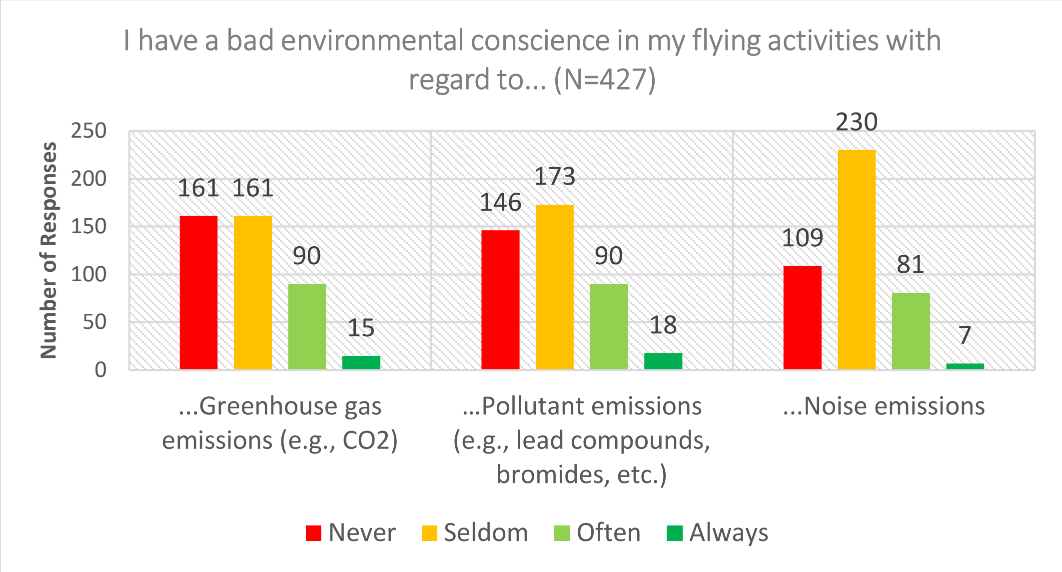

FIGURE 18: ENVIRONMENTAL CONSCIENCE OF PILOTS, SURVEY RESULTS

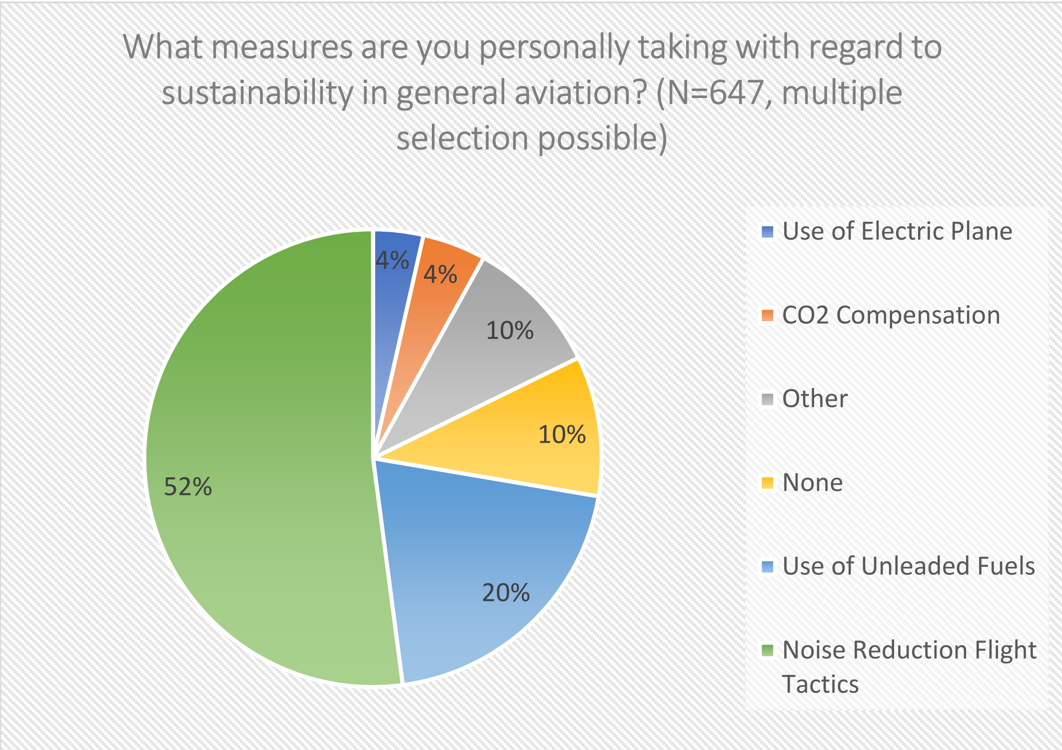

FIGURE 19: RESPONDENTS' PERSONAL SUSTAINABILITY MEASURES IN GENERAL AVIATION, SURVEY RESPONSES

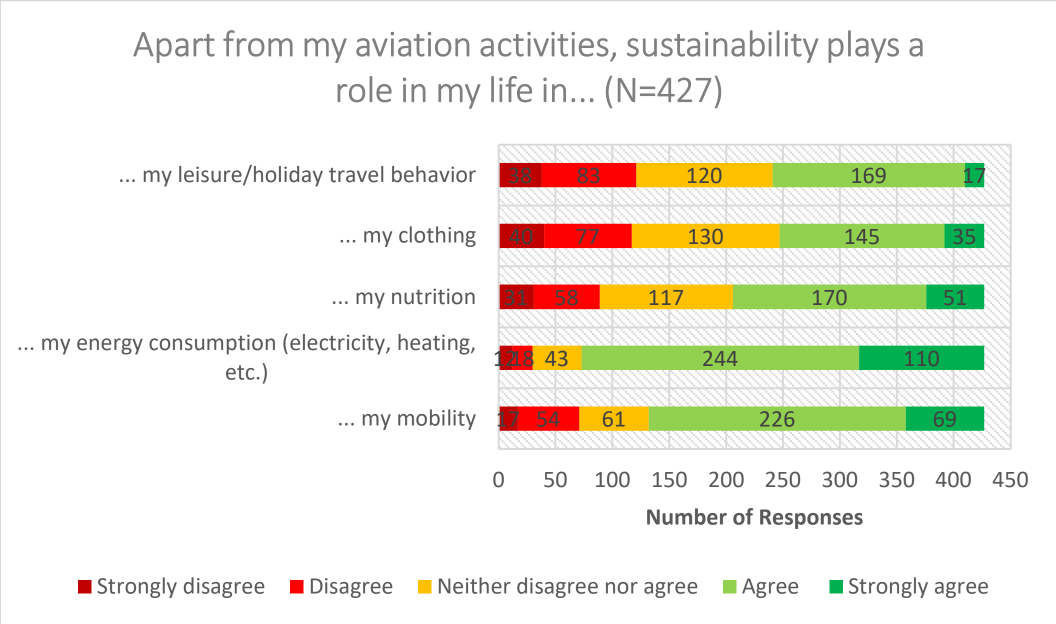

FIGURE 20: ROLE OF SUSTAINABILITY IN GA STAKEHOLDERS' PRIVATE LIVES, SURVEY RESULTS

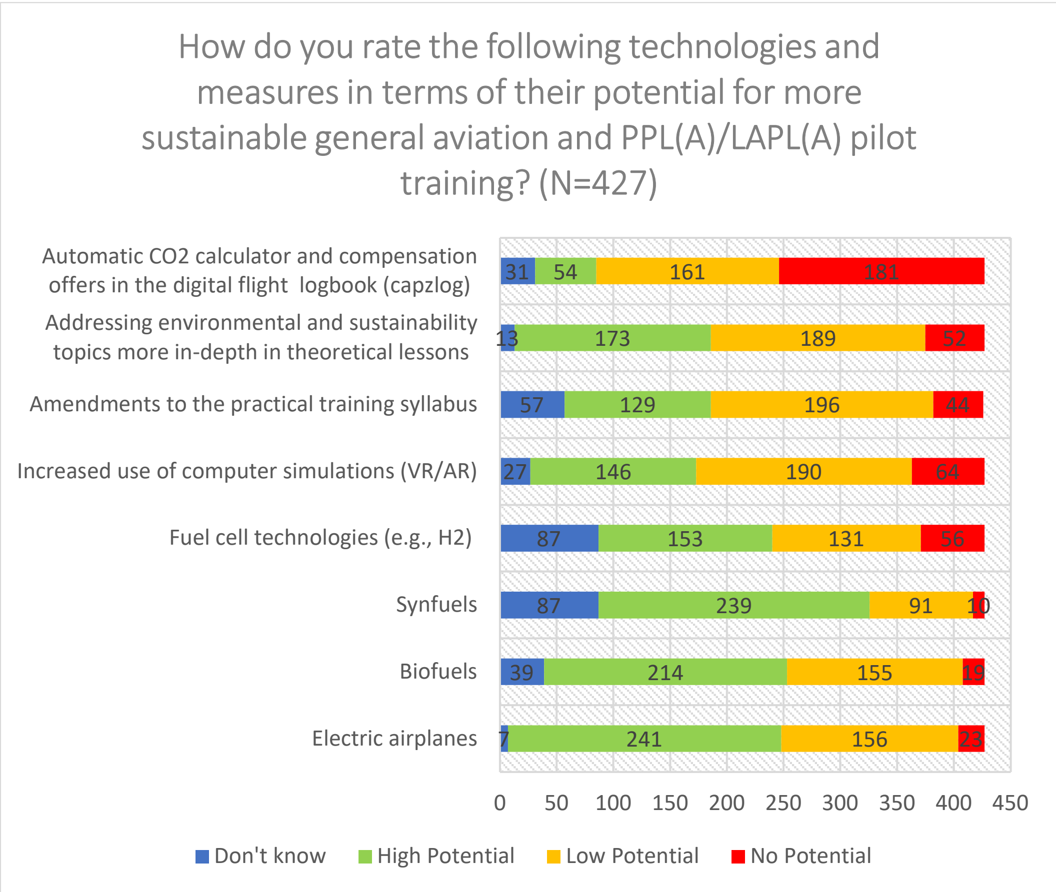

FIGURE 21: RESPONDENTS' RATING OF THE POTENTIAL OF VARIOUS TECHNOLOGIES AND MEASURES FOR SUSTAINABLE DEVELOPMENT IN GA AND PPL/LAPL(A) TRAINING, SURVEY RESULTS

5 Discussion and Conclusion

This mixed-methods study sought to find qualified answers to the question: What are feasible pathways to sustainability in general aviation and private pilot training? The empirical study findings draw on combined, i.e., “triangulated”, data from eight in-depth expert interviews and a predominantly quantitative online survey. This means that 1) qualitative statements from both methods were carefully synthesized, and 2) quantitative data were used to confirm or critically reflect on qualitative findings which, due to an interviewee sample of only eight experts, may not always indicate the opinions or attitudes of the majority of GA stakeholders considered in this study context. This has reduced uncertainties and increased the reliability and representativeness of the presented findings.

The study results showed that there are varying views on what the greatest sustainability challenges in GA and private pilot training are, ranging from noise to pollutant emissions (lead, bromides) to CO_2/GHG emissions. Nevertheless, it became clear in the interviews and survey responses that the largest obstacles to sustainable development and innovation in GA are bureaucracy, politics, overregulation, and high costs. Furthermore, the availability of truly practical and feasible technological solutions for more sustainable GA and PPL/LAPL(A) training is rather limited. There is a relevant trend regarding the use of electric aircraft in pilot training. Although most survey respondents supported and saw high potential in electric aircraft, the findings of vast enthusiasm for electric aircraft found in Edwards and Parker (2022) could not be confirmed. Nevertheless, the technology does currently not allow to conduct a full flight training according to the PPL(A) syllabus due to limited endurance. In addition, relatively long charging times and low MTOW[13] pose further limitations contributing to continuing to be inferior to conventional fossil fuel-powered GA aircraft. Furthermore, the introduction of these planes is currently relying on federal subsidies from FOCA, which triggers the question of economic sustainability. However, this question also keeps being asked concerning the subsidization of electric automobility. The CO_2 analysis in Chapter 4.2. showed potential savings of up to 1,591kg CO_2 depending on the utilized plane when supplementing the flight training with electric flights, which, in addition, contributes to noise abatement and prevents the emission of pollutants such as atmospheric lead and bromides.

[13] (1) Not suitable for taking luggage, e.g., backpack with documents, lunchbox etc.; (2) Not suitable for “tandem” flight training (one student in the back observing his/her fellow student; (3) Some flight instructors with large body height and weight are physically barred from teaching on this plane

While the interviewees and survey respondents showed great environmental awareness and concern, there was no unanimity regarding the future of sustainable development in GA. Due to uncertainty in regulation and fast technological developments, it is currently impossible to propose the "right" pathway toward sustainable GA and private pilot training. Nonetheless, some aspects are rather certain, such as the phaseout of leaded AVGAS by 2025[14] (European Union) that will force GA stakeholders to accept and adopt the use of unleaded aviation fuels. There seems to be hope and potential for biofuels and synfuels which, however, may unfold only in the long run since short-term changes are atypical for GA. The trend of electric aircraft with potentially increasing endurance, longer battery life, and shorter charging times is likely to continue and make electric aviation ever more attractive for private pilot training and flight schools, and other GA actors. Potential future financial advantages of electric planes due to increasing fossil fuel prices may also contribute to increasing the attractiveness of electric GA.

Since the topic of sustainable development in GA and private pilot training is still under-researched, it would be advisable to connect further inter-and transdisciplinary research to the findings from this study in exchange with other researchers and stakeholders active in the field.

Whereas a reduction of GA's small CO_2 profile would not mean a major contribution to climate protection, the sustainability transformation of GA and private pilot training can be considered an important symbolic act. This will be key to driving sustainable innovation as well as improving the environmental reputation, popular acceptance, and eventually the survival of GA.

[14] Sunset Date *de facto* Fall 2024, cf. https://www.iaopa.eu/contentServlet/iaopa-europe-enews-august-2021---special-edition, accessed June 11, 2022

6 Ethical Considerations

Despite sustainability being a growing concern in the public and political discourses, this research focus was neither ethically sensitive nor involving critical social dilemmas. Furthermore, the research participants belonged to no social class or group that would be classifiable as vulnerable. That is why the topic could be investigated without major ethical concerns. Still, throughout the project, especially during the empirical research phase, a large emphasis has been put on adherence to good research etiquette including aspects such as properly informing study participants about the research project, use of data, participant rights, as well as the obtainment of the interviewees' consent to record during interviews. During the interviews, no detrimental power imbalances regarding age, gender, race, social status, etc. were present between the interviewees and the interviewer, which permitted relaxed and free conversations. Lastly, the survey was distributed to and answered by adults (Swiss context) so parental consent was not required.

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Appendix A – Stakeholder Overview

STAKEHOLDER OVERVIEW REGARDING GA AND PPL(A) TRAINING IN SWITZERLAND AND INTERNATIONALLY

Stakeholder Group	Name	Location	Contact E-Mail	Contact Tel	Website	Electric Plane?	REMARKS
SWISS Flight Schools (PPL(A), LAPL(A))	Air-Fribourg Services SA	1730 Ecuvillens	info@aerodrome-ecuvillens.ch	+41 26 411 12 14	http://www.aerodrome-ecuvillens.ch/	YES	
	Air-Club d'Yverdon-les-Bains	1400 Yverdon-les-Bains	admin@air-club-yverdon.ch	+41 24 425 27 24			
	Alpine Flugschule Zweisimmen	3600 Thun		+41 77 470 57 52	http://www.mfgo.ch/		
	AéroFormation B. Hanhart SA	1018 Lausanne	af@aeroformation.ch	+41 21 646 42 01	http://www.aeroformation.ch/		
	Ecole d'Aviation Aéro Club du Val de Travers	2112 Môtiers NE	ecole@acvt.ch	+41 32 863 15 55	http://www.acvt.ch/	YES	
	Ecole d'Aviation du Groupement Vol à Moteur	1018 Lausanne	office@gvm.ch	+41 21 648 15 25	http://www.lausanne-aeroclub.ch/	YES	
	Société d'Aviation de la Gruyère	1663 Epagny	bureau@aerodrome-gruyere.ch	+41 26 921 00 40	http://www.aerodrome-gruyere.ch/	YES	
	Ecole de vol à moteur du Chablais	1880 Bex	secretaire@gvmc.ch	+41 24 463 15 16			
	Ecole de vol à moteur de Neuchâtel	2013 Colombier NE	secretariat.gvm@bluewin.ch	+41 32 841 31 56			
	Ecole d'aviation GVM Sion	1950 Sion	info@gvmsion.ch	+41 27 323 57 07			
	Flugschule Sarnen-Kägiswil	6060 Sarnen	fbag@motorfliegen.ch	+41 41 660 34 24	http://www.motorfliegen.ch/	YES	

	Flugschule der Motorfluggruppe Olten	4601 Olten	info@mfgolten.ch		http://www.mfgolten.ch/	
	Flying Ranch AG	6234 Triengen	info@flyingranch.ch	+41 41 933 38 80	http://www.flyingranch.ch/	
	Flugschule Fricktal	4325 Schupfart	info@flugschule-fricktal.ch	+41 62 871 22 22		
	MaximAir AG	2540 Grenchen	info@maximair.ch	+41 32 652 55 44		
	Airport Grenchen	2540 Grenchen	info@airport-grenchen.ch	+41 32 396 96 96	http://www.airport-grenchen.ch/	YES
	Flugschule Reichenbach	3713 Reichenbach		+41 33 673 20 51		
	Flugschule der Motorfluggruppe Pilatus	6371 Stans		+41 41 612 02 91		
	Flugschule Seeland	2501 Biel/Bienne	flugschule@lszp.ch	+41 32 384 46 84		
	Motorflugschule Chur	7310 Bad Ragaz				
	Motorflugschule der Motorfluggruppe Langenthal	4932 Lotzwil				
	Albis Wings	8915 Hausen am Albis	info@albiswings.ch		http://www.albiswings.ch/	
	Flubag Flugbetriebs AG	6025 Neudorf	flubag@flubag.ch	+41 41 930 18 66	http://www.flubag.ch/	
	Motorflugschule der MFG Thun	3604 Thun		+41 33 336 07 04	http://www.mfgthun.ch/	
	Alpine Segelflugschule Schänis AG	8718 Schänis	info@flugplatz-schaenis.ch	+41 55 250 50 00		
	Gruppo Volo a Vela Ticino	6596 Gordola	scuola@gvvt.ch	+41 91 745 37 77		
	AERO Locarno	6596 Gordola	info@aerolocarno.ch	+41 91 745 20 27	https://aerolocarno.ch/index.php/de/location-de	YES

	Groupe de vol à moteur de Porrentruy	2900 Porrentruy 2	info@gvmp.aero	+41 32 466 60 73	http://www.gvmp.aero/	
	Fliegerschule Ostschweiz	9444 Diepoldsau	info@fliegerschule.ch			
	Silver Goose Aviation Ltd.	5330 Zurzach			http://www.silvergoose.ch/	
	SWISS Flying Club	8058 Zürich	flugschule@swissflyingclub.ch	+41 44 500 11 56	http://www.swissflyingclub.ch/	
	Swiss Alpine Flying Center	7503 Samedan		+41 81 851 08 51		
	Fly 4 Fun GmbH	7208 Malans GR				
	GoodFlight Sàrl	1295 Mies	info@goodflight.ch			
	Zulu Flight Training S.A.	1201 Genève	zuluflighttrining@icloud.com	+41 22 547 11 87		
	Flugschule Solothurn FSS	3303 Jegenstorf				
	Schleppgemeinschaft Knonaueramt	6340 Baar				
	Aviathor GmbH	6370 Oberdorf NW	office@aviathor.com	+41 78 627 21 12 / +41 78 804 66 77	https://www.aviathor.com/	YES
	Flugschule Papa Sierra	5073 Gipf-Oberfrick	flugschule-papa-sierra@gmx.ch			
	Flugschule Oberwallis	3942 Raron	info@fgo.ch	+41 27 934 17 93		
	Fly Alpenrose	8915 Hausen am Albis	info@flyalpenrose.ch			
	MFGT Motorfluggruppe Thurgau	9506 Lommis	info@mfgt.ch	+41 52 366 33 33	https://www.mfgt.ch/kontakt/	YES
	Pitch Power Elektroflugschule	8718 Schänis	sekretariat@elektroflugschule.ch		https://www.elektroflugschule.ch/velis-electro-hb-syf	YES
	Scuola di piloti aerei Avilù SA	6982 Agno TI	info@avilu.ch	+41 91 610 16 16	http://www.avilu.ch/	YES

	AlpinAirPlanes GmbH	1730 Ecuvillens	info@alpinairplanes.ch	+41 26 411 34 05	www.alpinairplanes.ch	YES	
EVENTS	Electrifly-In (eTrophy & Symposium @Bern Airport Sep 10-11, 2022)	Bern Airport			https://electrifly-in.ch/en/mission/		
ELECTRIC AIRCRAFT BUILDERS	PIPISTREL d.o.o.	SI – 5270 AJDOVŠČINA	info@pipistrel-aircraft.com	+386 5 36 63 873	https://www.pipistrel-aircraft.com/about-us/		
	Textron Aviation	Wichita, KS 67215		+1 (316) 517-6000 / +1 316 517 8270	https://txtav.com/en/contact		
	H55 S.A.	1950 Sion	contact@h55.ch		https://www.h55.ch/contact		
	Diamond Aircraft Industries GmbH	2700 Wiener Neustadt	office@diamondaircraft.com	+43 2622 26700	https://www.diamondaircraft.com/en/service/electric-aircraft/		
	Bye Aerospace	Englewood, CO. 80112	byepress@byeaerospace.com	+1(303) 459-2862	https://byeaerospace.com/about/		
AVGAS / SYNFUEL RELATED	Zero Petroleum Limited	LONDON SW3 6RD	enquiries@zeropetroleum.com		https://zeropetroleum.com/		World's first synthetic AVGAS flight Nov 2, 2021 at Cotswold Airport (RAF pilot Captain Peter 'Willy' Hackett)
	GAMI (General Aviation Modifications Inc.)	Ada, OK 74820	comments@gami.com	1-580-436-4833	https://gami.com/g100ul/g100ul.php		First Ever High Octane Unleaded Avgas Approved by FAA (July 27, 2021)
	Hjelmco Oil	SE-192 48 SOLLENTUNA		+46(0)8 626 93 8	https://www.hjelmco.com//pages.asp?r_id=13403		

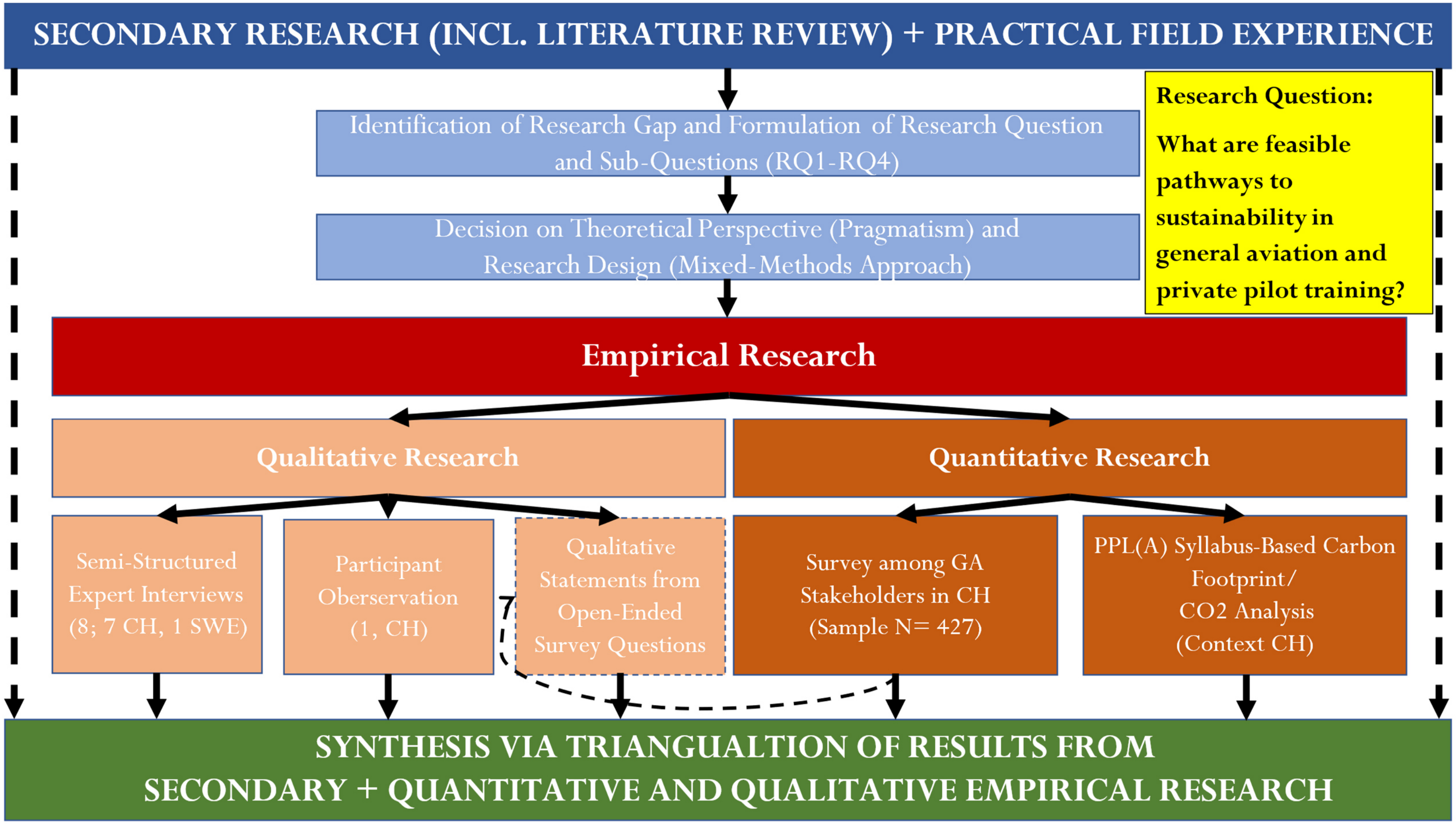
Associations	Aero-Club Schweiz	6006 Luzern	info@aeroclub.ch	+41 41 375 01 01	https://www.aeroclub.ch/	Maybe Contact Andreas Ryser ryser@aeroclub.ch, +41 (0)79 350 87 73
					https://www.facebook.com/groups/elektroflugzeug/	
Facebook Groups	Elektroflugzeug					

Appendix B – Research Plan

Master's Thesis Time Plan Come Fly with Me (Sustainably): Pathways to Sustainable General Aviation and Private Pilot Training														
Task Description	**Calendar Week (Year 2022)**													
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Secondary Research and Literature Review														
Syllabus-Based Carbon Footprint/CO2 Analysis (PA28 Warrior II + DA20 Katana vs. Pipistrel Velis Electro) PPL(A)									**MS1**					
Preparation of Interview Guide(s) for Stakeholder Interviews														
Identification of Relevant Stakeholders and Recruitment of Interview Candidates														
Expert Interviews												**MS2**		
Preparation and Digital Realization of Survey														
Fielding of Survey (incl. Pretesting)														
Statistical Evaluation of Survey													**MS3**	
Identification and Summary of Obstacles and Pathways to Sustainability in PPL(A) Training													**MS4**	
Write-Up/Synthesis of Results														
Thesis Submission														
Presentation and Thesis Defense														**MS5**

RESEARCH MILESTONES (MS)
MS1: Carbon Footprint/CO2 Analysis and Comparison of Typical AVGAS 100LL Piston Engine Powered Training Planes vs. Pipistrel Velis Electro
MS2: Stakeholder and Expert Insights into Key Sustainability Challenges in Private Pilot Training
MS3: Perceptions, Attitudes, Opinions of Key Stakeholders (e.g., Student Pilots, Pilots, Flight Instructors, Flight School Operators, etc.) on Sustainability in PPL(A) Training
MS4: Identified and Critically Commented Sustainability Pathways for Private Pilot Training
MS5: Thesis Defense and Final Submission

SCHEMATIC RESEARCH OVERVIEW, ABBREVIATIONS: CH = SWITZERLAND, SWE = SWEDEN



Appendix C – Interview Guide (GER/EN)

INTERVIEW GUIDE FOR EXPERT INTERVIEWS (GERMAN AND ENGLISH VERSION)

1) GERMAN VERSION

Come fly with me (sustainably)

Interviewleitfaden

I. Einleitung und Warm-Up:

- *Wie geht es Ihnen heute?*
- *Vielen Dank, dass Sie sich heute Zeit genommen haben!*

II. Teilnehmerinformation:

- *Zusammenfassen der Ziele, Fragen und Umfang des Forschungsprojekts*
- *Erklären, wie die Interviewdaten verwendet werden*
- *Teilnehmer informieren über sein Recht, die Beantwortung von Fragen zu verweigern, und sein Recht, das Interview jederzeit abzubrechen und die Einwilligung jederzeit, auch nachträglich zu widerrufen*
- *Fragen, ob der Teilnehmer in Publikationen anonymisiert werden möchte*
- *Um die Zustimmung des Teilnehmers bitten, das Interview zur späteren Transkription und Auswertung aufzeichnen zu dürfen*

Kategorie/Phase	Frage	Follow-Up Frage
1. Hintergrund	1.1. Können Sie ganz kurz etwas zu Ihrer Person und Ihrer Rolle/Hauptaufgabe in der Organisation sagen?	
	1.2. Seit wann bekleiden Sie diese Rolle?	1.2.1. Bekleiden Sie noch andere Ämter?
	1.3. Was verbindet Sie mit der GA?	
	1.4. Wie sind Sie ursprünglich in den	

	Bereich der GA gekommen?	
2. Nachhaltigkeits-herausforderungen	2.1. Was sind die aktuell größten Nachhaltigkeitsherausforderungen bzw. Hürden hinsichtlich Nachhaltigkeit in der GA?	2.1.1. Was sind die größten Nachhaltigkeitsherausforderungen für Ihre Organisation/Institution?
	2.2. Welche Nachhaltigkeitsaspekte/Dimensionen (Soziales, Wirtschaft, Umwelt) spielen die größte Rolle? (z. B., CO_2 Emissionen, Verbleites Benzin, Lärm, soziale Ungerechtigkeit etc.)	
	2.3. Könnten Sie das Image/die Reputation der GA unter dem Gesichtspunkt der Nachhaltigkeit beschreiben?	2.3.1. Ist Flugscham/Flight Shaming ein relevantes Thema für die GA?
3. Einstellungen, Meinungen zu Nachhaltigkeit	3.1. Welche Rolle spielen Themen wie Umwelt und Nachhaltigkeit in Ihrer Organisation/Institution? (entweder im Flugbetrieb oder in sonstigen Operationen)	3.1.1. Welche Rolle spielt Nachhaltigkeit in der GA für Sie persönlich?
4. Lösungsansätze, Visionen	4.1. Wo stecken Ihrer Meinung nach die größten Nachhaltigkeitspotenziale in der GA?	4.1.1. Gibt es besondere Maßnahmen oder Technologien, die in der GA eine nachhaltigere Entwicklung fördern könnten? 4.1.2. Was ist Ihre Meinung zu alternativen Antrieben oder Treibstoffen in der GA? (Elektro, Wasserstoff, SAF)
	4.2. Welche sind die wichtigsten Akteure/Treiber in der nachhaltigen Entwicklung in der GA?	4.2.1. Gibt es gegenläufige Kräfte oder Barrieren zu einer nachhaltigen Entwicklung in der GA? 4.2.2. Welche Verantwortung

		tragen verschiedene Stakeholder wie Piloten, Flughäfen/Flugplätze, Passagiere, Regierung etc. für die nachhaltige Entwicklung in der GA?
	4.3. Welche Maßnahmen hat Ihre Organisation ergriffen, ergreift oder plant sie zu ergreifen hinsichtlich nachhaltiger Entwicklung?	
	4.4. Was ist Ihre persönliche Vision für eine nachhaltige GA?	
5. Abschluss/ Abschied	5.1. Gibt es noch etwas, dass Sie gern mit mir teilen möchten bezüglich GA und Nachhaltigkeit in der Fliegerei?	

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2) ENGLISH VERSION

Come fly with me (sustainably)

Interview Guide

I. Introduction and Warm-Up:

1. *How are you today?*
2. *Thank you for taking your time today!*

II. Participant information:

3. *Summary of the objectives, questions and scope of the research project*
4. *Explain how the interview data is used*
5. *Participants inform about his right to refuse to answer questions and his right to cancel the interview at any time and to revoke the consent at any time, even retrospectively*
6. *Questions whether the participant would like to be anonymized in publications*
7. *Ask for the participant's consent to be allowed to record the interview for later transcription and evaluation*

Category / Phase	Questions	Follow-up questions
1. Background	1.1. Can you say something for your person and your role / main task in the organization?	
	1.2. Since when do you work in this position?	1.2.1. Do you have roles in other organizations/institutions?
	1.3. What connects you with GA?	
	1.4. How did you originally come to the area of GA?	
2. Sustainability Challenges	2.1. What are the currently largest sustainability challenges or hurdles regarding sustainability in GA?	2.1.1. What are the biggest sustainability challenges for your organization / institution?
	2.2. Which sustainability aspects / dimensions (social, economy, environment) play the biggest role? (eg, CO2 emissions, leaded gasoline, noise, social injustice etc.)	
	2.3. Could you describe the image / reputation of GA from the point of view of sustainability?	2.3.1. Is Flight Shaming Shaming a relevant topic for GA?
3. Attitudes, opinions on sustainability	3.1. What role do issues such as environment and sustainability play in your organization / institution? (either in flight operations or other operations)	3.1.1. What role does sustainability play in GA for you?
4. Solutions, visions	4.1. Where do you think about the biggest sustainability potentials in the GA?	4.1.1. Are there any special measures or technologies that could promote more sustainable development in GA?
		4.1.2. What is your opinion on alternative drives or fuels in GA? (Electric, Hydrogen, SAF)
	4.2. Who/what are the main actors / drivers in the sustainable development in the GA?	4.2.1. Are there any opposing forces or barriers to a sustainable development in GA?
		4.2.2. What is the responsibility of various stakeholders such as pilots, airports / airfields, passengers, government, etc. for sustainable development in GA?
	4.3. What measures has your organization seized, taken or plans to take them with regard to sustainable development?	

	4.4. What is your personal vision for a sustainable GA?	
5. Conclusion/ farewell	5.1. Is there anything else that you would like to share with me regarding GA and sustainability in aviation?	

Appendix D – Survey Questionnaire (GER/EN)

SURVEY DISTRIBUTION EMAIL (NEWSLETTER MOTORFLUGVERBAND SCHWEIZ MFVS, MAY 10, 2022)

MFVS - Umfrage

Schweizerischer Motorflugverband <info@mfvs.ch>
Di, 10.05.2022 13:30
An: michaelstiebe@hotmail.com <michaelstiebe@hotmail.com>

Wird diese Nachricht nicht richtig dargestellt, klicken Sie bitte **hier**.

MFVS FSVM

Liebe Mitglieder des Motorflug-Verbandes der Schweiz

Das Thema Nachhaltigkeit gewinnt auch in der Aviatik zunehmend an Bedeutung. Eines unserer Mitglieder, Michael Stiebe, ist hauptberuflich in der universitären Forschung im Bereich der nachhaltigen Mobilität tätig. Er führt gerade eine Studie zur Nachhaltigkeit in der Leichtaviatik und Privatpilotenausbildung durch.

Im Rahmen der Studie „**Come Fly with Me (Sustainably): Pathways to Sustainability in Private Pilot Training**" findet eine kurze, freiwillige **Online-Umfrage** statt, welche anonym ist und circa 10 Minuten Eurer Zeit in Anspruch nimmt. Die Umfrage richtet sich sowohl an ausgebildete Pilotinnen und Piloten als auch in Ausbildung befindliche Piloten und Pilotinnen. Eure Meinungen und Erfahrungen sind wertvoll für die Forschung und die weitere nachhaltige Entwicklung in der Fliegerei.

Hier ist der Teilnahmelink zur Umfrage (Deutsch): https://forms.office.com/r/tBxbGAQxVf

Herzlichen Dank im Voraus für Eure Teilnahme an der Umfrage!

Freundliche Fliegergrüsse
MFVS (Motorflug-Verband) und Michael Stiebe

Wenn Sie diese E-Mail (an: michaelstiebe@hotmail.com) nicht mehr empfangen möchten, können Sie diese **hier** kostenlos abbestellen.

Schweizerischer Motorflugverband
Lidostrasse 5
6006 Luzern
Schweiz

+41 41 375 01 01
info@mfvs.ch
www.mfvs.ch

SURVEY QUESTIONS (GERMAN VERSION)

(DE) Umfrage zum Thema Nachhaltigkeit in der General Aviation und Privatpilotenausbildung

(For Survey in English, please go to: https://forms.office.com/r/MxqzW0NcvG)

Willkommen!

Mein Name ist Michael Stiebe. Hauptberuflich arbeite ich als Wissenschaftlicher Mitarbeiter in Forschungsgruppe Nachhaltige Mobilität am Institut für Nachhaltige Entwicklung der Zürcher Hochschule für Angewandte Wissenschaften (ZHAW). Nebenbei bin ich Flugschüler (PPL(A)) in der Flugschule Sarnen-Kägiswil und interessiere mich sehr für die nachhaltige Entwicklung in der Aviatik.

Diese kleine Umfrage findet statt im Rahmen meiner Studie "**Come Fly with Me (Sustainably): Pathways to Sustainability in Private Pilot Training**".

- **Die Umfrage nimmt ca. 10 Minuten in Anspruch.**
- **Die Teilnahme an der Umfrage ist anonym und absolut freiwillig.**
- **Sie haben die Möglichkeit, die Umfrage jederzeit zu beenden.**

Bei dringenden Fragen können Sie sich gerne persönlich per Mail oder Telefon an mich wenden:
E-Mail: michaelstiebe@hotmail.com
Mobil: +41762764745

Herzlichen Dank im Voraus für Ihren wertvollen Beitrag zur Nachhaltigkeitsforschung!

Freundliche Grüsse
Michael Stiebe

* Erforderlich

Fragen zu Ihrer fliegerischen Tätigkeit/Ausbildung sowie Nachhaltigkeits- und Umweltthemen

1. Ich bin: *
(Mehrfachauswahl möglich)

- ☐ Flugschüler (PPL(A)/LAPL(A))
- ☐ Fluglehrer (PPL(A)/LAPL(A))
- ☐ Privatpilot
- ☐ Berufspilot
- ☐ Militärpilot
- ☐ Testpilot
- ☐ In der Administration oder im Betrieb eines Flughafens/Flugplatzes tätig
- ☐ In der Administration oder im Betrieb einer Flugschule tätig
- ☐ In der Flugzeugherstellung/Fluggeräteherstellung tätig
- ☐ Sonstiges

2. In welchem Jahr planen Sie Ihre Privatpilotenausbildung (bzw. Single Engine Piston Rating) abzuschliessen? *

- ○ Bereits abgeschlossen
- ○ 2022
- ○ 2023
- ○ 2024
- ○ 2025
- ○ 2026
- ○ 2027
- ○ Sonstiges

3. In welchem Jahr haben Sie Ihre Privatpilotenausbildung (bzw. Single Engine Piston Rating) abgeschlossen?

4. In welchem Land/welchen Ländern machen Sie bzw. haben Sie Ihre Privatpilotenausbildung (bzw. Single Engine Piston Rating) gemacht?

5. Welcher Flugplatz/Flughafen ist Ihre 'Homebase'?
Name und/oder Kürzel

6. Besitzen Sie ein eigenes Flugzeug? *

- ○ Ja
- ○ Nein

7. Was für ein Flugzeug besitzen Sie?

8. Mit was für einem Flugzeug bzw. Flugzeugen (Kategorie: GA) sind Sie meistens unterwegs?
z. B.: P28A, Cessna 182 etc.

9. Bitte bewerten Sie folgende Aussagen: *

	Stimme gar nicht zu	Stimme nicht zu	Weder noch	Stimme zu	Stimme voll zu
Nachhaltigkeit und Umwelt sind wichtige Themen in der Leichtaviatik	○	○	○	○	○
Umwelt und Nachhaltigkeit werden als Themen in der **theoretischen** Flugausbildung ausreichend thematisiert	○	○	○	○	○
Umwelt und Nachhaltigkeit werden als Themen in der **praktischen** Flugausbildung ausreichend thematisiert	○	○	○	○	○
Der fortwährende Einsatz von verbleitem AVGAS ist problematisch	○	○	○	○	○
Die allgemeine Luftfahrt hat ein negatives Umwelt-Image	○	○	○	○	○
Die Leute sind überempfindlich	○	○	○	○	○

...ich gegenüber Lärmemissionen	○	○	○	○	○
Lärmemissionen sind ein grosses Problem in der Leichtaviatik	○	○	○	○	○
Treibhausgasemissionen sind ein grosses Problem in der Leichtaviatik	○	○	○	○	○

10. Bewerten Sie bitte folgende Aussagen:
Ich habe bei meiner fliegerischen Tätigkeit ein schlechtes Umweltgewissen hinsichtlich... *

	Nie	Selten	Oft	Immer
...Treibhausgasemissionen (z. B. CO2)	○	○	○	○
...Schadstoffemissionen (z. B. Bleiverbindungen, Bromide etc.)	○	○	○	○
...Lärmverursachung	○	○	○	○

11. Wie beurteilen Sie die folgenden Technologien und Massnahmen in Hinsicht auf deren Potenzial für nachhaltigere Leichtaviatik und PPL(A)/LAPL(A) Pilotenausbildung? *

	Kein Potenzial	Geringes Potenzial	Grosses Potenzial	Weiss nicht
Elektroflugzeuge	○	○	○	○
Biofuels	○	○	○	○
Synfuels	○	○	○	○
Brennstoffzellentechnologie (z. B. H2)	○	○	○	○
Vermehrter Einsatz von Computersimulationen (VR/AR)	○	○	○	○
Anpassung des praktischen Ausbildungssyllabus	○	○	○	○
Vertiefte Thematisierung von Umwelt und Nachhaltigkeitsthemen im Theorieunterricht	○	○	○	○
Automatischer CO2 Rechner mit Kompensationsangeboten im digitalen Flugbuch (capzlog)	○	○	○	○

12. Sind Sie schon einmal mit einem Elektroflugzeug (z. B. Pipistrel Velis Electro) geflogen? *

○ Ja

○ Nein

13. Ich bin schonmal auf einem Elektroflugzeug geflogen zum...
mehrere Antworten möglich

☐ Fliegen Lernen

☐ Fliegen Unterrichten

☐ Sonstiges

14. Welche der untenstehenden Aspekte sind Ihrer Meinung nach problematisch bei der Benutzung von Elektroflugzeugen? *

	Kein Problem	Eher kein Problem	Eher ein Problem	Grosses Problem	Weiss nicht
Hohe Kosten	○	○	○	○	○
Brandrisiko der Batterie	○	○	○	○	○
zu kleine Reichweite/Endurance	○	○	○	○	○
zu wenig Platz	○	○	○	○	○
zu niedriges zulässiges Gewicht	○	○	○	○	○
unzureichende Ladeinfrastruktur an Flugplätzen/Flughäfen	○	○	○	○	○
lange Ladezeiten	○	○	○	○	○
hohe Batterieabnutzung	○	○	○	○	○
Umwelt- oder ethische Probleme durch die Batterieherstellung (z. B. Kinderarbeit im Kobaltabbau)	○	○	○	○	○

15. Welche Massnahmen ergreifen Sie persönlich hinsichtlich Nachhaltigkeit in der Leichtaviatik? *
mehrere Angaben möglich

- ☐ Keine
- ☐ CO2 Kompensation (z. B. über myclimate)
- ☐ Lärmmindernde Flugtechniken/Taktiken
- ☐ Fliegen mit unverbleiten Treibstoffen
- ☐ Nutzung von Elektroflugzeugen
- ☐ Sonstiges

16. Was sind Ihrer Meinung nach die grössten Hürden in der nachhaltigen Entwicklung in der Leichtaviatik bzw. Privatpilotenausbildung? (z. B. Bürokratie, Kosten, persönliche Einstellungen etc.)

17. Bewerten Sie bitte folgende Aussagen:
Ausserhalb meiner fliegerischen Tätigkeit spielt Nachhaltigkeit in meinem Leben eine Rolle bei... *

	Stimme gar nicht zu	Stimme nicht zu	Weder noch	Stimme zu	Stimme voll zu
... meiner Mobilität	○	○	○	○	○
... meinem Energieverbrauch (Strom, Heizung etc.)	○	○	○	○	○
... meiner Ernährung	○	○	○	○	○
... meiner Kleidung	○	○	○	○	○
... meinem Ferien/Urlaubsverhalten	○	○	○	○	○

Soziodemografische Fragen

Untenstehend sind ein paar Fragen zu Ihrer Person, welche zur **anonymen**, statistischen Auswertung der Umfrageergebnisse verwendet werden.

18. Was ist Ihr Geschlecht? *

- ○ Männlich
- ○ Weiblich

19. Bitte geben Sie Ihr Alter an:

20. In welchem Kanton wohnen Sie?

21. Was ist Ihr höchster Bildungsabschluss?

- ○ Keiner
- ○ Obligatorische Schule
- ○ Berufsausbildung
- ○ Matura
- ○ Studium FH/ETH/Uni
- ○ Sonstiges

22. Was ist Ihr Hauptberuf?

23. Was ist Ihr (ungefähres) jährliches Bruttoeinkommen?
absolut freiwillige Angabe

- ○ < 30,000 CHF
- ○ 30,000 - 59,000 CHF
- ○ 60,000 - 89,000 CHF
- ○ 90,000 - 109,000 CHF
- ○ 110,000 - 149,000 CHF
- ○ 150,000 - 199,000 CHF
- ○ 200,000 - 249,000 CHF
- ○ > 250,000 CHF

24. Haben Sie noch Anmerkungen oder Kommentare?

SURVEY QUESTIONS (ENGLISH VERSION)

(EN) Survey on Sustainability in General Aviation and Private Pilot Training

(For Survey in German, please go to: https://forms.office.com/r/tBxbGAQxVf)

Welcome!

My name is Michael Stiebe. I am researcher in the Sustainable Mobility Research Group at the Institute for Sustainable Development at the Zurich University of Applied Sciences (ZHAW). Besides, I am a student pilot (PPL(A)) at the flight school Sarnen-Kägiswil and I am very interested in sustainable development in aviation.

This short survey is part of my study "**Come Fly with Me (Sustainably): Pathways to Sustainability in Private Pilot Training**".

- **The survey will take approximately 10 minutes to complete.**
- **Participation in the survey is anonymous and completely voluntary.**
- **You have the option to end the survey at any time.**

If you have urgent questions, please feel free to contact me personally by mail or phone:
Email: michaelstiebe@hotmail.com
Mobile: +41762764745

Thank you in advance for your valuable contribution to sustainability research!

Kind regards
Michael Stiebe

* Erforderlich

Questions about your flying activity/flight training as well as sustainability and environmental topics

1. I am: *
(Multiple selection possible)

- ☐ Student Pilot (PPL(A)/LAPL(A))
- ☐ Flight Instructor (PPL(A)/LAPL(A))
- ☐ Private Pilot
- ☐ Commercial Pilot
- ☐ Military Pilot
- ☐ Test Pilot
- ☐ Working in the administration or operation of an airport/airfield
- ☐ Working in the administration or operation of a flight school
- ☐ Working in aircraft manufacturing/aircraft equipment production
- ☐ Sonstiges

2. In which year do you plan to complete your private pilot training (or Single Engine Piston Rating)? *

- ○ Already completed
- ○ 2022
- ○ 2023
- ○ 2024
- ○ 2025
- ○ 2026
- ○ 2027
- ○ Sonstiges

3. In what year did you complete your private pilot training (or Single Engine Piston Rating)?

4. In which country/countries do you or did you do your private pilot training (or Single Engine Piston Rating)?

5. Which airfield/airport is your 'home base'?
Name and/or Code

6. Do you own an airplane? *

- ○ Yes
- ○ No

7. What airplane do you own?

8. What kind of aircraft or aircraft (category: GA) do you usually fly with?
e.g., P28A, Cessna 182 etc.

9. Please rate the following statements: *

	Strongly Disagree	Don't agree	Neither agree nor disagree	Agree	Strongly agree
Sustainability and the environment are important topics in general aviation	○	○	○	○	○
Environment and sustainability are sufficiently addressed as topics in **theoretical** flight training	○	○	○	○	○
Environment and sustainability are sufficiently addressed as topics in **practical** flight training	○	○	○	○	○
The continued use of leaded AVGAS is problematic	○	○	○	○	○
General aviation has a negative environmental image	○	○	○	○	○
People are overly sensitive to noise emissions	○	○	○	○	○
	Strongly Disagree	Don't agree	Neither agree nor disagree	Agree	Strongly agree
Noise ...					

emissions are a major problem in general aviation	○	○	○	○	○
Greenhouse gas emissions are a major problem in general aviation	○	○	○	○	○

10. Please rate the following statements:
I have a bad environmental conscience in my flying activities with regard to... *

	Never	Seldom	Often	Always
...Greenhouse gas emissions (e.g., CO2)	○	○	○	○
...pollutant emissions (e.g., lead compounds, bromides, etc.)	○	○	○	○
...Noise emissions	○	○	○	○

11. How do you rate the following technologies and measures in terms of their potential for more sustainable general aviation and PPL(A)/LAPL(A) pilot training?

	No potential	Low potential	High potential	Don't know
Electric airplanes	○	○	○	○
Biofuels	○	○	○	○
Synfuels	○	○	○	○
Fuel cell technologies (e.g., H2)	○	○	○	○
Increased use of computer simulations (VR/AR)	○	○	○	○
Amendments to the practical training syllabus	○	○	○	○
Addressing environmental and sustainability topics more in-depth in theoretical lessons	○	○	○	○
Automatic CO2 calculator and compensation offers in the digital flight logbook (capzlog)	○	○	○	○

12. Have you ever flown an electric aircraft (e.g. Pipistrel Velis Electro)? *

○ Yes

○ No

13. I have flown on an electric aircraft...

multiple selection possible

☐ ... to learn flying

☐ ... to teach flying

☐ Sonstiges

14. Which of the aspects below do you think are problematic in the use of electric aircraft? *

	No problem	Rather no problem	Rather a problem	Big problem	Don't know
High costs	○	○	○	○	○
Fire risk of the battery	○	○	○	○	○
Too little range/endurance	○	○	○	○	○
Too little space	○	○	○	○	○
Too little permitted weight	○	○	○	○	○
Insufficient charging infrastructure at airports/airfields	○	○	○	○	○
Long battery charging times	○	○	○	○	○
High battery wear	○	○	○	○	○
Environmental or ethical problems caused by battery production (e.g., child labor in cobalt mining)	○	○	○	○	○

15. What measures are you personally taking with regard to sustainability in general aviation? *
Multiple selection possible

- [ ] None
- [ ] CO2 compensation (e.g., via myclimate)
- [ ] Noise-reducing flight techniques/tactics
- [ ] Flying with unleaded fuels
- [ ] Use of electric aircraft
- [ ] Sonstiges

16. In your opinion, what are the biggest hurdles in sustainable development in general aviation or private pilot training? (e.g. bureaucracy, costs, attitudes, etc.)

17. Please rate the following statements:
Apart from my aviation activities, sustainability plays a role in my life in... *

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
... my mobility	○	○	○	○	○
... my energy consumption (electricity, heating, etc.)	○	○	○	○	○
... my nutrition	○	○	○	○	○
... my clothing	○	○	○	○	○
... my leisure/holiday travel behavior	○	○	○	○	○

Sociodemographic Questions

Below are a few questions about yourself, which will be used for **anonymous**, statistical analysis

18. What is your sex? *

- ○ Man
- ○ Woman

19. What is your age?

20. In which canton do you live?

21. What is your highest education?

- ○ None
- ○ Obligatory school
- ○ Apprenticeship
- ○ Matura/Abitur/A-Levels
- ○ Higher education (college, university, technical university ETH, etc.)
- ○ Sonstiges

22. What is your main profession?

23. What is your (approximate) gross annual income?
absolutely voluntary information

- ○ < 30,000 CHF
- ○ 30,000 - 59,000 CHF
- ○ 60,000 - 89,000 CHF
- ○ 90,000 - 109,000 CHF
- ○ 110,000 - 149,000 CHF
- ○ 150,000 - 199,000 CHF
- ○ 200,000 - 249,000 CHF
- ○ > 250,000 CHF

24. Do you have any remarks or comments?

Appendix E – Syllabus Analysis

		Assumption for Piper PA28-161 Warrior II												Assumptions for Pipistrel Velis Electro	
		LOW Consumption	MEDIUM Consumption	HIGH CONSUMPTION	LOW Consumption	MEDIUM Consumption	HIGH CONSUMPTION	LOW Consumption	MEDIUM Consumption	HIGH CONSUMPTION	LOW Consumption	MEDIUM Consumption	HIGH CONSUMPTION		
Flight	Converted Minutes	AVGAS Consumption (8.5 USG/h)	AVGAS Consumption (9.25 USG/h)	AVGAS Consumption (10 USG/h)	AVGAS Consumption (8.5 USG/h) in LITERS	AVGAS Consumption (9.25 USG/h) in LITERS	AVGAS Consumption (10 USG/h) in LITERS	AVGAS Consumption (8.5 USG/h) in KG	AVGAS Consumption (9.25 USG/h) in KG	AVGAS Consumption (10 USG/h) in KG	CO2 Emissions in KG	CO2 Emissions in KG	CO2 Emissions in KG	Electric Energy Consumption (26kWh)	CO2 Emissions in KG (128g CO2e/kWh)
Flight 1.1	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.2	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.3	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.4	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.5	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.6	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 1.7	60	8.50	9.25	10.00	32.17	35.01	37.85	23.16	25.21	27.25	72.97	79.41	85.84	26.00	3.33

Flight 2.1	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 2.2	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 2.3	50	7.08	7.71	8.33	26.81	29.18	31.54	19.30	21.01	22.71	60.81	66.17	71.54	21.67	2.77
Flight 2.4	50	7.08	7.71	8.33	26.81	29.18	31.54	19.30	21.01	22.71	60.81	66.17	71.54	21.67	2.77
Flight 2.5	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 3.1	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 3.2	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 3.3	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 3.4	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 3.5	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 4.1	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 4.2	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22

Flight 4.3	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 4.4	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 4.5	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 4.6	50	7.08	7.71	8.33	26.81	29.18	31.54	19.30	21.01	22.71	60.81	66.17	71.54	21.67	2.77
Flight 5.1	55	7.79	8.48	9.17	29.49	32.09	34.70	21.23	23.11	24.98	66.89	72.79	78.69	23.83	3.05
Flight 5.2	55	7.79	8.48	9.17	29.49	32.09	34.70	21.23	23.11	24.98	66.89	72.79	78.69	23.83	3.05
Flight 5.3	120	17.00	18.50	20.00	64.35	70.02	75.70	46.33	50.42	54.50	145.93	158.81	171.69	52.00	6.66
Flight 6.1	80	11.33	12.33	13.33	42.90	46.68	50.47	30.89	33.61	36.34	97.29	105.87	114.46	34.67	4.44
Flight 6.2	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 6.3	55	7.79	8.48	9.17	29.49	32.09	34.70	21.23	23.11	24.98	66.89	72.79	78.69	23.83	3.05
Flight 6.4	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 7.1	80	11.33	12.33	13.33	42.90	46.68	50.47	30.89	33.61	36.34	97.29	105.87	114.46	34.67	4.44

Flight 7.2	60	8.50	9.25	10.00	32.17	35.01	37.85	23.16	25.21	27.25	72.97	79.41	85.84	26.00	3.33
Flight 7.3	140	19.83	21.58	23.33	75.07	81.69	88.32	54.05	58.82	63.59	170.26	185.28	200.30	60.67	7.77
Flight 7.4	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 7.5	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22
Flight 7.6	80	11.33	12.33	13.33	42.90	46.68	50.47	30.89	33.61	36.34	97.29	105.87	114.46	34.67	4.44
Flight 7.7	150	21.25	23.13	25.00	80.43	87.53	94.63	57.91	63.02	68.13	182.42	198.51	214.61	65.00	8.32
Flight 8.1	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 8.2	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 8.3	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 9.1	30	4.25	4.63	5.00	16.09	17.51	18.93	11.58	12.60	13.63	36.48	39.70	42.92	13.00	1.66
Flight 9.2	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 9.3	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50

Flight 9.4	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 9.5	45	6.38	6.94	7.50	24.13	26.26	28.39	17.37	18.91	20.44	54.73	59.55	64.38	19.50	2.50
Flight 9.6	90	12.75	13.88	15.00	48.26	52.52	56.78	34.75	37.81	40.88	109.45	119.11	128.77	39.00	4.99
Flight 9.7	80	11.33	12.33	13.33	42.90	46.68	50.47	30.89	33.61	36.34	97.29	105.87	114.46	34.67	4.44
Flight 10.1	60	8.50	9.25	10.00	32.17	35.01	37.85	23.16	25.21	27.25	72.97	79.41	85.84	26.00	3.33
Flight 10.2	60	8.50	9.25	10.00	32.17	35.01	37.85	23.16	25.21	27.25	72.97	79.41	85.84	26.00	3.33
Flight 10.3	70	9.92	10.79	11.67	37.53	40.85	44.16	27.02	29.41	31.79	85.13	92.64	100.15	30.33	3.88
Flight 10.4	40	5.67	6.17	6.67	21.45	23.34	25.23	15.44	16.81	18.17	48.64	52.94	57.23	17.33	2.22