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eVTOL's (Electric Vertical Take-Off and Landing aircrafts) as air taxis – A realisable urban air mobility solution or An innovation overpromise on being green and sustainable – Case Study on City of London

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Executive Summary

With EHang, a Chinese eVTOL aircraft company, receiving its type certification from Chinese domestic airworthiness certification body the Civil Aviation Administration of China (CAAC) for the multicopter EH216-S, a first in the whole world. A new chapter has thus begun in the aviation industry and a significant milestone is achieved in the word of Advanced Air mobility and Aviation as a whole.

Common scenes at recent air shows across the world are huge crowds gathered to sit in model cockpits, walk around, sit and experience the interiors of eye catching either concept or retired prototypes of electrical aircrafts promising a greener way to fly and radical promises of potential for Zero-emission aviation industry.

Technological advancements since the industrial revolution have gone together with an extensive exploitation of natural resources and massive destruction of the environment. The negative impact of the advanced technologies on environment, depletion of natural resource and disposal of harmful substances are not fully accounted for while evaluating the true value of modern innovations.

Evolution of humans as a dominant race above, below and beyond the biosphere is only due to their ability to question the existence of the elements of the universe and power to innovate. Nevertheless, not all human innovations have bought them and the biosphere they live in good fortune and favours but also catastrophes and disasters. One should not be blinded by the glitter, beauty and usefulness of the innovation but also fully assess and understand the darker side of it. We humans will never be able to forget the mayhem caused due to some of histories best and the worst innovations such as supersonic passenger jets (Concord), harvesting nuclear energy through fission and fusion, pest control through Dichlorodiphenyltrichloroethane (DDT), refrigeration through Chlorofluorocarbons (CFCs), dynamite, zeppelins, heavy metal based paints, microplastics, chemical fertilisers, to name a few.

Achieving Climate change goals and net zero goals is impossible without first understanding and controlling the source of the causes. As much import the corrective actions are towards climate change, far more important are the preventive actions. This is a juncture where avoiding new sources of emissions is far more important than ever, such as the new mode of urban transport, the eVTOLs unless they are proven to be more sustainable than the existing ones.

At the outset, the purpose of this study was to analyse and evaluate this new eco-innovation, the ***eVTOLs***, as a viable green urban decongestion solution. Effort was made to identify a suitable method of evaluating such eco-innovations and use it to evaluate the green appeal of eVTOLs. Method of digital and document survey was used in the Life Cycle Assessment of eVTOLs critical emission parameters.

The study concludes by identifying lack of factual evidences and data to fully evaluate the green appeal of the eVTOLs. Study finds that eVTOLs are ideal solution for travel distances of over 100kms and are not emission efficient for air taxi application, not at least with the current technology. It is noted that, it is import to follow the technologies advances in the field of eVTOLs and re-evaluate the current findings. Alternative solutions for urban decongestions are recommended as well as areas for further study and analyses are advised.

About the Author

Author of this dissertation is a chartered mechanical engineer working in the aerospace industry for the past 22 years. Author has vast experience in various platforms of aircraft design and development including airframe, aircraft interiors, landing gear and engine nacelle. Author is currently working in the aircraft interiors design office as a Lead structural Stress engineer and is an expert at aircraft structural analysis and airworthiness certification.

As a lead stress engineer, handles a team of 5 senior and junior stress engineers and guides them in achieving structural substantiation of aircraft first class, business class and premium seating systems. Providing detailed analysis support, concept substantiation, alternative design, support in achieving compliance to airworthiness certification standards, mentoring and programme management are the key responsibilities of this role.

Author is an expert in aircraft interior stress analysis and airworthiness certification. This role requires providing expert support and advice in conceptual design of aircraft interiors, defining airworthiness certification pathway, help and achieve resolution of design and certification road blocks. Support type certification, naive subject testing of interior products, participate in the panel of experts and advisory group in evaluation and review of product innovations.

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1. INTRODUCTION

Globally, due to rapid urbanization and growing urban population demand for private and public transportation has only been increasing. This has resulted in aggravation of already existing urban issues such as congestions, delays and depletion in urban air quality to name a few. Aviation industry has been eyeing on providing air mobility solution as an alternative for urban transportation requirements through their Vertical Take Off and Landing capable aircrafts (VTOL). Air mobility for urban areas can be described variously as Urban Air Mobility (UAM), On Demand Mobility (ODM), Air Taxi Operations or Advanced Air Mobility (AAM).

Air Taxi is essentially the one "Providing point-to-point passenger transportation and are not operated on regular schedules or routes", (Reiche et al., 2018).

Air taxi services are estimated to be commencing in 2024 in the Middle East and are expected to have a compound annual growth rate of 45.9% with an estimated 430,000 units operational by the end of 2040 (Frost & Sullivan, 2019). Airport Shuttle and Air Taxi markets are valued at an estimated $500 billion in just the U. S, for a fully unconstrained scenario (Reiche et al., 2018).

Invention of practical VTOL's is not new and dates back to 1940's. Helicopters are the horizontal rotary wing aircrafts which revolutionised the air transport industry without the need for a long run way or a run up to take to skies. Helicopters have been serving the mankind ever since they were invented both in times of peace and in war. But, this invention has always suffered from technical challenges such as high vibration, excessive noise and emission of green house gases.

Increased awareness towards greener cities, tighter legislations on allowable noise levels, increasing cost of aviation fuel, need for better control and automation of aircrafts has pushed the aircraft design firms to look for novel and innovative solutions.

Recent advancements in the area of electrical aircraft propulsion, electrical energy generation, storage and distribution from greener sources as well as battery technology for in-vehicle storage, have lead to the birth of electric Vertical Take Off and Landing aircrafts, called in short as eVTOLs.

Of the many promises these eVTOL's are making, biggest among them are induction of eVTOLs into urban transportation system to ease urban traffic congestion by improving urban transport efficiency and reducing carbon foot print. Aviation industry calls this as Urban Air Mobility or in laymen terms electric Air Taxi.

Although, it is practically impossible to fully substitute the standard modes of modern day transport with UAM's, it is certain that UAM will supplement to a very large extent in the near and far future.

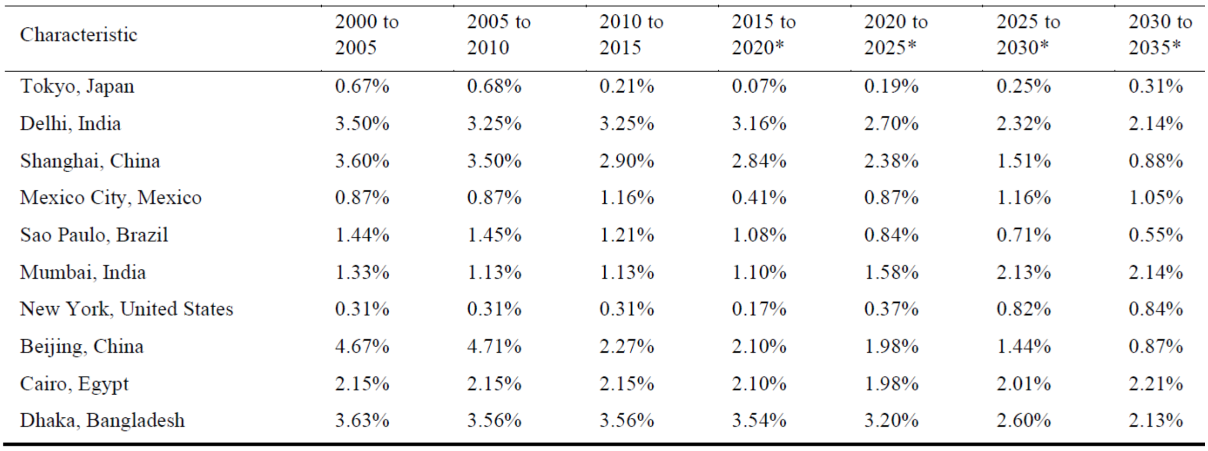
eVTOLs, though they run on a greener power, they are not entirely carbon neutral as neither the electricity they use are from fully renewal resources nor the way they are manufactured, operated and maintained are carbon free. One vital question to be answered at this point in time is "From a green and sustainability point of view, are the eVTOLs' a reliable urban air mobility solution or innovation overpromise".

1.1.Background and Context

According to the Office of National Statistics (ONS), UK, in 2015, 11 major city regions had over 27million residents, which is 40% of the total UK population of 65million (Science, 2021) and it is growing at a rate of 7.6%.

An estimated 23% of world's population (1.7billion) lived in a city with at least 1 million inhabitants, in the year 2018. Projection for the year 2030 is that, about 28% of people worldwide will be concentrated in cities with a minimum population of 1 million inhabitants. Megacities, cities with over 10 million inhabitants, are projected to rise from 33% in 2018 to 43% in 2030 (United Nations, 2018). There were 371 cities with 1 million inhabitants at the turn of new millennium 2000 and by 2030 this is projected to surpass 706. Megacities, which were about 33 in 2018 are expected to be 43 by 2030.

Table 1 shows the average annual growth rates of world's largest urban agglomerations for the period from 2000 to 2035 (Smirnov et al., 2023).



Characteristic	2000 to 2005	2005 to 2010	2010 to 2015	2015 to 2020*	2020 to 2025*	2025 to 2030*	2030 to 2035*
Tokyo, Japan	0.67%	0.68%	0.21%	0.07%	0.19%	0.25%	0.31%
Delhi, India	3.50%	3.25%	3.25%	3.16%	2.70%	2.32%	2.14%
Shanghai, China	3.60%	3.50%	2.90%	2.84%	2.38%	1.51%	0.88%
Mexico City, Mexico	0.87%	0.87%	1.16%	0.41%	0.87%	1.16%	1.05%
Sao Paulo, Brazil	1.44%	1.45%	1.21%	1.08%	0.84%	0.71%	0.55%
Mumbai, India	1.33%	1.13%	1.13%	1.10%	1.58%	2.13%	2.14%
New York, United States	0.31%	0.31%	0.31%	0.17%	0.37%	0.82%	0.84%
Beijing, China	4.67%	4.71%	2.27%	2.10%	1.98%	1.44%	0.87%
Cairo, Egypt	2.15%	2.15%	2.15%	2.10%	1.98%	2.01%	2.21%
Dhaka, Bangladesh	3.63%	3.56%	3.56%	3.54%	3.20%	2.60%	2.13%

Table 1: Average annual growth rates of world's largest urban areas

It is a fact that, rapid urbanisation is the current trend and the trend for the near future. Growing urban population and growing number of urban areas demand a parallel growth of infrastructure. One of the important urban infrastructures is transportation. Transportation is the blood of the urban areas which keeps the cities alive through circulation of vital resources.

Urban areas with growing population suffer from:

- long commute times,
- ground congestion,
- traffic safety,
- increased emission levels and related health issues,
- increased cost of travel for passengers,
- increased demand for fossils fuels, creating need for energy sustainability (XIE et al., 2021),
- increased demand for lubricants, vehicle maintenance and related price effects on everyday commodities,
- increased noise levels and mental health issues,
- increased loss of lives and properties due to delay in response of emergency services to the sites in need.

One can only appreciate the issue of traffic congestion if they have ever tried commuting in cities like Bogota in Colombia, Bucharest in Romania, New York City in USA, Moscow in Russia or Philadelphia in USA, which are ranked the top 5 congested cities to commute in 2019 & 2020 (Pishue, 2020).

According to (Inrix, 2022) London tops the list of world's top ten highest traffic delay times by City at 156 hours. (Smirnov et al., 2023) "In the UK, drivers spend an average of 124 hours in traffic jams and this number is expected to increase to 136 hours by 2030. The cumulative cost of traffic congestion to the UK economy between 2013 and 2030 is estimated at $405 billion".

Most urban areas in the world are built in and around or over cities which have existed since several years, decades or centuries. And hence the possibility of easing out the urban transport issues by improving infrastructure on ground using the traditional 2D space is very limited. Using the unutilised space, that is the space over the head and leveraging this 3D cubic space to our best capability is probably one potential solution for the plethora of urban traffic inconveniences (Wang & Qu, 2023 Feb).

Authorities and governments have made every possible effort in their best capacities to alleviate traffic congestion such as charges for Low and Ultra Low Emission Zones, Congestion charges, promotion of public transport, automatic and AI based traffic signal control, high occupancy driving lanes, vehicle & ride sharing, road space rationing, reduction of max speed limits, Satellite bus stations & Park and Rides, etc. However, these measures can only reduce the impact ever so slightly due to the fact that the core of the problems is the imbalance between ever growing demand for travel and fixed transport infrastructure in a two-dimensional urban transportation setup. It is certainly a need of the day for urban areas to find a pragmatic solution for its traffic congestion problems. The solution to the problems is in the space above the head of urban areas, the third dimension, which is currently clearly underutilized.

eVTOLs like electric cars are not new to the world, but modern eVTOLs are very innovative in the way the electrical technology in conjunction with latest aircraft engineering is utilised to create light weight and fully electric flying machines. Urban Air Mobility with eVTOLs sounds really cool, promising and exciting. But will they live up to their promise of being a viable urban transport solution and are they practically greener in comparison to the current normal modes of transport in urban areas such as the City of London?

eVTOL's designed for Urban Air Mobility solutions can be classified as ***Eco-Innovations*** for that they boast they are contributing towards the Sustainable Mobility Systems and pledge to lower environmental impact. This dissertation intends to assess the credibility of this innovation in urban transport solution. Aim is to research the viability and sustainability of eVTOLs as urban taxis in typical European cities with large population and underdeveloped infrastructure to operate electric aircrafts. Due to the limited scope of the research, the focus is only on the UK urban areas.

1.2.Purpose of this Study

For eVTOL's success, along with Citizens' and future UAM users' confidence and acceptance, it is equally critical to prove they are eco-friendly, not just with their emissions in-service, but with respect to their production, maintenance, service requirement and *end-of-life* treatment as well.

Purpose of the current research is to try and account for negative externalities associated with high-tech ***Eco-Innovations*** such as the eVTOLs. Intention is to research for methods of evaluating eco-innovations, measure the eco-innovation, analyse measured parameters and provide inferences for educated use by the public, policy makers, investors and academicians for further study.

Why measure this innovation?

An eco-innovation is expected to be environmentally friendly from a holistic view and not just being a zero emission product from an everyday usage basis. This is where the common man gets it all wrong. Hence a thorough investigation and revelation of investigation of green appeal is imperative.

The benefits of measuring eco-innovation can be described as five-fold (Arundel & Kemp, 2009):

1. Helping policy makers to understand, analyse, and benchmark the overall trend of eco-innovation activity (increasing, decreasing, transitions in the nature of eco-innovation such as from end-of-pipe towards cleaner production and increased recycling and reuse); as well as trends in specific product categories (such as wind turbines).
2. Helping policy makers to identify drivers and barriers to eco-innovation. This information can aid in the design of effective policies and framework conditions such as pollution taxes.
3. Raising awareness of eco-innovation among stakeholders and encourage companies to increase eco-innovation efforts based on an analysis of the benefits for companies, sectors and nations.
4. Helping society to decouple economic growth from environmental degradation.
5. Making consumers aware of differences in the environmental consequences of products and life styles.

1.3.Methodology

This research is conducted through a hybrid method of data collection and analysis. Technique of Environmental Life Cycle Assessment is utilised for analysis of data gathered through Digital and Documentary Source Analysis. Literate review showed that, due to the naive nature of the research subject, factual evidences for analysis were scarcely available. Hence, reliance on digital and documentary resources was elevated. Information gathered were further reviewed within the Inventory and Impact assessment stages of the environmental LCA.

2. Literature Review

This section is dedicated to the thorough survey of the available literature in and around UAM, UAM market potential, eVTOLs and eVTOL's as air taxis and their sustainability appeal. Effort is made to research on the available methods and techniques for the measurement and evaluation of modern and green Innovations and their efficiency in order to select a feasible method to further evaluate the potential for eVTOL's to be a sustainable means of urban air transportation.

2.1.UAM Solutions

History of flight is ever so fascinating. Humans have always dreamt of reaching the skies bodily. From myths of Pegasus, King Kaj Kaoos of Persia to Pushpakavimana of Ravana of Lanka to practical flight concepts of kites of china, Leonardo da Vinci's Ornithopter, Joseph & Jacques's first air balloon, the dream to fly has only been getting deeper and deeper (NASA, n.d.).

Late 19th to early 20th century was the time when aviation actually got its wings and started fulfilling mankind's dream of flying like birds. On December 17, 1903, at 10:35am, Orville and Wilbur Wright lifted from level ground their six hundred pound "Flyer" in North Carolina, to a sustained flight of 120 feet in twelve minutes.

Figure 1 (Liu et al., 2017) shows the timeline of development of aerial vehicles for personal use from early 1900 to now. It is interesting to see that, mankind has always thrived to fly personally just as in a personal car and continue to do so. eVTOLs of today can be that solution.

Figure 1: Timeline of development of personal aerial vehicles, (Liu et al., 2017)

Since then mankind has developed and utilised all forms and trades of aircrafts including passenger to cargo, commercial to private, sub-sonic to supersonic and manned to un-manned ones.

Although the history of manned flight is spanned over a century, sustained low altitude, intermittent, shuttle and low range flights for urban use has not been as practical. Helicopters have been around for a while both in civilian and military services, but have been of limited use only in emergency and rescue operations due to their inherent issues related to high noise levels, vibrations, low fuel efficiency, dependency on fossil fuel and need for larger landing and takeoff spaces.

With the advent of battery technologies to utilise cleaner, greener form of energy as well as advancements in electric motors, communication & geospatial technology, advanced automation in flight control, advanced materials & processes techniques and efficient production lines, it has been possible for the aerospace companies to build lighter, greener and smaller aircrafts for low altitude and low range flying, especially with capability to lift off and land vertically rather than needing a long run-up to achieve the same.

Urban Air Mobility (UAM) or Advanced Air Mobility (AAM) is thus an emerging air transport solution utilising these light weight, mostly electric flying machines to deliver packages as delivery drones and moving passengers as air taxis over populated areas ranging from small towns to larger cities.

There are currently various Vertical Takeoff and Landing (VTOL) aircraft concepts in development worldwide including Multicopter, Lift & Cruise and Vectored thrust powered by electricity, fossil fuel or hybrid.

2.2.UAM Market Potential

Various market research firms focussing on the aviation industry across the globe have projected different numbers, albeit, they all show a similar exponential growth trend. According to Morgan Stanley (Morgan Stanley, 2021), global UAM market is projected at a whopping $9tn by 2050. According to (Brandessence, 2023), Global UAM Market is valued at $1.6 billion in 2021 and expected to reach 15.6 billion by 2028, with a compound annual growth rate of 37.3%. Joint study by Aerospace Industries Association and Deloitte shows in the Unites States alone the Air Mobility Market could reach $115 billion by 2034 (Aerospace Industries Association, 2021).

(Reiche et al., 2018) identified 36 potential UAM markets across 16 market categories. Of which, Air Taxi is one of the main markets coming under the Air commute category.

UK Research and Innovation (Swanson Aviation Consultancy Limited, 2022) analyses 20 potential routes in the United Kingdom for the Advanced Air Mobility operations. This research considers 14 electric Conventional TOL routes and 6 eVTOL routes, requiring 160 4-seater eVTOLs and 64 19-seater eSTOLs which is a total of 224 aircrafts. If these journeys were to replace conventional on-road car journeys, an estimate 9,000 tonnes of carbon emissions per annum from cars can be reduced.

Figure 2: UK Research and Innovation (Swanson Aviation Consultancy Limited, 2022)

2.3.eVTOLs

eVTOLs are the third revolution of manned aviation, first of which was the human powered biplanes and second using thrust generator jet engines using fossils fuels. Neither vertical lift & landing nor electric propulsion was new to the aviation industry. But, it was not until the advent of high energy density batteries came to the automotive industry that the electric propulsion for aircrafts gained momentum. It was around 2012 the eVTOL movement, so to say, gained heat with the likes of Uber publicly announcing their vision for fast, point-to-point, intra-urban air transportation and reinforcing its vision by promoting Uber Elevate in 2016.

eVTOLs come in all shapes and sizes, including but not limited to, vectored thrust, lift and cruise, wingless multi-copters, electric rotorcraft and hoverbike categories (Horne, 2022). Vertical Flight Society (eVTOL News, 2023), a non profit organization for advanced vertical flight maintains a design directory for eVTOL and it has now exceeded 900 entries from 400 companies worldwide. Search on Google Patents for “eVTOL design” report over 1743 results, indicating the number of patents being filed. Nevertheless, what it indicates is the sheer size of the design & development industry and the amount of innovation happening in and around the eVTOLs.

Figure 3 gives a bird’s eye view of electric aircrafts’ architecture with key performance parameters compared.

Figure 3: Comparison of potential electric aircraft architectures (Roland Berger, 2018).

As of December 2022, around 7487 eVTOLs have been ordered by airline operators worldwide, 50% of which are from commercial passenger airliners and about 30% by business and general aviation operators and the rest by non main stream air space users (Alan Lim, 2023).

Figure 4: eVTOL's market share, Picture courtesy (Alan Lim, 2023)

Major eVTOL companies that have gone public in the recent years are Joby, Lilium, Vertical, Eve, EHang and Archer. With a market capitalization of $3.6 billion, Joby stands at the first place followed by Vertical Aero with $1.46 billion and Lilium with 770million (Horne, 2022).

Apart from the Ehang, a Chinese eVTOL aircraft company, receiving its type certification from Chinese domestic airworthiness certification body the Civil Aviation Administration of China (CAAC) for the multicopter EH216-S, as of date, there has not been any successful eVTOL airworthiness certifications anywhere in the world. There are projections of certification ranging from 2023 – 2030 but the forecast has always slipped towards the right.

Figure 5 shows the airworthiness certification status of eVTOL's currently in design stage (EASA, 2021). None of them are fully certified as of now and the forecast for any commercial flights is only after 2024, but that is not certain.

Figure 5: eVTOL Passenger vehicle certification schedule announcements

2.4. eVTOL – Advantages and Challenges

Five key promises by the eVTOLs businesses are (Roland Berger, 2018):

1. Faster travel option
2. Reasonable Fares
3. Safe and Enjoyable Flight Experience
4. Integrated Mobility Solution
5. Passenger Winning Service

Other general advantages of eVTOLs over standard modes of urban transportation that one can foresee are:

- Use of clean and green energy for flight
- Save time by defying congestion in urban travel
- Environmental friendliness
- Less noise
- Comfort
- Ability to use the services of air transport at any time
- Operational organization of the flight
- Pre-flight passenger services
- High performance guarantees safety during flight.

Challenges:

- Airworthiness authorities are only gearing up now
- Insufficient regulations by legislation
- Certification and establishment of rules for the operation of aircraft
- Creation of a system of control, flight control and coordination of departures
- Development of infrastructure for takeoff & landing (vertiports), charging stations, ground support, Maintenance Repair Overhaul
- Speciality pilots to operate them and their training requirements
- Law and legislation around their operation in urban areas
- Safety of passengers and insurance
- Load on Electric grid
- Establishment of supply chain for spare parts and related logistics
- End of life for aircrafts and batteries
- Societal acceptance of Air Taxis

Figure 6 shows environmental impact as one of the top five challenges for the success of eVTOLs for UAM application. This indicates, for Air-taxi application, environmental impact will be far more important and crucial for its commercial success.

Figure 6: Challenges for UAM (EASA, 2021)

2.5.Environmental concern & societal acceptance of air taxis

One of the major concerns identified with eVTOLs during the societal acceptance survey by (EASA, 2021) is its environmental and climate impact for production and operation. Survey indicated that 74% of the total respondents agreed that, as a measure of improving societal acceptance, an Eco-label similar to that with other household and commercial appliances for eVTOLs can be adopted.

Figure 7: Societal acceptance of Air Taxis, (EASA, 2021)

The outcome of the survey simply indicates the gravity of the concern by general public on the issue of green appeal and hence the emphasis on evaluation of the credibility of the notion of green and sustainability of the eVTOLs.

2.6.Green/Eco Innovation Evaluation Approaches

Measurement of innovations is a vast and complex subject in itself. Eco-innovation measurement is a step higher in complexity as this is a relatively new and fairly less well understood branch of innovation. Furthermore, eVTOL's are only in design stage globally and none are either certified or commercialised as yet. Measuring an eco-innovation for its intended use and ecological benefits at its infancy has its own challenges, drawbacks and risks. Nonetheless, it is imperative that a study be carried out to understand the severity of the negative externalities / environmental impact. Having said that, it is important to understand at this juncture that the current study is of academic importance only and not associated with any organisations, policy makers, environmental or innovation evaluation bodies.

At first, it is important to understand what eco-innovation is and does the product selected for measurement qualify for being a candidate for evaluation as eco innovation.

The notion of green innovation or eco-innovation has several definitions by several people/organisations. In layman terms, green OR eco-innovation is **about developing new technologies and processes that are environmentally friendly and sustainable**.

According to Fussler and James (1996) as cited by (Dean Bartlett, 2010), Green innovation, also called as Eco-innovation is:

> *"new products and processes which provide customer and business value but significantly decrease environmental impacts".*

The Europe INNOVA panel states that (cited from (REID & MIEDZINSKI, 2008));

> *"eco-innovation means the creation of novel and competitively priced goods, processes, systems, services, and procedures that can satisfy human needs and bring quality of life to all people with a* ***life-cycle-wide minimal use of natural resources*** *(material including energy carriers, and surface area)* ***per unit output, and a minimal release of toxic substances****".*

According to OECD/Eurostat Oslo Manual (OECD and Eurostat, 2005, Third Edition), eco-innovation can be defined as:

> *"the implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which, with or without intent, lead to environmental improvements compared to relevant alternatives".*

Current research is largely relying on this definition from OECD.

2.6.1. eVTOLs are Product Eco-innovations

For the measurement or evaluation of a given innovation, it is vital to understand which category of innovation it fits in to. Identification of category helps in the selection of appropriate tools and techniques for evaluation.

MEI (Arundel & Kemp, 2009) classifies eco- innovations into following four categories:

1. Environmental Technologies – focussed on technologies directly involved in handling environmental issues
2. Organisational Innovations – Innovations within management systems to prevent environmental degradation and support improvement
3. Product and Service Innovations – new and environment friendly goods and services
4. Green System innovation – Alternative / green solution to existing systems of production and consumption

Also, according to (REID & MIEDZINSKI, 2008), "Product eco-innovations include any novel and significantly improved product or service produced in a way that its overall impact on environment is minimised. Products can include various goods with a different number of components".

Hence, according to MEI's measure, eVTOLs are a ***"Product and Service Innovation"*** as they are designed or at least they claim to be sustainable and environmentally friendly.

2.6.2. Methods and Techniques for measuring Product eco-Innovation

Literature search for keywords such as "electric aviation innovation measurement", "electric aviation innovation evaluation", "electric aviation green policy", etc., does not provide any favourable results. There are no specific or standard methods or tools or techniques being specified or advised by policy makers or governing bodies or government bodies for the measurement and enumeration of electric air mobility vehicles. Quite understandably so, as they are still in their infancy and not in service in any capacity.

(Arundel & Kemp, 2009) Identifies the following 4 key areas for eco-innovation measurement:

1. Input measures – Measurement of inputs such as R&D costs, Design costs specifically for the environmental technologies ,
2. Intermediate output measures – Measurement of patents and scientific publications,
3. Direct output measures – Number of green innovation, Sales, profits, product performance etc.,
4. Indirect impact measures – derived from aggregate data.

(Kemp & Pearson, February 2007) defines the following 3 methods for measuring eco-Innovations for the four key areas of a product identified :

1. Community Innovation Survey (CIS) Analysis
2. Patent Analysis
3. Digital and Documentary Source Analysis

2.6.2.1. CIS Analysis

This is primarily used for input measures. Due to the novel nature of eVTOLs as a product and general awareness of its production techniques, supply chain and end of life treatment technologies, it is highly likely that a large portion of the population is unaware of specifics of it. This makes the data collection difficult as well as the analysis results to be quiet un-reliable.

2.6.2.2. Patent Analysis

Patent analysis can be very useful for intermediate output measures, provided the product /technology as a whole or in large part is new and patented or in the process of application. Eco-patents are required to be filed by the eVTOL developers claiming innovations that underline *green products* and *end of pipe technologies*, which can then be used for the current study. But, per the innovation matrix (Satell, 2017), eVTOL's are incremental innovations only, as what needs to be achieved is well understood and the technologies being used are abundantly available and largely well understood. But are modified and improved for better performance and reduced carbon foot print. Due to the low level of inventive activity, it is unlikely that this method would provide a reasonable amount of data for evaluation. Also, it is possible that, lager firms file large number of patents and are biased, whereas small firms may never file one.

2.6.2.3. Digital and Documentary Source Analysis

UAM's, AAM's and eVTOLs are still under research and development, there is nothing tangible in terms of product or the data related to the product in the open sources. In such instances, it is found that the most effective way of identifying the direct output measures and indirect impact measures for analysis are the literature and the Digital data (OECD, 2009), such as :

1. New product announcements in technical & trade journals,
2. Product information databases
3. Company websites
4. News and Media broadcasts
5. Independent agencies' assessment and published data

Apart from the technical & trade journals, where the data is more controlled and reduced biases, rest of the sources suffers from the influence of advertisements, marketing stunts, speculations, biased views and diluted information from source to publication.

2.6.3. Data Analysis and Interpretation

There are several techniques available, both qualitative and quantitative, for the analysis of digital and documentary Source data. Some of the tools developed over years for environmental impact assessment are (Finnveden & Moberg, 2005), (Ness et al., 2007):

1. Life Cycle Assessment (LCA)
2. Strategic Environmental Risk Assessment (SEA)
3. Environmental Impact Assessment (EIA)
4. Environmental Risk Assessment (ERA)
5. Cost –Benefit Analysis (CBA)
6. Material Flow Analysis (MFA)
7. Ecological Footprint and
8. Eco Efficiency indicators.

As, there is no single specified, prescribed or standard method available, no single indicator or method is likely to be sufficient for the measurement of eco-innovations.

Two of the suitable techniques that can be considered for the current study are:

1. Eco-efficiency Indictors
2. Lifecycle Assessment (LCA) indicators

2.6.3.1. Eco-Efficiency Indicators

Eco efficiency is an indication of change in absolute impact of a product or a service. Eco efficiency in simple terms means, less environmental impact per unit of product or service. According to (WBCSD, 2006) eco-efficiency means, "doing more with less".

2.6.3.2. Lifecycle Assessment (LCA)

"*Life Cycle Assessment (LCA) is a technique of assessing the environmental impacts associated with a product or service, during its lifecycle*" (Thore, 2002). LCA measures Environmental impacts from all stages of production and consumption of a product/service. Example, Ecological foot print, carbon foot print. The International Organisation for Standardisation (ISO) has developed standardized scientific method and requirement for the LCA under the Environmental Management category ISO 14044 (ISO 14040:2006, 2006).

LCA aims at providing an account of all the environmental impacts an eco-product has. Which include, anything that is drawn from nature and the ones that are disposed back into the nature. Ideally all impacts should be quantified, both in physical units and in terms of the harm done. LCA has been used since 1990 when the first scientific publication emerged (Finnveden et al., 2009). LCA focuses on the assessment of the product or good from a life cycle perspective considering all possible attributes of natural environment, resources and human health (ISO 14040:2006, 2006).

Therefore, current research employs environmental LCA as the tool of assessment or method of evaluating the eVTOLs as Air-taxis for the city of London and hence a greener solution for urban decongestion.

3. Problem Definition

Two of the most significant challenges to be fulfilled by eVTOLs as Taxis are:

1. Commercialisation potential of eVTOL's as UAM solutions
2. Green, sustainable, eco-friendly, carbon sensitive appeal of eVTOL's as UAM in comparison with traditional methods of public transport.

The environmental impact of eVTOL's may be closer to zero on a local emissions level, but the required electricity still has to be generated by some means and the vehicle components have to be manufactured, assembled and eventually disposed off. Not some or all of these is carbon free.

Enough work has been carried out in understanding and mitigating the challenges for UAM's including, infrastructure, safety, noise, technology, regulations, air traffic management, certification, communications, cost, economics, societal acceptance, public acceptance, legal framework, operations, public perception & security (EASA, 2021).

Whereas, literature review regarding research on the green and eco-friendly motive of eVTOL's seems to be in its infancy and further research in this regard will only improve our understanding and provide further evidence of how eco-friendly the eVTOL's are as solution for urban decongestion.

Per (Kemp & Pearson, February 2007), "The relevant criterion for determining whether an innovation is an eco-innovation is that its use is less environmentally harmful than the use of relevant alternatives". Current research focuses on identifying, measuring, evaluating and inference on the relevant eco-innovation indicators for eVTOL's as UAM solutions.

3.1. Scope and limitation:

eVTOLs are a class of product in themselves. There never had been any product similar to eVTOLs. Due to lack of a standard specimen product to measure against, Environmental benchmarking is not possible. Of the various possible applications of the eVTOLs, the most talked and hyped about is them being air Taxis or air Cars, boasting to be the solution for urban decongestion.

A direct comparison of eVTOLs with a competing similar product is not possible. The only product that can be called similar on the basis that they both use similar technology and are utilised for the same purpose, but not by same means are the Electric Passenger Vehicles of capacity 4-6. A direct comparison of eVTOLs and eVehicles will be much like an apple to orange one, but, that's where the parallels are being drawn by the media and the industry.

To encompass a more logical research within the purview of this dissertation, a deep dive into the green-mobility and sustainable appeal of eVTOL's as *air taxis* is considered for the current research.

Furthermore, to keep the depth of research at its deepest, rather than being wide and shallow, current study is focussed only on manned eVTOL's and not self driven. Although, the research objectives of this study can largely be interpreted for self driven eVTOL's as well.

Case Study: To set the expectation of the study clear, eVTOL's are measured for their eco-innovation performance against the current standard mode of public transport for ***the City of London***. Section 3.2 provides a brief of the UK urban areas and defines the basis for selecting London for the case study.

Considering the current pace of technological advances, validity of outcomes of current study can roughly be for a period of 4 to 5 years. Hence, the study focuses only on manned eVTOLs (i.e. with a pilot on board) for the transport of people, as it appears unlikely that unmanned transport of people in urban environments may take place within that timeframe.

Specific goal and scope of the study of eVTOLs for environmental Life Cycle Assessment is defined in section 4.1.

3.2.Urban Areas – UK

Urban population of the UK in 2022 was approximately 56.52 million in comparison to the rural population of 10.45 million (statista, 2023). According to the UN estimate, percentage of UK's population residing in urban areas is currently at 83.9%, in 2030 this is predicted to reach 86.3% and in 2040 to 88.2% (Trend-Monitor Ltd, 2020). Major urban areas of the United Kingdom which are to play a key role in the UAM business are listed in Table 2 in the descending order of their population(citypopulation, 2023).

	Name	Adm.	Population Census (C) 2021-03-21
1	London	ENG	10,558,797
2	Manchester	ENG	2,720,316
3	Birmingham	ENG	2,590,363
4	Leeds	ENG	1,860,546
5	Glasgow	SCO	*1,026,880*
6	Liverpool	ENG	891,211
7	Southampton	ENG	888,145
8	Newcastle	ENG	790,636
9	Nottingham	ENG	762,786
10	Sheffield	ENG	688,981
11	Bristol	ENG	680,377

Table 2: Major Urban Areas of the UK

London is the most populous city in the United Kingdom with a population of 10.5million and about 4 times as much as the second most populous city in the UK, the city of Manchester. London ranks number 1 in the global traffic index according to (tomtom, 2022) & (Inrix, 2022) with an average travel time per 10km of 36min 20 seconds with the lowest average speed in rush hours of 14km/hrs. This makes London the best candidate for study to see if air taxis can be viable greener solution for traffic decongestion.

4. Environmental Life Cycle Assessment (LCA) of eVTOLs

Just as with the electric road vehicles and electric locomotives, eVTOLs from the projected prospects look very green. Unless, the balance sheet shows and accounts for the negative externalities associated with every aspect of the product, including sourcing of raw material, manufacturing, distribution & transport, use & maintenance, disposal & recycling, it is incomplete.

Current study utilises the approach of *Conceptual LCA* (BPA, n.d.), which looks at the qualitative inventory of components that have the highest relative environmental impacts. Conceptual LCA utilises generic computer tools as well as simple/basic graphical & statistical tools such as block diagrams, tables & Flowcharts (Peiris et al., 2019). Either the simplified LCA or the Detailed LCA are out of scope of this study due to the high level of research , detailed mathematical modelling and deep dive into finer elements of environmental negative manipulations are involved and hence are beyond the scope of this dissertation.

Figure 8 shows the principle phases of typical lifecycle of eVTOLs from production to disposal. Blocks of the diagram represent actions or processes. Resources such as energy, sub assemblies, assemblies, man power flow between the blocks. Reading the diagram top down represents a conventional production chain starting from design then to production & Distribution and eventually to disposal of the product.

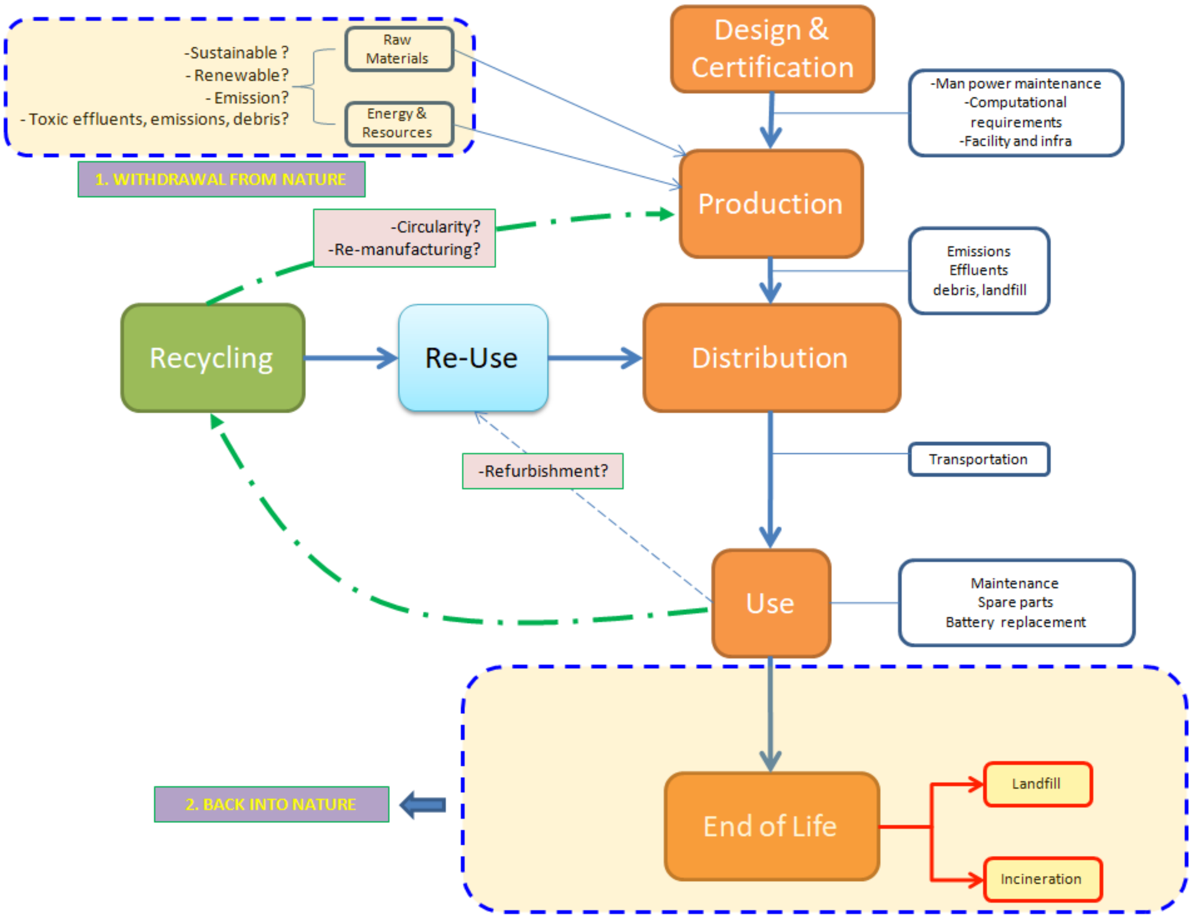


Figure 8: Life cycle of typical eVTOLs

Every single phase of the life cycle is associated with use of resources from nature and disposal to nature. None of which is accounted for in the cost of innovation or new product development in terms of the damage done to the elements of nature, human health and harm and toxicity injected into the eco-system.

Two major feedback loops are illustrated in the block diagram:

1. Recycling: Return of the used up and discarded product and/or parts as input into production and
2. Re-use: Return of used and discarded products and /or parts at the distribution phase.

First feedback loop is about:

Re-manufacturing & Circular Economy

Second feedback loop is about:

Refurbishment, repossession, extended life goal assessment and up-gradation.

These two feedback loops play crucial role in the sustainability of a product and positive efficiency of these is important to lower the environmental impacts at end-of-life of the product. Current research will try and focus on two key ingredients of eVTOL recipe, the batteries and the thermoset composites through LCA.

There are four phases in a LCA study (ISO 14040:2006, 2006):

1. Goal and Scope Definition
2. Life Cycle Inventory Analysis (LCI)
3. Life Cycle Impact Assessment (LCIA) and
4. Interpretation & Improvement Assessment.

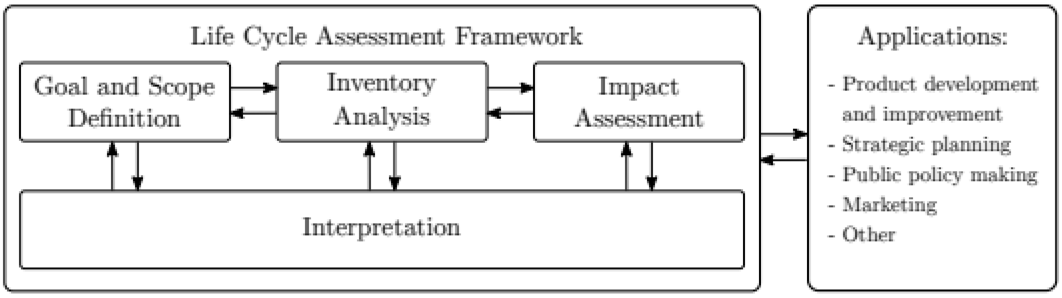


Figure 9: Life Cycle Assessment Framework, (ISO 14040:2006, 2006)

4.1.Goal and Scope of LCA

Primary goal is to conduct environmental sensitivity study of all the elements in the life cycle of typical eVTOLs when used as urban air taxi. Considering the volume of the subject in hand, it is not plausible to measure in detail every single input and output within the life cycle of the eVTOLs to a high level of detail. Where there is good substantiation for an element of study to be considered too trivial or deemed to be beyond the purview of current study, they will have to be set outside this study.

LCA will be focussed on the Air-taxi use case of eVTOLs for the city of London. References can be made to other cities or regions of the world where deemed necessary from the point of substantiation or emphasis of a fact, feature or a parameter.

Three main aspects of study which are of environmental importance in relation to air taxis are:

1. Operational Emission of GHG in comparison to standard modes of transport, Taxi use case only,
2. Environmental impact due to production and end-of-life treatment of Batteries and
3. End-of-life treatment of special materials used in construction of eVTOLs.

Special materials called composites are used extensively in the construction of eVTOLs to keep them light enough for easy lift and thrust. Study of environmental impacts of production and disposal of these silent killers is of prime importance. End of life of small to large airplanes, in general, is systematically ignored by both the industry environmental experts and academicians equally, resulting in hectares of land in desserts being used as mass graves of airplane boneyards. Issue of end-of-life could be far more severe with eVTOLs, for they utilise batteries and a viable technological solution of recycling them is not available as yet. Emphasis will be given to the End-of-life assessment of the eVTOLs during the LCA.

4.2. Life Cycle Inventory Analysis (LCI)

Apart from the North London suburb of Brent Cross Vertiport, which is only approved very recently (FutureFlight, 2023), there is no other confirmed information regarding the planned locations and numbers of any other vertiports in and around London. Recent announcements including Urban-Air Port and Ferrovial have been about utilising the exiting airfields and airports to build the Vertiport network. With no other firm data available on the specific spots for vertiports, an estimate of trips will have to be made based on the existing airfields and central London.

Figure 10: London Airports Map (Maps London, 2023)

From	To	Distance by Road, km
Central London	Heathrow	32
	Gatwick	45
	Luton	56
	Stansted	64
	Southend	65
	City	16
Average Distance, km		**46.3**

Greater London commuter belt, including Reading, Aldershot, Aylesbury and Maidstone is at approximately 64km (40miles) radius from Charing Cross (Academic Accelerator, n.d.), via roads. As well, average distance to all the London airports from city centre is about 46.3km by road. However, the aerial distance will be much shorter than that.

This does not make much sense to call eVTOLs as air taxis, if they were to only fly to connect the existing airports and not to areas of high business concentrations to reduce congestion.

According to Erostat (Eurostat, 2021), average urban travel distance per person per day ranges from 5.6Km in Greece to the longest of 19.0Km in Germany. Considering just two trips of standard to and fro travel for the longest trip yields 9.5km only.

Hence, a fair assumption for considering the best use case for Air Taxis is between 15km to 50km in order for eVTOL's to deliver any credible time savings and be the fastest urban mobility option. For the current study an average trip length of **25km** for the city of London is deemed adequate, considering a mid Vertiport between any two points of existing airfields and centre of London city.

Demand for eVTOLs for the city of London is assumed at 5% of Greater London personal vehicle trips between each assumed vertiports. This demand is expected to grow up until 10% in 10 years from the start of the service. According to 2011 statistics, London residents made six million car journeys every day, of which 1.4million are passenger journeys (Transport for London, 2011). Perhaps this data is overly outdated, but in light of unavailability of latest date this is considered baseline. Considering a 5% nearby passenger trip to be substituted by eVTOLs, accounts for 70,000 trips per day. With the utmost efficiency and a 24hours of service schedule, considering a trip time of 45mins and 15mins for ground time account for 24 trips per day per aircraft. This amounts to a whopping 2,917 aircrafts in total. Accounting for any grounded aircrafts due to maintenance, charging lay over etc., an extra 15% makes it a minimum of 3350 aircrafts. One can imagine the chaos in air traffic, load on electric grid, elevated security concerns of accidents, air traffic management and a modern nuisance over London if even half of these were to fly at once.

4.2.1. GHG Emission for air taxi use case

Vertical Aerospace has published generic emission data in its white paper, see Figure 11. For an average journey of 113km with 68% load factor, emissions of eVTOL are only comparable to an electric car with 1 passenger or a diesel car with 4 passengers, if not better. But, nothing specific to the air taxi use case are published

Figure 11: Vertical Aerospace, BEIS, (Bryce Tech, 2023).

Similar is the case with Joby. For an average trip of 40km with 2.5 passenger (of a 5 seater eVTOL) when manufactured at scale and operated for 20,000 hours, on a per passenger basis the GHG foot print to be approximately 1.5 times smaller than that of an electric passenger car (carrying an average of 1.2 passengers per car trip) (Joby, 2022).

Volocopter is primarily developing its version of air taxi called the Volocity (eVTOL News, 2023), a 2 seater 18 rotor aircraft with a range or 35-65km and max speed of 110km/hrs. Volocopter has also not published any specific data on emissions per flight mission. No emission data available from Lilium either.

An independent investigation carried out by (Kasliwal et al., 2019) shows that the GHG emission values are highly sensitive to the ***trip length*** as well as ***occupancy***. From the graph in Figure 12, for a base case of single passenger, internal combustion engine vehicles (ICEV) perform better than eVTOLs up to ~35km due to high energy needed by eVTOLs to hover during landing and takeoff. For trips longer than ~50km eVTOLs emissions drops exponentially. Figure 13 Shows the energy efficiency comparison among different eVTOLs. Higher ranges and higher occupancies are more energy efficient.

Figure 12 : Typical eVTOL flight profile for Taxi use case and GHG emissions normalized by vehicle-km travelled, (Kasliwal et al., 2019)

Figure 13 : Energy efficiency of different eVTOLs, (Sripad & Viswanathan, 2021)

4.2.2. Batteries

All eVTOLs under development today irrespective of type of electric motor technology use lithium ion batteries to power them. These are the exact same batteries used in our cell phones but with high storage capacity and stacked up to produce enough current to propel an aircraft. Lithium is the linchpin of these batteries and also a major cause for concern for eVTOLs eco-innovation challenge. A typical cell phone battery weights about 32grams, with a lithium content of about 3grams, that is about 10-11% of battery by weight. eVTOL batteries can weight anywhere from 200kg to 600kgs, meaning lithium content of 20kg to 60kg per aircraft.

Battery life and replacement frequency:

EVs such as the Tesla Model 3 and BMW-i3 have manufacturer warranted battery life of eight years or 100,000 miles at 70% charge capacity retention. This is corresponding to 385 battery equivalent full cycles (EFCs) for a Tesla model-3 of range 260 miles and 650 EFC for a BMW i3 of range 153miles. Considering 1600 EFCs per year for a typical eVTOL (Yang et al., 2021), meaning from a EV battery warranty perspective it needs changing batteries every 3-5 months, which raises concerns over the overwhelming cost and maintenance issues. Even with a battery warranty of 1million mile corresponding to ~3300 EFCs, will needs to be replaced every two years. Conventional aircrafts are built to last for a minimum of 50,000 flight cycles or over 25 years. Uber (Holden & Goel, 2016) estimates an average life of 13 years in service, meaning battery replacement at least six times in an aircrafts life time.

In Figure 14 a comparison of EV v/s eVTOL battery requirements is made. It shows eVTOL batteries have far more severe requirements in comparison to standard EV batteries in aspects such as safety, average charge rate, fast charge frequency, annual equivalent cycles and peak power duration. This makes eVTOLs less popular and less cost effective and less greener in comparison to electric road vehicles.

Figure 14: Battery requirement comparison between eVTOLs and EVs, (Yang et al., 2021)

Exact or even estimates of battery specifications or Li-ion cell chemistry are not well published by the manufacturers. With limited or no data available in the public domain, some of the values in Table 3 are taken from available literature as referenced.

Make	Model (seats including pilot)	Range Miles	Battery tech	Battery Weight kg	Li Content [2] kg	Proposed Recycling method	Reference
Lilium	Lilium Jet 2 Seater	152	Li-ion cells	240	24	Second life application & raw material recovery	(Bacchini & Cestino, 2019)
Lilium	Lilium jet 5 seater	152	Li-ion cells	900	90	Second life application & raw material recovery	(Bacchini & Cestino, 2019)
Vertical	VX4, 5 seater	100	Li-ion, Cylindrical cell	900[1]	90	Not published	(evtol news, 2023)
Joby	S4, 5 Seater	100	Li-ion cells	1000	100	Employ third party recycling company	(Sripad & Viswanathan, 2021)
Archer	Midnight, 5 Seater	50	Li-ion cells	1000	100	Not published	(evtol news, 2023)
E-Hang	E-Hang 216, 3 Seater	22	Li-ion cells	92	9.2	Not published	(Bacchini & Cestino, 2019)

[1] Not available from product tech spec, assumed by comparison to similar products

[2] Considering 10% of the battery weight

Table 3: Battery specifications for major eVTOL models proposed for entry into service in the next 5 years

It is surprising to see that none of the front runners of eVTOL taxis have honestly disclosed any data regarding the actual demand for batteries for their aircrafts and a credible and sustainable plan for battery recycling. Most white papers regarding technical specifications of their products are missing from their official websites.

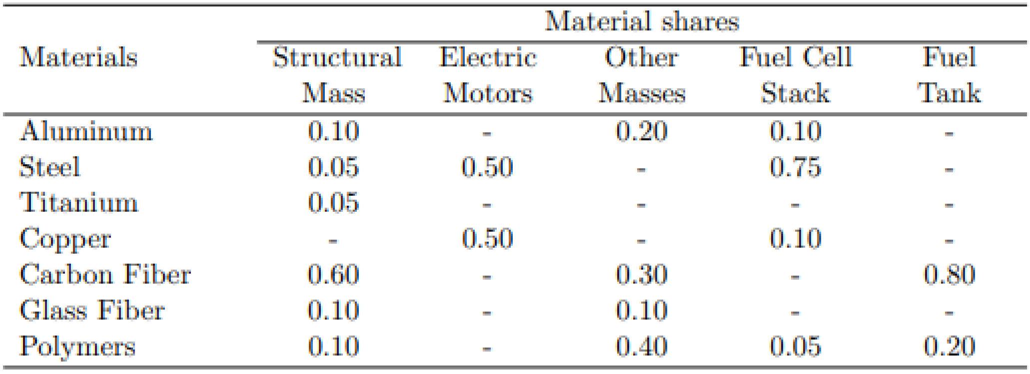
4.2.3. Composites

As with the batteries, none of the eVTOL manufacturers have publicly disclosed the principle material composition of their aircraft build. Nor there is any credible data in terms of quantities and numbers available from the OEMs on the emissions and environmental impact assessment of extracting minerals for Composite parts manufacture and end of life treatment.

Reading through the OEM web pages, partner & supplier web pages and trade journals, it is clearly understood that keeping weight under control is of paramount importance for all eVTOLs makers. Hence, most of the structural load bearing parts including fuselage, empennage, wings, fan blades, control surfaces are all made out of Carbon Fibre Reinforce Plastics (CFRP). Interior structures are made out of glass skin composites with Nomex cores. Metals are used cautiously due comparatively lower strength and stiffness to weight ratios. Metals are used mostly where composites are not a viable solution either from manufacturing or cost perspective.

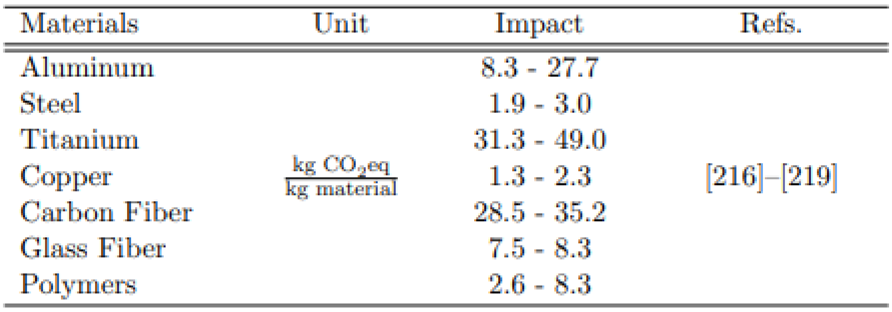
Modern, larger people carriers such as Airbus A350 and Boeing 787 have circa 50% composites by volume, meaning the rest ~50% is non-composite, majority of which will be metals such as Aluminium, Steel and titanium. Whereas, eVTOLs are expected to have about 70% or more composites by volume, meaning higher composite raw materials required and larger material disposal per passenger.

In Table 4, Nicolas André (Andre, 2022) has estimated 60% of structural mass, 80% of fuel tank mass and about 30% of other masses are contributed by Carbon Fibres themselves. Table 5 provide the GHG emission indices in ***sourcing*** of typical eVTOL build materials. Although, largest GHG is for Titanium, it is only 5% by mass usage in an eVTOL. Highest impact is from carbon fibres, which has GHG emission index of 28.5-35.2 kgCOeq/kg material, which is used for about 60%-70% by weight of typical eVTOLs.



Materials	Material shares				
	Structural Mass	Electric Motors	Other Masses	Fuel Cell Stack	Fuel Tank
Aluminum	0.10	-	0.20	0.10	-
Steel	0.05	0.50	-	0.75	-
Titanium	0.05	-	-	-	-
Copper	-	0.50	-	0.10	-
Carbon Fiber	0.60	-	0.30	-	0.80
Glass Fiber	0.10	-	0.10	-	-
Polymers	0.10	-	0.40	0.05	0.20

Table 4: eVTOL component material compositions – Assume, (Andre, 2022)



Materials	Unit	Impact	Refs.
Aluminum	$\frac{\text{kg CO}_2\text{eq}}{\text{kg material}}$	8.3 - 27.7	[216]–[219]
Steel		1.9 - 3.0	
Titanium		31.3 - 49.0	
Copper		1.3 - 2.3	
Carbon Fiber		28.5 - 35.2	
Glass Fiber		7.5 - 8.3	
Polymers		2.6 - 8.3	

Table 5: GHG indices of eVTOL build materials, (Andre, 2022)

Figure 15 **(Roy, 2023)** shows projection of composite material demand until 2030 by the eVTOL industry. Demand is steeply rising from mere 1.1million pounds to whooping 26million lbs by the end of 2030, which is over 20 times in a span of just six years.

Figure 15 : Composite material demand v/s eVTOL production Volumes (Roy, 2023)

Joby in its Environmental, Social and Governance Report (Joby, 2022) briefly mentions that carbon fibre composites in all its in-production planes meant for prototyping will be fully recycled through a third party recycling vendor. But it does not speak of any robust plans for serial production aircrafts plans for as well as glass fibre composites at their end of life. And so is the rest of the industry, which have not as yet provided any credible evidence/commitments of plans to handle the composite recycling at the end of life. What is also not covered in this inventory is the 'in-production' composite scrap/waste recycling due to lack of data in public domain. This might seem a relatively smaller issue but certainly to be accounted for in a full composite LCA consideration.

4.3.Life Cycle Impact Assessment (LCIA)

Data collected in the inventory analysis phase is highly limited for any statistical data analysis for impact assessment. And the data is neither directly from the eVTOL producers, official or accredited independent assessment agencies or authorities nor are from any other credible sources. Hence the impact assessment in this section is only based on the limited data available and mostly subjective in nature.

4.3.1. GHG Emission for air taxi use case

For eVTOLs to be emission competitive to their on - road counterparts including BEVs & ICEVs:

1. Trip distance for typical eVTOLs have to be less than 35km. Estimated average trip distance for the city of London for best case taxi use scenario is 25km. Meaning a lot of energy is used up hovering in landing and takeoff and hence high emissions.
2. Should have a minimum occupancy of 50% for a five seater eVTOL. Lower occupancy indicates higher emissions.
3. Energy utilised from concept, prototyping, production, operation, maintenance to end of life treatment of eVTOLs should all come from renewable resources. Less renewable sources of energy indicates lower sustainability and higher emissions.
4. Vertiport location and design should target reduced transit transportation requirement using road vehicles.

4.3.2. Batteries

From a London city perspective:

1. Considering only 5% substitution of passenger road trips by eVTOLs, a sum of 3350 eVTOLs are required at any time. Average lithium required per 5 seater eVTOL is 80.8kg. Considering an average battery life of 2 years with current battery technology, 271 tonnes of lithium, either new or recycled, is required once every two years just for the city of London.
2. A 10% substitution to road trips means, easily 500 tonnes every 2 years.
3. eVTOLs battery requirements are far more severe to BEV ones, indicating need for higher technology and better risks management tools and techs.
4. Sustainable sourcing of Lithium is not demonstrated by any eVTOL developers or their battery suppliers as yet
5. A clear and greener path for End of life handling of eVTOL batteries either by eVTOL developers or London city authorities is not available.

4.3.3. Composites

eVTOL structural build on average utilises 60% -70% composites by mass, this can be over 70% by volume. Composites have the highest GHG index among all the materials for eVTOL build. Composite manufacturing requires speciality tools and tool rooms with high carbon requirement. This means, composite material share per passenger or carbon emission due to composites (sourcing and disposal) per passenger per flight is much higher in eVTOLs than commercial airliners.

From a London city perspective:

1. Considering only 5% substitution of passenger road trips by eVTOLs, for a sum of 3350 aircrafts in service at one time, considering an average composite material weight per aircraft of 1300kgs, amounts to a total composites weight of 4355 tonnes. Average empty weight of 2000kgs for a 5 seater aircraft and a composite content of 65% by weight is considered for calculation. So, there is about 4355 tonnes of composite waste to be handled every 10-13 years, just for the city of London.
2. Considering 10% substitution to passenger road trips will make this number close to 9000 tonnes for every 10-13 years.
3. Just as with batteries, eVTOL developers have neither promised nor proposed any credible or sensible way of handling end of life of composites. Re-use and remanufacture is also not discussed by any eVTOL developers so far. Part of the problems with re-use of fibre based composites is the need for expensive Non Destructive Testing & inspection methods to prove parts' structural integrity for second or subsequent use and low level of design modifications possible due to off the tool bespoke designs.
4. Sustainability in sourcing of composites is not demonstrated by any eVTOL developers so far.
5. Proof of alternative material or willingness to explore better and eco-friendly material technologies for future aircrafts is also not demonstrated by the eVTOL developers.

4.4.Interpretation

4.4.1. GHG Emission for air taxi use case

Published data by the eVTOL developers regarding the GHG emissions is insufficient to draw conclusions of any sort, including loose opinions. Also, there is not much data available on the air taxi use case from independent sources such as researchers, educational institutions, government bodies or regulatory authorities, not at least in the free domain.

From what is available as the data, it is evident that eVTOLs are very emission efficient in the cruise mode and not as much during landing and takeoff. Shorter trips such as for a city hopper involve multiple landings and takeoffs. In the trip ranges below 35km, much of the power is taken to hover vertically for landing and takeoff. Hence higher emission per trip for shorter trips, which is what, is expected of an air taxi.

For the air taxi use case for cities such as London, where average city hop-on hop-off services could be between 25 & 45 km only, more credible emission data is needed to assess its comparable advantage over standard modes of transportation.

With the available data for the City of London, where the locations of vertiports is completely unknown, it is very difficult to factor in for the emission contribution due to transfer shuttles to and from vertiports per trip of eVTOL. This is not something one can ignore if an honest assessment is to be conducted. Current inventory analysis shows for average trip lengths of 35km, a BEV with occupancy of 1.5 seats or a diesel car with full occupancy is of similar or better emission efficiency than an eVTOL at occupancy of 2.5 seats.

For the United Kingdom, electricity from renewable sources only account for about 48% of all electricity supplied to the grid. Meaning, until a full decarbonisation goal set for 2035 is met, substantial amount of electricity will have some carbon foot print and hence eVTOLs passive emission.

From an emission perspective, air taxis for the city of London seem pointless unless proven otherwise by more credible ground data.

4.4.2. Batteries

Irrespective of the company, type, capacity, shape or country developing the eVTOL, all of them universally use Li-ion batteries, although in varied quantities based on factors such as the design payload, aircraft weight, range, speed and type of motors.

Just by operations within the city of London, 270-500 tonnes of lithium is expected to be handled every 2 years or 135-250tonnes every year. Although this number does not sound too much, from an eco-innovation perspective this is less attractive to BEVs, which use lower capacity batteries with longer life expectancy for a similar commute.

Lithium battery recycling process, if done at large scales, is associated with a number of health and safety concerns due to the volatile mineral contents to be handled. Neither the eVTOL manufactures themselves nor the London City local authorities have devised plans to recycle high volumes of lithium based batteries. Nor a plan of action to mitigate the risks involved is drawn by any one as of now.

On the surface, battery operated devices and vehicles seem to be sustainable, but the bare reality is that neither the sourcing of the battery ingredients nor their end of life is fully sustainable and green. Extraction of lithium though is a highly profitable business due to the current trend in battery operated vehicles; it is an unbelievably dirty business. It takes an estimated 500,000 gallons of water to process 1 ton of lithium. Some of the countries rich in lithium ores have the least water resources for human and live stock consumption, such as Chile’s Atacama salt flats.

Demand for lithium is estimated at 2.2million tonnes by 2030 (Kaunda, 2020), whereas the global supply itself is estimate at 16million tonnes. There are two possible scenarios to be foreseen. One, if this demand continues, then the supply of Lithium will be a supply chain problem. Two, considering current trend in new battery technologies that are trying to move away from Lithium, what is the future use of loads of lithium from these used batteries? Should all have to go into land fill in third world countries or any alternative, second or further use?

4.4.3. Composites

eVTOLs are expected to contribute to anywhere from 4000-9000 tonnes of composite waste every 10-13 years for the city of London. There is whole lot of other vehicles which use composites for their light weight construction, including passenger cars, racing cars, large transport airplanes, which will all add to the amount of composite waste to be handled.

Empty or bare structural weight for the major part of the dead weight the aircraft has to carry irrespective of the payload and hence will decide the size of the battery pack for intended range and speed. Almost all of the eVTOL manufacturers have therefore resorted to the magic material called Composites to keep their weights low. These materials are nothing new to the aerospace world and are being used since the 1990's by large airframers, spaceship builders, supercar manufacturers and offsite windmill blade producers.

Composites are a combination of two or more materials. Most popular among them are the carbon fibre and Glass fibre ones. Generally, fibrous cloth, either glass or carbon are impregnated with epoxy or phenolic thermoset resin are stacked up and cooked in an oven or under a press in a controlled environment. This produces parts with various forms and shapes for structural use. Composite have the advantage of having high specific strength and specific stiffness in comparison to any other general purpose aerospace material including metals or ceramics.

Thermoset Composites at their end of life are not as easily recyclable as metals. In fact, so far there has not been any viable technology to recycle composites in full, as they are made with thermosets. Joby Aviation has mentioned about extracting carbon fibres for re-use but has not in any detail described how and where it will be carried out and in what scale or capacity for production planes. Nor it has discussed about recycling the thermoset part of the material which contributes to over 60% by volume. The only currently practiced methods of end of life of thermoset composites are either landfill or incineration. Both of which are not considered eco-friendly or sustainable.

None of the eVTOL developers have defined a clear path for composite end of life. This is a grey area which unless addressed fully will never make the eVTOLs eco friendly or an eco-innovation.

Conclusions

French politicians have opposed the use of eVTOLs as air taxi operations during the 2024 Paris Olympics (The Local , 2023), this has taken the whole aviation industry by surprise. Germans in general are hesitant to the use of urban airspace for low altitude transport, including air taxis (62%), a study by “Sky Limits” research jointly lead by the Technical University Berlin and Wissenschaft im Dialog gGmbH (Kellermann & Fischer, 2020). Although, not entirely disregarding the idea of urban air travel, there is clear resistance, at least for now.

Evaluation of eco-innovations is never a straight forward task, especially when no standards and approved methods are established to measure against. eVTOLs are hence no different, with the number of variables and parameters involved in the study, evaluation of eco-efficiency of eVTOLs is much complex than we initially though. Comparing eVTOLs with road based transport solutions, especially internal combustion engine and battery electric vehicles are also no simple task especially with not credible ground data availability.

Occupancy on-board and emission:

Inventory analysis regarding the operational emissions clearly indicates significantly higher pressure on eVTOLs with fewer on-board passengers to be emission efficient. To outperform ground based vehicles for a similar trip, eVTOLs have to fly at full or near –full capacity. Current airlines utilise advanced booking software systems to maximise booking capacity. It is expected that eVTOL operators will venture in the same way as their big brothers or will be better than them in achieving high density occupancy per flight. Also, a single passenger road trip is inefficient than a full capacity counterpart. A ride share on road trip is being tried out by many operators but has not been as popular due to longer rides with larger passenger group. Unlike, road based transport, eVTOLs can be very attractive to ride share due to reduced trip time. Passenger behaviour to trade-off between cost and time of travel for cities like London is expected to be towards shorter travel time, which is the main benefit of eVTOLs for their adoption as UAM. Cost analysis and comparison to road based travel data is essential to survey the popularity for eVTOLs and its impact on operational emissions. A robust flight management system to run near full load is required to achieve benefits of lower emissions and profitability of operations. Pivotal success factors are the choice of right aircraft with right passenger seating capacity equipped with efficient booking system.

GHG emissions and trip lengths:

Trip length is the foremost important factor from the point of GHG emissions for the adaptation of eVTOLs in UAM solutions. eVTOLs emission are lesser for trips above 35km long. Energy intense hover for landing and take-off are dominant in a typical short hop city flight profile, which restricts the eVTOL from harvesting its best aerodynamic performance in a cruise condition. Average London city trips are less than 25km long and therefore eVTOLs will be less effective in contributing towards a sustainable urban mobility system. Ground based conventional vehicles prove to be inefficient, slow and unpleasant where trips are longer than 35km, routes with higher congestions, routes with inevitable geographical barriers, intercity travel, inter airport travel, trips involving indirect routing. These routes are ideal for eVTOLs and hence can prove to be efficient and sustainable. Replacing conventionally powered regional jets and turboprops like the Embraer ERJ135, 145, De Havilland Dash 8, Bombardier Q400, ATR 42/72 used by regional airlines such as Ryanair, Flybe can reduce

GHG emissions and help support air travel sustainability. Nevertheless, conventional road based travel have no restriction on the length of travel, maybe it is half a mile or a 500 mile trip is possible with shorter refuelling times.

Carbon Intensity of Grid and eVTOLs:

An emission free vehicle should ideally not contribute to carbon emissions. The GHG emissions of eVTOLs are directly related to the carbon intensity of the supply grid. Currently city of London is still dependent to a large extent on fossil fuel to power its grid. Plans are in place to go fully renewable at some point in future, but not known when. As the renewable sources of electricity grow, eVTOLs emission efficiency in comparison to conventional fossil fuel powered road vehicles will grow.

Dependency on road based service:

Vertiports play a major role in the operation of eVTOLs. City of London will for sure have a couple of them, but for now, it is not known how many there will be and where. Although, most of the eVTOL designs so far have consideration for landing and take-off from unprepared and unconventional landing pads, it is not proven by means of tests, validation and certification. Therefore, dependency on road based transit transport services from and to the vertiports is almost certain and this adds to the emissions of overall eVTOL operational emissions, which might never be completely eliminated. The fact that, from the point of origin of journey to the point of final destination needing some kind of land based transit service partially fails the purpose of its intended service.

Batteries, better be good:

It is the very early stage in the evolution of the battery powered vehicle world. Battery operated electric vehicles in commercial use have been around for about a decade and eVTOLs are still in the conceptual stage. With BEV's numbers growing on road and if the eVTOLs takes to skies as predicted, demand for batteries will only increase. eVTOLs require several times more power in comparison to BEV's for the same pay load but provide the luxury of shorter travel time. Battery and battery technologies will be a limiting factor for the positive evolution of eVTOLs as air taxis due to elevated demand for power in short hop city rides. Better battery technology might increase energy density of the batteries, but will certainly be more demanding in terms of the minerals used in the construction. Either ways, the demand for minerals such as lithium will only increase with increased use of battery operated land or aerial vehicles. Sadly, neither the eVTOL developers nor local authorities have clearly shown path for effective recycling or second or further life for battery minerals. It is hoped that legislations will be put in place for the eVTOL operators to provide a road map for end of life of batteries.

Composites - the right material?

Tokyo, 2nd Jan 2024, Japan Airline's (JAL) A350 burnt for almost 6 hours after collision with a patrolling Bombardier Dash 8 (Leussink & Sugiyama, 2024). Does this ring any alarm bells, is it an eye opener or is it just another plane crash gone into the history books. Airbus A350 is at least 50% thermoset composite made. Composites are combustible material provided the right environment. All of the 367 passengers and 12 crew members were rescued, given the mishap was in an airport where fire fighting is expected and prepared for. Had this been in a remote area away from any sort of rescue support, one can image the chaos and causalities it could have caused. Investigation has not yet proven the actual contribution of composites to huge fires, but major role of thermosets cannot be eliminated. This incident has raised many questions regarding the build material for flying objects. This concern should be addressed by the eVTOL developers as they plan to make 70% of the aircraft to be composite made.

Wind turbine industry has been facing the backlash since decades from the media, environmental organisations and administrations regarding its inefficiency in recycling composite blades. The blades are being piled up in landfill creating secondary environmental issues. Wind turbine industry is still to find a viable solution to composite disposal problem. This could be the fate of the eVTOLs, making them less sustainable and far less eco-friendly if composites end of life fate is not clearly planned.

Current research provides an important first basis for assessing the sustainability of eVTOLs for air taxi use case for cities of the likes of London. In an ever changing world of rapid innovation and high end technologies, especially in the flying car space, eVTOL could emerge way too differently than the current assumptions in this research, which can alter the findings of the current research by varied proportions. Current research does not fully encompass all the factors defining the eco-innovation appeal of eVTOLs and further research is essential once there is more clarity and data available regarding the material selection, design, supply chain, manufacturing processes and disposal.

Finally, eco-innovations are expected to be green and sustainable from sourcing of raw materials to disposing off the product at end of life, not just during its operational life. eVTOLs in their current state of their design do not completely satisfy the eco-innovation frame work with several open ended questions, they have to go that extra mile to achieve sustainability.

It would be right to say eVTOLs will not replace the existing mobility solutions but is expected to take a pivotal part in the urban mobility. eVTOLs will also have to prove their feasibility as viable future air transportation for UAM option not just from the point of sustainability but also from the point of satisfying regulations, consumer and societal acceptance.

More Questions than Answers:

Current study, rather than providing evidences to the eco-innovation nature of eVTOLs, has raised several questions, which needs answering for their successful acceptance as viable UAM solution.

1. Are eVTOLs creating a separate niche market for themselves in an attempt to substitute road trips? This is a very serious question as this world does not need more modes of transportation than there already are, but needs more efficient modes in existing transportation.
2. What is the price mankind is paying to solve decongestion issue by going for eVTOLs?
3. London taxi statistics for year 2021 shows the average number of trips taken per person by taxi or PHV was 7 and the average distance travelled per person by taxi or PHV was 34miles and the trend is reduced taxi or PHV travel year on year (National Statistics, 2023). Does this indicate the taxis in future will not be a popular means of commuting in London? Would air taxis make a real difference in these numbers, considering the ease of utility issues they have?
4. What is the effect or eVTOLs on urban vegetation and wild life, which are already in danger due to increased air and noise pollution?
5. Would a couple of thousand eVTOLs over London skies be any noise annoyance? Should noise pollution and negative impact on urban ecosystem be accounted towards eco-innovation negative externalities?
6. Is the eVTOL industry prepared to handle the mammoth supply chain challenge and related sustainability issues should demand soar?
7. Does changing work culture of working from home and hybrid working have a detrimental effect on eVTOL UAM dream?
8. What plans does City of London has in the coming decades for greener London:
    8.1. Any Green Neighbourhood and cities plans, programmes from the govt of the UK or London council, similar to Finland's DigiEcoCity project (Sitra, n.d.) and Sweden's Hammarby Sjostad eco-neighbourhood (Ignatieva & Berg, 2014)?
    8.2. London city public policy for now and future, towards green, low carbon initiatives. Would eVTOLs blends and gel well within those plane?

Not all innovations in the world have had a successful end, but some have failed to meet their design intent for several tech and no tech reasons. Supersonic jet Concorde would ferry passengers from London to New York in under 3 hours is now collecting dust in museums as they were too loud and dangerous. World's so called cheapest car the TATA Nano is nowhere to be seen on roads now, as they failed to entice common man due to poor quality. Google glasses believed to be tech marvel were actually banned from use in public due to them being considered as spy devices and utter distractions. Hoover boards and e-scooters are banned on public roads and believed to cause more harm to humans than help. It is not to say eVTOLs will meet the same fate, but it is too immature for now to say with a level of certainty and confidence on how successful they can be as eco-innovations. Technological advances combined with innovation ideas have always surprised mankind in unthinkable ways. World will have to wait to see how eVTOLs would emerge as air taxis.

Possible alternative solutions to the question of congestions in urban area:

a. SkyCab Personal Rapid Transit (PRT) system can be a better alternative to eVTOLs in many ways.
b. Congestions can be handled by decentralisation of industries, govt offices, facilities, high density public gatherings.
c. Encourage and incentivise walking and cycling. Create separate cycling lanes.
d. Encourage car pooling/ride share, penalise based on size and occupancy of vehicles.
e. Encourage and incentivise use of mass transportation such as busses and trains. A single bus, as big as 4 cars foot print and of 40 passenger capacity can in theory, effectively, reduce 36 single occupant cars off the road. Current cost of public transportation in London generally puts public off, cost optimisation is the key.
f. Encourage and incentivise working from home and hybrid working where possible.
g. Avoid non-essential travels, optimise essential travel, and switch to walking or cycling for short journeys.
h. Optimise working around the clock to calm down rush hours.

Recommendations and Further Work

eVTOLs are new to the world and there is more speculation than data in hand for research. Current research has only laid a corner stone in evaluating eVTOLs as eco-innovations and there is so much to be researched now and in future as the eVTOLs evolve as practical mobility solutions. Current study focussed primarily on gathering data and analysing for the city of London. By no means, London can be a standard benchmark for the rest of the highly populated and congested cities in the world. Dynamics of cities such as Beijing, Bombay and Tokyo is very different to London. A wider study is needed to understand the feasibility of eVTOLs as air Taxis for other major cities in the world to paint a better picture.

An attempt was made to compare the eco-efficiency of eVTOLs over their road based counterparts such as ICEV and BEVs based on currently available data. There are several conceptual urban mobility solutions such as the SkyCab, Self-driving monorail Pods, Smart Pods, Google invested Shweeb human-powered PRT, claiming to be more eco-friendly and sustainable. Some research into a comparative study of eVTOLs with these will benefit researchers in understanding the relative advantages or disadvantages.

Literature review indicates most eVTOL developers have turned a blind eye towards the end of life considerations of eVTOL build material, especially the batteries and composites. Current study considered only the City of London and only up to 10% substitution to regular road trips to evaluate the impact on end of life, but did not quantify in detail the ecological impact due to lack of availability of numerical data. Emissions indices published by (Ashby, 2012) indicate that the carbon emission of material incineration is by one order of magnitude smaller than the carbon emission of material production. Also, the carbon impact of material production is by one order of magnitude smaller than the carbon impact of operation in the air taxi mode. The impact of incineration on carbon foot print is thus tiny in comparison to the operational impact. It is much worse with batteries as the secondary or final life cycle of battery minerals is still unclear. Nevertheless, from a sustainability point of view EoL should be much more than just incineration and landfill. Further research and structured study is needed in understanding the EoL impacts and environmental issues of eVTOL materials.

Current research chose LCA as a tool of assessment for the evaluation of eVTOL as an eco-innovation. Intent was to acquire by way of digital and documentary source survey as much data as possible for eco evaluation. This proved to be a baseline study only in the evaluation of innovation. There are several other widely used tools for environmental impact assessment, such as Ecological Footprint analysis, Material flow Analysis, Environmental Risk Assessment. One or more of these tools can be utilised to further asses the eVTOLs for the air taxi use case environmental impact assessment.

Only few of the components from within the lifecycle of eVTOLs were considered for current research. Carbon impacts due to the design efforts, distribution, maintenance, transportation between the lifecycle elements, reuse and redistribution is equally necessary to obtain a holistic view of eVTOLs’ eco performance.

Following are some of the recommended areas of research that can be carried out both to further enhance our understanding of the eco efficiencies of eVTOLs and to find parallel or alternative techs and solutions for urban mobility /decongestion: some of these are more technical than other.

- Conduct a comparative study between eVTOL as air taxi and SkyCab PRT on their relative carbon impact.
- Assess practicality of engineered bacteria to recycle critical minerals from EV batteries (imeche, 2023) to minimise battery EoL environmental implications.
- Hydrogen fuel cell systems as solution to eVTOLs' sustainability as Air Taxis.
- Utilisation of Battery and Hydrogen fuel cell hybridization technology for range extension and reduce downstream emission (Ng et al., 2021).
- Carbon impact related to manufacturing and disposal of electric motors for eVTOL use.
- Quantification of emissions related to manufacturing, operation and maintenance of vertiports, including their lighting, charging ports, maintenance hangers, and transit facilities to commuter hubs.
- Comparative study of Ultra low emission propulsion systems – reduced emission/green rotorcrafts and eVTOLs for air taxi use.
- Electrical helicopter v/s eVTOLs as air taxis
- Carbon emission from eVTOL mass production processes such as parts production, transport of parts, assembly, machining, composite manufacturing, paint shop, trims and finishes, etc.
- Systematic Statistical study to obtain optimum percentage of traffic diversion into air taxis – from a sustainability point of view.
- Detailed mathematical modelling and evaluation of decongestion to assess the viability of Air taxi use case for the city of London.
- Study on effects of eVTOLs producing higher downwash (CAA, 2023) and out wash on the urban lifestyle, acceptance and wildlife for the air taxi use case.
- Study of commuter behaviour change in the recent years, especially after Covid and study of modern trends in urban move around and its effect on future travel options such as eVTOLs.
- Explore alternative and greener battery technologies for eVTOLs such as:
    - Zinc based storage batteries such as Zinc-air,
    - Sodium-sulphur
    - Nickel based- alternative to lithium
    - Nickel – Cadmium
    - Non-conventional material technologies:
        - Graphene & Saltwater based AquaBattery (Fildes, 2018)
    - Combination of above battery technologies for better emission and EoL yield.
- Study of Bio composites or composites with biodegradable matrix or natural fibres as potential green option to classic thermoset composite for eVTOL application.
- Study of some of the main areas of concern in eVTOL commercial use: use as armed drones, safety concerns, privacy concerns, elitism, environmental irresponsibility (noise and battery lifecycle costs) and ethical considerations such as loss of jobs and fear of autonomy.

Current research focussed mainly on the eco-innovation aspects of eVTOLs in air taxi use case. Commercialisation potential of innovation is equally important for their success along with being eco-friendly and sustainable. Following is a list of areas of possible research to evaluate commercial potential, advantages and shortfalls of eVTOLs as air Taxis.

Primary parameters for research in evaluating the commercial practicality measurement of eVTOLs are listed below.

- Range of travel per charge
- Numbers of aircrafts required at a point in time, quantify requirement to assess airspace density
- Economy of travel (£/mile)
    - Vehicle charging cost
    - Maintenance costs
    - Pilots remuneration
    - Pilot training costs
    - Buy/lease options in comparison with classical modes of transport
- Infrastructure needs
    - Charging stations
    - Load on electric grid
    - Pickup and drop points
    - Parking, waiting, storage
    - Repair and Maintenance facilities
- Challenges related to flying at night
- Return on Investment and profitability – break even analysis
- Human factors
    - Willingness to fly short distances
    - Affordability and percentage of population that can afford
    - Human behavioural traits towards air taxis
- Law and legislation
    - How prepared are the urban travel authorities in the UK for air taxis?
    - Do we have legislation in place for air taxis? Speed, altitude of flight, no fly zones, designation of spaces for taxi stands, definition of routes and traffic control, licensing taxis and pilot licensing, definition of noise levels, limitation of number of operators and number of taxis.
    - Accidents, claims, insurance and preparedness of law and judiciary around these issues
    - Legislation for people with special needs
    - Fare control
- Airworthiness certification challenges and when can they actually start taxi service?

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GLOSSARY

a/c – Aircraft

AAM – Advanced Air Mobility

BEV / EV – Battery Electric Vehicle / Electric Vehicle

CFRP – Carbon Fibre Reinforced Plastic

eSTOL – Electric Short Takeoff and Landing

eVTOL – Electric Vertical Takeoff and Landing

EASA – European Union Aviation Safety Agency

EFC – Equivalent Full Cycles

EoL – End of Life

GHG – Green House Gases

LCA - Life Cycle Assessment

CIS – Community Innovation Survey

ICEV – Internal Combustion Engine Vehicle

ISO - The International Organisation for Standardisation

JAL – Japan Airlines

LCI - Life Cycle Inventory Analysis

LCIA - Life Cycle Impact Assessment (LCIA)

Li-ion – Lithium - ion

NASA – National Aeronautics & Space Administration

ODM – On Demand Mobility

OECD – Organisation for Economic Co-Operation and Development

PHV – Private Hire Vehicles

PRT – Personal Rapid Transit System

Type Certification – Airworthiness certification of a new aircraft or its sub-assemblies

TOL – Takeoff and Landing

UAM – Urban Air Mobility

VTOL – Vertical Takeoff and Landing