Noise in sustainable transition of aviation

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ABSTRACT

Aviation noise emissions are coupled to air transportation system development, including its on-going transition to reduce CO2 emissions, and introducing advanced air mobility (AAM) and urban air mobility (UAM). Noise is still treated as an externality despite increases in community annoyance complaints and growing evidence of noise effects on health and well-being. The study identifies noise issues in on-going transitions of aviation and shows how sociotechnical aspects influence aviation noise. A system analysis based on interviews from a wide range of stakeholders reveals socio-technical aspects of aviation noise. Climate goals drive initiatives to accelerate aviation's sustainable transformation. Electrification and sustainable fuels are seen as solutions that simultaneously allow the aviation sector to grow and achieve transportation goals. Accessibility and mobility goals support development of AAM/UAM systems especially targeted to regional and urban transportation challenges. Noise correlates to the amount of traffic and annoyance is anticipated to increase with numbers of exposed citizens and introducing new sound sources in an urban context. Noise should be factored in already in the design of future solutions to mitigate effects on health and well-being, but also to maximize societal benefits from aviation allowing conditions for realizing innovation which otherwise risk be restricted.

1. INTRODUCTION

Engineering systems [1] is a field that studies the increasing and added complexity in our technology and systems that has grown over time in both scale and scope. Systems have evolved from artefacts like cars, light bulbs, and telephones to systems for transportation, energy, and communication. Today these systems are also becoming intertwined with each other, forming engineering systems. The benefits of their core societal functions are undisputable. Engineering systems have in general solved societal problems and met human needs in societies. However, today, many of these systems have lost control over biproducts and unintended consequences, which today manifests as downsides for humans in societies globally as well as locally. Now threats of climate change have reached a point which is pressing for urgent change. Transportation, including aviation has evolved, over time, and still brings essential core functions and value for individuals, businesses, societies, and nations. There are therefore strong interests in responding to this change with maintained and even improved accessibility and mobility as well as growth for businesses and communities.

There is an on-going transition of aviation with a clear objective to reduce its carbon footprint. In 2022 aviation accounted for 2% of global energy-related CO2 emissions [2]. Aviation also has a noise

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footprint. However, on a global scale CO2 reduction has precedence over noise. Perhaps noise is still in general considered a mere nuisance or disturbance. Still, noise is the "most significant cause of adverse community reaction related to the operation and expansion of airports" [3] not CO2. In recent years there has been an increased awareness of noise and its severe effects on health and well-being on large portions of urban population [4].

Aviation noise has been an issue since the dawn of aviation [5]. According to [5] the first airport noise case was brought to court in 1928. The paper is from 1977 and warns that "disturbances caused by such noise not only adversely affect those who live or work in the vicinity of airports serious as this is but, unless solved or substantially ameliorated, the problem also threatens to stifle the development of air commerce itself" [5].

There is also an emerging new industry in aviation, introducing several drone concepts [6]. Advanced Air Mobility (UAM) and Urban Air Mobility (UAM) concepts come with promises of solutions to another pressing challenge on a more local level – urbanization. Our growing cities need increased mobility and accessibility but are suffering from road traffic emissions and congestion. Private cars and vans were in 2022 responsible for 10% of the global energy-related CO2 emissions [2]. There are already high-level strategies in place assuring that infrastructure for AAM and UAM is provided for [7]. Yet, after safety, noise is considered as the top concern for integrating UAM. Like the early warnings of stifling air commerce [5], the same concern could be relevant for UAM. And, more importantly, with respect to citizens' health and well-being, there is already a concern for introducing new noise sources to an already noisy urban context.

Clearly, aviation noise footprint has still, today, not gotten anywhere near the attention its' CO2 footprint gets. The background for this paper origin from research resulting from the establishment of KTH Centre for sustainable aviation [8]. This center came about due to a settlement after a community complaint to Arlanda airport. The objective of the center has been to conduct research with the objective of reducing noise around Arlanda airport. After almost 10 years of research and some 17 projects, there are challenges to argue for opportunities or conditions under which results from this research could have real impact on noise reduction. One reason being that aviation is a mature infrastructural system. Known characteristics of these are stagnation and resistance to change due to complex networks of actors and other sociotechnical issues [9]. This paper will analyze the on-going developments in aviation, both in commercial aviation and future drone systems of UAM in relation to noise.

Models explaining goal driven transitions in sociotechnical systems will be used to explain driving forces, trends and challenges for various problem formulations and solutions. The approach taken is to use the multi-level perspective model [9] developed from case studies describing sustainable transitions [10]. This model describes stakeholders' interests at multiple levels. The macrolevel, called landscape, together with the microlevel, called niche of technological innovation, put pressure on the mesolevel, called the current sociotechnical regime. In a system analysis, system perspectives can identify representing technology development on a niche level, a sociotechnical regime of current stakeholders and a needs or goal driven landscape pressure. From such analysis, prospects for reducing aviation noise and annoyance will be discussed. Two cases will be analyzed. Current commercial aviation and future aviation like AAM/UAM. Each case will be discussed from perspectives of problem formulation, on-going technology and industry development, solutions with respect to climate, transport, and noise. The analysis will inform and explain conditions for mitigating and managing the noise in sustainable transformation of aviation.

The purpose of this study is to identify sociotechnical aspects influencing aviation noise.

RQ. What are noise issues in on-going transitions of aviation?

2. METHOD

From a systems and engineering perspective, best practice was applied by performing a system analysis and frame problems sufficiently to assure understanding of what choices are being made, what is prioritized and why. This paper is based on two case studies, one from commercial aviation context and one from on-going development plans for integrating and implementing UAM.

2.1. Interviews, workshops, and documents

The case studies were based on data collected through interviews, workshops, and documentation from stakeholders in the air transportation system. The projects had a broad approach that continuously engaged stakeholders through discussions and interviews with representatives from the Swedish Transport Administration and Agency, Arlanda airport, citizen noise organization, the City of Stockholm and its Region, the Swedish Environmental Protection Agency, air traffic service providers, and drone manufacturers' networks. Interviews have been complemented with studying webpages and public reports by the same stakeholders.

2.2. Re-visioning

The commercial aviation project identified challenges in managing the complexity of aviation noise to be messy and as a wicked problem [11, 12]. Wicked problem formulation is argued to require a "rich picture" [13] to allow externalities to be factored in already in design to avoid surprises with undesired and unintended consequences, even though there is no optimal solution to the problem.

In both projects a problem formulating method from engineering systems was used called re-visioning [1]. This approach to formulate the problem alternates between starting from a solution and defining the system as part of this solution or, instead, considering the problems or externalities this solution has and what features of the system that is associated with them. This approach has been suggested to capture problem areas from other perspectives than one stakeholder's own view. System (re)thinking entails twisting and turning the system and adopting different perspectives. A model supporting this rationale describes solution space, design space and problem space (Figure 1 and 2). At any point in analysis the perspective may alternate between these and will vary and contribute to a "richer picture" from which aspects of most relevance and leverage can be chosen depending on the scope of analysis. Solution space includes the system or concept in question, a solution to a particular need or problem. The surrounding design space includes alternative designs, potentially future designs or those abandoned in trade-off analysis. Solutions and alternative designs cause problems which are represented in nodes in the problem space.

A re-visioning of commercial aviation (Figure 1) was performed from three main network of problems associated to aviation noise issues [11]: 1. Neighbors exposed and annoyed by noise, 2. Service providers and operators challenged with development and innovation, and 3. Actors that govern and control air transport with respect to transport and societal goals.

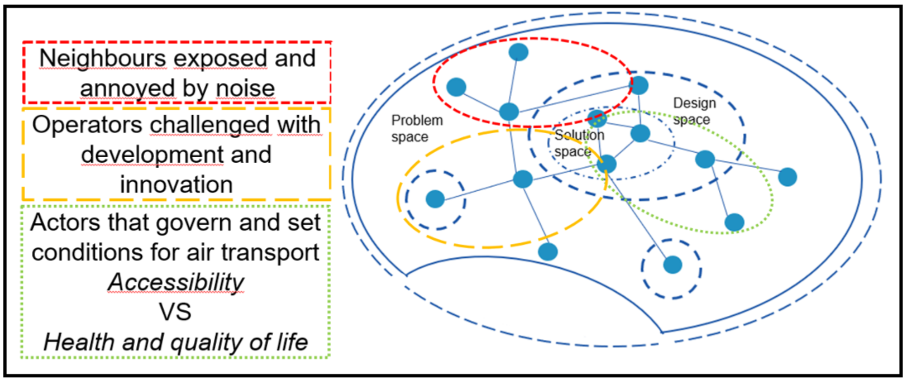

Figure 1: Network of problem formulations in commercial aviation [11].

A re-visioning of UAM development (Figure 2) was performed from three main network of problems associated to aviation noise issues [6]. 1. Stockholm citizens, 2. City (municipality) and regional planning, and 3. Service providers and technology developers and operators.

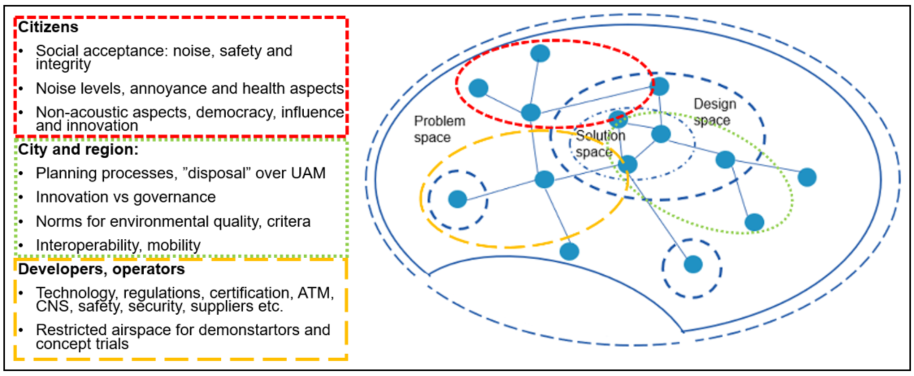

Figure 2: Network of problem formulations UAM development [6].

3. RESULTS

3.1. Noise issues in aviation

Noise is defined as undesired sound and aircraft noise is undesired sound from flights and airport operations. Individuals with the same noise exposure may not experience the same annoyance. For those that experience aviation noise disturbing and annoying, it can be experienced as a constant, ongoing, and intrusive problem, affecting quality of life [11].

The aircraft itself is the sound source. A common perception is that the engine is the dominant noise source on the aircraft and that noise is worst during take-off when the engine's thrust is high. In fact, take-offs expose relatively few residents close to the airport area for a relatively short time. The noise also decreases when the distance to aircraft increases. Aircraft noise exposure is perceived worse during approach and landing when the aircraft is flying at a relatively low altitude, and slower, which means exposing the residents for a longer duration at a shorter distance. Here the noise increases as it approaches and peaks while passing. During this phase of the flight, it is not the engine that is the main sound source, but the airframe. The aircraft body is developed to create as little air resistance as possible during flight in order to increase flight performance and reduce fuel consumption. For common commercial aircraft, the airframe may even produce more noise than the engine above about 200 knots. During approach and landing the aircraft need to lose energy and reduce speed. Brakes consist of flaps, slats and not the least, the use of lowering the landing gear. Engine sound reduction is not effective here!

Regulators encourage aviation stakeholders to implement the Balanced approach framework [14] in efforts to manage aviation noise issues. It consists of four areas:

1. Reduction of Noise at Source - demand for quieter aircraft in the future, differentiated take-off fees.
2. Land-use Planning and Management – airport placement and design of airspace and flight paths both laterally and vertically (while maintaining safety and fuel-emissions)
3. Noise Abatement Operational Procedures - noise isolation and physical planning
4. Operating Restrictions (at last resort), for example, restriction of aircraft types, runways in use, and operational times of the day.

If the problem formulation is focused on engines the solution is framed quieter engines. ICAO imposes noise requirements on aircraft manufacturers and there is some improvement, in the order of 0.1 dBA/year [14]. By developing quieter engines and gradually phasing out older models, the noise from individual aircraft can be reduced. If the annoyance of people is the problem, one solution is to try to fly around. This moves the noise away from those annoyed. However, depending on the surroundings, new citizens might become exposed. Obviously, aircraft noise disappears if we stop flying and if we stop flying to inhabited areas, which makes no sense given the role aviation has in our societies. Operationally, aircraft noise footprints can be reduced by applying various methods that increase the distance between residents and the aircraft. Three methods are operationally and technically feasible [15]:

1. increased glide path angle (fly in higher and land steeper and closer to the airport)
2. moving threshold (fly in higher and land further into the runway at the airport)
3. curved approaches (increasing the distance to targeted residents by flying around an area).

It is also possible to reduce exposure to existing aircraft noise by protecting individuals and their indoor and outdoor environment, measures at receivers (earplugs, headphones, soundproof houses (windows, walls and roofs), building options (quiet houses and yards) and noise ceilings/fences.

In terms of physical planning, vulnerability can be reduced by not building housing close to airports. For example, there are plans that apply to the entire Arlanda region. In 2015, 137,000 people lived in the Arlanda region, and now it is planned for 175,000 inhabitants by 2030. This applies to Arlanda's neighboring municipalities.

Finally, we can reduce aircraft noise by flying less frequently over residential areas or by only flying at certain times, what is known as flight restrictions. This also includes restrictions for certain aircraft types and runway usage patterns.

Sound perception is sensitive to reacting to sudden or rapidly approaching sounds. Airplane noise is intermittent, coming and going. A continuous sound is easier to ignore. The wider the spectrum of a noise, the more people react to it, unusual noise can trigger a stress reaction and repeated sounds are more difficult to accept than single ones.

An example of noise management issues comes from Boston Logan airport [16] where precision flights were seen as a means to increase capacity at the airport. However, this also increased the precision of noise. Precision flights gave rise to an increased number of noise complaints for those who now received more concentrated noise. In Boston, they experimented with "fair" noise distribution, what in numbers look fair, however, those introduced to aviation noise reacted strongly.

There are also non-acoustic factors [17][18] that affect the degree of annoyance from aviation. At a very basic level it concerns individuals' experiences and feelings such as anger, control, fear, justice, trust, and satisfaction. These are governed by, among other things, perceived transparency, communication, predictability and respect from system builders and decision makers during planning processes. Good examples of how to reduce the degree of annoyance are local job offers, compensation, noise measures and forums with influence over planning. There is an increased emphasis on citizens' quality of life presented through the European green deal [19] which also puts emphasis on democratic processes. In summary, it is expected to become a challenge to come up with strategies that citizens agree on.

3.2. Health issues noise and annoyance

In the latest WHO report, with guidelines [4] it is recommended that the average value of aircraft noise be reduced to a level below 45 dB Lden, as noise above this level is associated with serious health effects. Furthermore, it is recommended that aircraft noise at night be reduced to 40 dB Lden for the same reason. According to the design of the guidelines, these recommendations are classified as "strong" and are thus considered to be applicable in policies by decision-makers in most situations. WHO assesses that the recommendations outweigh the unwanted consequences, which these guidelines would mean for e.g. business and society. WHO's new guidelines are below the guidelines around most airports.

A health effect of noise exposure is disturbed sleep and long-term exposure also increases the risk of heart and vascular diseases [4][23][24]. “In total, it is estimated that 395,000 people, corresponding to 17.7 percent of the county's population, are exposed to noise levels from traffic (road, rail or air traffic) that exceed 55 dB LAeq, 24h. If one instead starts from the WHO guidelines, which are stricter than the Swedish guidelines and set solely from a health perspective, it is estimated that 926,000 people (corresponding to 41.6 percent) are exposed to at least one noise source at home" [24]. It has also been shown that noise masks speech and can have effects on cognitive abilities. High levels of noise can affect hearing and be a contributing cause of tinnitus. Those who are disturbed by noise can become stressed because they feel that quality of life and mental health are negatively affected.

3.3. Strategies for future aviation

Although the aviation industry is undergoing a large transition to more sustainable fuels and electric aircraft the environmental impact from noise is not expected to decline. At a recent governmental hearing for the investigation of the future of Arlanda [11], it was made clear that not only current but also future aviation industry is still anticipating and planning for an increase of air traffic world-wide.

Linked to aviation sustainability transition, drones have potential for a future fossil-free transport economy, enabling sustainable mobility [6]. In the near future, 5-10 years, the aviation industry envisions that existing aviation will be supplemented with a national transport system in the lower airspace with drones for freight and taxis. The European Union has defined a service-oriented architecture to provide air traffic management for drones, called U-space [20]. New services intend drones to fly from point to point instead of airport to airport. Depending on airspace and flight procedural design both expansion of current traffic and introduction of drones will have implications on noise propagation, exposure, and annoyance from air traffic.

Despite the lack of a UAM concept for Stockholm there is plenty of evidence that this development is on-going and there are grand visions for UAM: "In 2045, fossil-free, fast, simple and cost-effective transport is a concrete reality. There is a nationwide fossil-free transport system for goods and people with electric and hydrogen-powered drones in the lower air. Taking drone taxis between different neighborhoods and cities is a reality" [21].

The Swedish government have issued assignments for Swedish transportation agency and administration to support and facilitate drone development.

3.4. Climate goals and transportation goals

The on-going sustainable transformation of fossil-dependent transportation has a necessary and strong influence on innovation. Most initiatives are directly set to reduce carbon emissions. Goals are set at a global level driven by UN's sustainable development goals (SDGs) that are broken down to goals formulated at lower levels like for example in EU strategies and then followed by national strategies and research policies.

The city's planning and development follows national goals, strategies, and plans which in turn are aligned with EU ambitions and based on UN's SDGs. The global goals derived from EU and UN SDGs and although local environmental quality is emphasized, for example int the "Green deal" [19], climate seems to be prominent.

The Swedish Government's policy goals for transport and climate are that "by 2030, emissions from domestic transport (excluding aviation) shall be reduced by 70 percent compared to 2010, with zero net emissions by 2045. The vast majority of Sweden's domestic carbon dioxide emissions from transport, approximately 93 percent (2017), come from road traffic. As road traffic constitutes around 85 percent of passenger transport work and 50 percent of freight transport work, the inescapable conclusion is that the main way to achieve climate goals is fossil-free transport" [22].

The overall goal of the transport policy is "to ensure a socially efficient and long-term sustainable transport supply for the citizens and businesses throughout the country". The functional goal states "the design, function and use of the transport system must contribute to providing everyone with basic accessibility with good quality and usability, as well as contribute to conditions for development throughout the country. Lastly there is a category of goals to ensure consideration of citizens and their local environment. The consideration goal states, "the design, function and use of the transport system must be adapted so that no one is killed or seriously injured, contribute to the achievement of the overall generational goal for the environment and the environmental quality goals, and contribute to increased health". One significant environmental factor that affects health and quality of life negatively is noise. More and more people are disturbed by noise, above all from road traffic, trains, and aviation, but also from neighbors and fans. The residents of Stockholm's inner city and those who live near airports suffer most.

One goal is an accessible region with a good quality of life with sub-goals such as:

- At least 22,000 homes should be built each year.
- Travel times between regional cores and Airport should be competitive with car travel times.
- The percentage of the county's inhabitants who experience disturbances caused by traffic noise and poor air quality should not increase.
- At least 95 per cent of new settlements should be built in the region's most accessible locations.

The four top challenges expressed by Stockholm region are:

1. Facilitate population growth while improving the region's environment and public health
2. Address capacity shortages while meeting growing needs
3. Become an internationally leading metropolitan region in a growing global competitive landscape
4. Reduce climate impact while enabling increased accessibility and economic growth.

3.5. Solutions driven by climate and transportation goals

National climate goals for transportation are putting pressure on transport stakeholders to desperately develop solutions that do not threaten their transportation goals. Similarly, cities are desperately developing solutions for their challenges with urbanization and mobility. Electrification and digitalization are argued to contribute to reaching these goals, for example by distance working, smart travel, electrical vehicles, and autonomous cars. By working from home, the aim is to reduce the overall number of travels. Smart travel applies digital tools to select travel off-peak hours to mitigate capacity limits in public transport and on the roads. Replacing fossil fuel cars with electric cars will reduce fossil emissions. Autonomous cars are anticipated to reduce the number of private cars and reduce congestion. Perhaps this logic has been applied to the planning of drones and UAM systems.

Aviation is not as successful in replacing its predecessor system function as in the case of electrifying road traffic. Electrified aircraft have significantly less range and cannot replace long-haul flights. Instead, a new aviation industry sees an opportunity to establish a fossil free transport economy based on drone concepts for advanced air mobility (AAM) and urban air mobility (UAM). These systems also rely on autonomous solutions for air traffic and unmanned vehicles, realized by a combined technological development in electrification and digitalization. It makes promises to reduce congestion, if implemented in full scale, and thus contributes to increased mobility [6]. Being fossil-free it is also claimed to contribute to reducing carbon emissions, since it is assumed to replace fossil-driven transportation [6]. Another common justification for advantages with electrification is a claim that these vehicles are less noisy. It is perhaps easy to reason that starting up a regular car engine sounds wroom, wroom but an electrical car engine does not. Then, must not the same be true for electrical airplanes and drones?

3.6. Noise from electrified vehicles

In the regional plan [25] the problem with noise and emissions from road traffic are "estimated to be able to decrease somewhat in the medium and long term thanks to technological development, for example through increasing elements of electrification". The logic behind this statement is not further explained but may be questioned. Reducing the number of cars and reducing the speed limit could reduce noise emissions from road traffic, but electric cars are not silent. They are silent or almost silent below 30-40 km/h [26] but the friction against the road is the main sound source around 50 km/h [26][27].

For this logic, even if it is a misconception assumes that noise exposure from transport is derived from its' fossil burning engines. As already mentioned, noise exposure may be more prominent during approach and landing and then the engine is not the main sound source. The same aerodynamics applies to electric aircraft. An aircraft engine can be powered by electricity but still have propellers or turbines to create thrust. This means that aircraft noise is not necessarily reduced with electrified aircraft [28]. The heavier the aircraft, the more it makes more noise as more lift is needed and it also makes more noise during braking during approach and landing. Problems with aircraft noise may increase as you may have to compensate for reduced capacity as electric aircraft are smaller (10-20 passengers) and may then have increased frequency on take-off and landing [28]. There is still uncertainty about what the entire fossil-free aircraft fleet will look like. It is uncertain how the aerodynamics of new models will be (wing profiles and body).

At this point, no one knows what the future noise exposure from UAM will be, and how annoying it will be perceived. This is partly due to the lack of explicit UAM concepts specifying drone traffic, including fleet composition and size, airspace design, and dominating noise characteristics [6[[20]. Considering that drones are planned from point to point in an urban environment a new social group will be exposed to, and potentially annoyed by, drone noise. In UAM it might be possible to randomize noise even on regular routes to spread and share the noise among many, to avoid reaching the annoyance threshold of a particular group or area. Managing noise from drones and UAM is critical for their acceptance in society [6][29].

4. ANALYSIS AND DISCUSSION

How climate change takes place in various sectors such as transport and energy is being studied in the field of industrial dynamics. A common model in sustainability case studies [10] is called the Multi-Level Perspective (MLP) [9]. The model consists of three levels: macrolevel, microlevel, and mesolevel. The macro level is called the socio-technical landscape and is defined as the system's external environment. The landscape level is outside the direct influence of the system's stakeholders but stimulates and exerts pressure on both the stakeholders and the system as a whole. At the landscape level, the general development of society is reflected, often according to deep-seated cultural patterns and political logic. The microlevel is called the niche level and here technology and knowledge development take place by various innovators. It is at this level that potential innovations can emerge, which change the system. Niches are described as a protected environment without the usual competition, to avoid good ideas being knocked out early before work height or critical mass has been achieved. The mesolevel, in between the others, consists of the socio-technical regime. This regime tends to stabilize the existing regime. It can be perceived as the regime "defending" the existing system. This corresponds to large technical systems and the momentum present when mature and in a stagnating phase [30]. All interwoven, this is usually referred to as the prevailing socio-technical regime (Geels, 2004). This is usually divided into different sub-regimes: technical regime, socio-cultural regime, market and user regime, and policy regime. It says something about what is included: laws, regulations and guidelines, policy and political direction decisions, methods and models, social relations, culture and different knowledge and expertise, technical systems and standards. What makes the system robust, but also sluggish, is that the various parts of the regime have developed together with built-in and intertwined dependencies and relationships between people, groups, various functions and roles in constituent institutions, such as businesses and authorities. The current regime sets the overall rules of the game for the system.

4.1. Sociotechnical aspects influencing aviation noise

Conditions for innovation are created by changing the established regime and adapting it to partially new rules of the game. According to MLP, this change is initiated by pressure being exerted from two directions, from the macro- and microlevel, together creating a crack in different parts of the regime at the mesolevel. With the necessary landscape pressure and demonstration of technical potential, the regime can open up for a change. In table 1 the main drivers for sustainability, transport and urbanization challenges are divided into the three levels in MLP including the main development providing what is argued for solutions.

Table 1. Main drivers and trends on the macrolevel, mesolevel and microlevel

Landscape	Global climate goals
	Global innovation policies
	National climate and transportation goals
	National innovation policy for industrial and export growth
Regime	Government agencies and airport are accountable to reach their operational targets aligned with their assignments
	Government assignments have been issued to facilitate development of drones (Swedish transport agency and administration)
	Stockholm region and city are accountable to reach their goals
Niche	Development of ATM technologies and infrastructure
	Development of electrofuels and hydrogen
	Electrical aviation entrepreneurs
	Technologies for autonomous vehicles, including drones

Within the regime there are at the same time challenges and goal conflicts. For example, a municipality has dual responsibilities with urbanization that requires housing, transport, mobility, businesses, and work opportunities etc., and at the same time they need to show concern for their citizens' environment and promote health and well-being.

4.2. On-going transitions in aviation with noise issues

National strategy aims to increase air travel and develop Arlanda airport. Regional development plans include building houses in municipals surrounding Arlanda airport. Plans are made to increase accessibility to and from Arlanda to facilitate municipal and airport growth.

Noise increases with the number of flights. Planning for expansion of the airport and increased traffic will produce more aviation noise. Arguments to justify these initiatives are described and discussed below. The government issues new assignments to agencies in terms of operational goals or to actively support change in one specific direction, for example through national strategies and policies.

Future airplanes will be larger and less noisy?

The statement of larger and less noisy aircraft was made when the governmental agency for transport presented revised noise curves surrounding Arlanda airport. No research references are made for this claim. This statement could be based on information based on data from studies of reduction of engine noise and logic that larger planes could become fewer with maintained capacity. The expected noise reduction could have an impact at the airport during ground operations, taxiing and take-off, but less during approach and landing. With the introduction of electric aircraft, airplanes will be smaller and compared to larger aircraft they will be less noisy. Compared to an aircraft with similar weight during approach and landing it will not. Due to expected size, the number of flights might increase to maintain capacity using electric aviation. Another aspect that needs to be considered is the use of propellers which will reduce the noise effect during taxiing and take-off.

Future aviation will be electrified and less noisy?

Politicians have stated this, and it is also implicit in strategy documents. No reference to noise studies is made. This argument could be based on a misconception that electric engines are silent and hence, with the rationale that engines are the main aviation sound source electrical aviation will be less noisy. With the introduction of electric aircraft, airplanes will be smaller and compared to larger aircraft they will be less noisy. Compared to an aircraft with similar weight during approach and landing it will not. Due to the expected size, the number of flights and noise might increase to maintain capacity using electric aviation. Another aspect that needs to be considered is the use of propellers which will affect noise during taxiing and take-off.

Precision flights and curved approaches will allow flightpaths to avoid populated areas.

Arlanda airport's environmental permit is based on a third runway and planned implementation of curved approaches by 2018. For reasons not entirely up to Swedish actors it was not. The new runway was opened without new procedures and citizens in "Upplands Väsby" found themselves living right under the approach for the new runway. When precision flights are implemented at Arlanda, these people will experience less noise. Still, this will move the noise, and this will introduce noise to others. However, with precision flights it is an option to develop routes with "fair" noise distribution.

4.3. A need for a niche that verifies solutions for unintended outcomes

Clearly there are noise issues with these on-going transitions which means that goals of consideration of health and well-being will not be met. Within the model promoting sustainable transitions there is no level of nor category for trade-offs and unintended consequences anticipated from the suggested solutions. This could be represented by alternative landscape pressure and a special niche for development of ideas and solutions to mitigate noise and annoyance. The projects in the KTH Centre for sustainable aviation represent alternative proposals for noise-reducing solutions and concepts that can reduce problems with aircraft noise through increased understanding of measurement and calculation, including methods for managing wicked problems. Methods for handling complex social problems could be one such area of development.

5. CONCLUSIONS

This extended problem formulation shows wicked issues with aviation noise. In earlier reports [11][12] wicked issues and several dilemmas with reducing aviation noise were identified. Inevitably, the future development of aviation will come with changes that affect noise. With some changes the noise exposure might shift to new groups of citizens being introduced to aviation noise. This calls for proactive development of improved noise annoyance mitigation methods [31], including non-acoustic aspects [17][18]. This study adds to earlier research the on-going development for UAM. Although some issues are similar, the UAM case differs in a significant way. The UAM system is not yet established, and there is still time to factor noise in, in integration and implementation of UAM to cities. Further justifications for its importance may be needed. Arguments could be strengthened with further research on drone noise exposure and footprint during different flight phases, depending on aircraft design etc., simulation of UAM traffic and noise in "what-if" concept of operations, regulatory guidelines for drone type of sounds, approaches for cities' innovation and implementation that maintain governance and disposition of "its" airspace.

With increased traffic and buildings closer to airports, noise complaints around the world have become more common [6]. If noise and annoyance is not sufficiently taken into account, there is a risk that the realisation of innovations with potential to meet human and societal needs will be delayed by lock-ins or even blocked in planning processes. There is a need to maximize benefits of current and future aviation while minimizing its costs.

It is clear that noise issues are not considered as an essential boundary requirement by the main stakeholders in the system. None of the central actors is individually intentionally causing undesired consequences. But all involved actors are responsible for producing aviation noise. Strategic and political decisions are embedded in the missions of various authorities and the goals of operations. These need to explicitly include noise. Noise needs to be factored in already in design of future concepts and developments to avoid surprises with undesired and unintended consequences from a sustainable transition of aviation.

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REFERENCES

1. de Weck. O.L., Roos, D. and Magee, C.L., (2015) Engineering Systems - Meeting Human Needs in a Complex Technological World, MIT press.
2. IEA https://www.iea.org/energy-system/transport/aviation
3. ICAO https://www.icao.int/environmental-protection/Pages/noise.aspx
4. WHO (2018) Environmental Noise Guidelines for the European Region (2018)
5. Lesser Joseph (1971) The Aircraft Noise Problem: Federal Power but Local Liability. The Urban Lawyer, Vol. 3, No. 2, Symposium: Airports in the Urban Setting(Spring, 1971), pp. 175-205 Published by: American Bar Association
6. P. Ulvengren, U. Orrenius, U. Tengzelius, J-O. Ehk, M. Åbom (2024) UAM system integration system analysis and noise simulations in support of regional and city planning, in Proc. of the 2024 DICUAM Delft International Conference on Urban Air-Mobility, Delft, The Netherlands.
7. EC European Comission (2022). Drone strategy 2.0 - för ett smart och hållbart ekosystem för obemannade luftfartyg i Europa
8. Åbom, M., Bolin, K., Ulfvengren, P (2018) Air traffic management and noise. Proceedings Internoise, 2018, August, Illinois, US.
9. Geels F.W. (2004). From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory. Research Policy 33 (2004) 897–920.
10. Papachristos, G. (2011) A system dynamics model of socio-technical regime Transitions Environmental Innovation and Societal Transitions 1 (2011) 202– 233.
11. Ulfvengren, P. (2023) INFRA – system analysis of problem network associated to aviation noise and annoyance. KTH CSA/ INFRA - TRV 2016/15206.
12. Ulfvengren (2022) Wicked problems in an aviation noise system, abstract accept, INTERNOISE, 2022 Glasgow.
13. Churchman, C (1971) Design Of Inquiring Systems Basic Books, 1971 the University of Michigan ISBN0465016081
14. ICAO, 2004 Balanced approach (Doc 9829 AN/451) Regulation (EU) No 598/2014
15. Moberg, B., Rignér, J., och Ulfvengren, P (2014) Förstudie för metodutveckling för inflygningsprocedurer för minskat buller, RPT-2014-103.
16. Hansman et al. (2021) Block 2 Procedure Recommendations for Boston Logan Airport Community Noise Reduction, Report No. ICAT-2021-01 June 2021, Copyright © 2021 Massachusetts Institute of Technology. All rights reserved.
17. Porter and Monaghan (2021)Aviation Noise Management & Research: Reflections and Challenges in Light of the Pandemic. Anderson Acoustics Limited
18. Leylekian, Covrig, Maximova (eds.) (2020) Aviation Noise Impact Management Technologies, Regulations, and Societal Well-being in Europe. European Union's Horizon 2020, Springer, ISBN 978-3-030-91193-5
19. EC:s green deal: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal
20. U. Orrenius, U. Tengzelius, P. Ulvengren, J-O. Ehk, M. Åbom, Noise simulation for UAM integration- Application to a health-care logistics system, in Proceedings of the 2024 DICUAM Delft International Conference on Urban Air-Mobility, Delft, The Netherlands, March 2024 (2024).
21. IBG (2022) Morgondagens flyg, rapport gjord på uppdrag av Transportföretagen.

22. TRV, Swedish Transport Administration (2022) Proposal national plan for transport infrastructure 2022–2033 – Summary 2022:028, ISBN: 978-91-8045-013-3
23. KI (2021) WHO Environmental Noise Guidelines i en svensk kontext. Institutet för Miljömedicin, 2021-10-29
24. CAMM (2019) Trafikbuller i befolkningen-Exponering, utsatta grupper och besvär. Centrum för arbets- och miljömedicin
25. Stockholm Region (2018) RUFS 2050, Regional development plan for the Stockholm region by Growth and Regional Planning Administration, www.sll.se/regional-utveckling.
26. Luigi MAFFEI, Massimiliano MASULLO (2014) Electric Vehicles and Urban Noise Control Policies, Archives of Acoustics – Volume 39, Number 3, 2014
27. Wolfgang Schade , Transport noise: a challenge for sustainable mobility, UNESCO 2003. Published by Blackwell Publishing Ltd., 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street,Malden, MA 02148, USA
28. CAA (2019) CAP 1766 - Emerging Aircraft Technologies and their potential noise impacts.
29. Shaheen, Susan, Cohen, Adam and Farrar, Emily (2018) The Potential Societal Barriers of Urban Air Mobility (UAM), DOI 10.7922/G28C9TFR, https://escholarship.org/uc/item/7p69d2bg
30. Hughes T.P. (1987). The evolution of large technological systems. In The social construction of technological systems. New directions in the sociology and history of technology, edited by W. E. Bijker, T. P. Hughes and T. Pinch. Cambridge, Massachusetts & London, England: MIT Press, 51-82.
31. Jordan, T. (2014). Deliberative Methods for Complex Issues: A typology of functions that may need scaffolding. Group Facilitation: A Research and Applications Journal, Nr 13, pp. 50–71