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Drones for parcel and passenger transportation: A literature review☐

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ABSTRACT

Delivery drones and 'air taxis' are currently among the most intensely discussed emerging technologies, likely to expand mobility into the 'third dimension' of low-level airspace. This paper presents a systematic literature review of 111 interdisciplinary publications (2013 - 03/2019). The review systematizes the current socio-technical debate on civil drones for transportation purposes allowing for a (critical) interim assessment. To guide the review process four dimensions of analysis were defined. A total of 2581 relevant quotations were subdivided into anticipated barriers (426), potential problems (1037), proposed solutions (737) and expected benefits (381). We found that the debate is characterized by predominantly technical and regulatory problems and barriers which are considered to prevent or impede the use of drones for parcel and passengers transportation. At the same time, definite economic expectations are juxtaposed with quite complex and differentiated concerns regarding societal and environmental impacts. Scrutinizing the most prevalent transportation-related promises of traffic reduction, travel time saving and environmental relief we found that there is a strong need to provide scientific evidence for the promises linked to the use of drones for transportation. We conclude that the debate on drones for transportation needs further qualification, emphasizing societal benefits and public involvement more strongly.

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1. Introduction

Recent years have shown that unmanned aerial vehicles (UAV), commonly termed 'drones', have the potential to become an iconic technology of the 21st century. Drones combine three key principles of technological modernity - data processing, autonomy and boundless mobility. They provide access to (new) spaces and enable their analysis with the help of unprecedented methods of data collection. These capabilities, previously a privilege reserved to the military, are now increasingly incorporated into civil domains. Thus, drones generate potential use-cases ranging from surveillance/sensing missions to novel forms of logistics and passenger transportation.

Regardless of their application, drones are driven by a general motivation to make processes faster and more flexible, while improving precision and cost-efficiency (Kitonsa and Kruglikov, 2018). As a consequence, the commercial use of drones is associated with vast economic opportunities.[1] Although drones as surveillance/sensor devices are already common in security services, geodesy, or agriculture their use as transportation devices is still in its infancy. Nevertheless, from a purely technical perspective delivery drones are already able to lift weights of up to 2–3 kg and conduct flight missions in an urban radius (McKinsey, 2016b). In addition to that, passenger drones, so called 'air taxis', have already proven their technical ability to transport passengers within or between cities (Horváth and Partners, 2019). This illustrates not just a historical turning point in aviation but marks the beginning of a new era where low level airspace may become the 'third dimension' of transportation.

Against this background, this paper presents a literature review of 111 interdisciplinary publications (2013 - 03/2019) that summarizes the current socio-technical debate on the use of civil drones for transportation purposes by asking: what are the *anticipated barriers, potential problems,*

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[1] The European Commission estimates an economic impact of 10 billion € annually by 2035 (15 billion € annually by 2050) and envisions the creation of more than 100,000 direct jobs. Considering indirect macroeconomic effects in drone-related industries the Commission even anticipates 250,000 to 400,000 additional jobs (SESAR Joint Undertaking, 2016). Similarly, the US foresees the creation of 100,000 jobs over a ten year period (2015–2025), accounting for an economic impact of $82 billion on activities directly and indirectly related to drones (FAA, 2016).

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proposed solutions and *expected benefits* that are central to discussions about the technology? This review aims to provide comprehensive orientational knowledge based on an overview of the key perspectives in the debate and allows for a (critical) interim assessment of the central arguments characterizing recent discussions.

In order to provide an interdisciplinary and holistic perspective on the use of delivery and passenger drones, we present an in-depth analysis of six thematic clusters: societal implications, safety and security, ethics, environmental issues, public acceptance, urban planning and infrastructure. Subsequently, three uniquely transport-related expectations related to the use of drones (traffic reduction, travel time reduction, environmentally friendly transportation alternative) are discussed and scrutinized more closely.

1.1. Theoretical background

The literature review uses the theoretical framework of technology assessment (TA) and mobility studies. TA generally aims to provide "knowledge for better-informed and well-reflected decisions concerning new technologies" (Grunwald, 2011, p. 14). Thereby, TA aims to increase reflexivity of technological development and implementation. It relies on early analyses of concerns and conflicts under consideration of social values and ethical principles. TA aims to either inform policy making or to involve stakeholders at different stages of technology governance by means of participatory approaches. With this aim, it often relies on literature reviews and secondary data analysis. This forms the basis for participatory and communication methods (Decker and Ladikas, 2004). In conjunction with prospective methods of trend extrapolation and scenario planning (Simonis, 2013) systematic literature reviews contribute to the overarching aim of institutionalizing a strategy of "responsible development and innovation" (Grunwald, 2011, p. 26).

Mobility research rejoins perspectives "that approach mobility in a more critical, contextual and less superficial manner" (Adey et al., 2014, p. 2). Mobility here is understood as a social phenomenon that must be evaluated according to its consequences for a variety of actors. In addition to an interest in the social 'production' of movements (Cresswell, 2010), contemporary mobility studies focus on sustainable mobility concepts and the understanding of the mobile 'subject'.

In this literature review TA and mobility studies are used as complementary theoretical perspectives to analyze the current debate on transportation drones. This not only adds to the few existing systematic reviews on drone technology already available (Otto et al., 2018) but particularly fills the gap of discussing drones as a possible new form of mobility.

2. Methodology

2.1. Systematic literature review and content analysis: goal and purpose

To answer our research question, a content analysis based systematic literature review was conducted (Okoli and Schabram, 2010; Vom Brocke et al., 2009). We worked with the qualitative content analysis software Atlas.ti (Version 8) which allowed access to greater amounts of data (Lu and Shulman, 2008, p.106) and direct collaboration in the research team (Kaefer et al., 2015). It is important to note, however, that the use of software has also been criticized for enticing researchers to focus on quantity rather than quality of data (St. John and Johnson, 2000). To counteract this, we used Atlas.ti only as a tool to organize our documents. All coding decisions were made by the authors themselves.

2.2. Document sampling

2.2.1. Document search

Documents were searched primarily through Google Scholar. To structure the search, a list of English and German search terms was established. Boolean operators AND, OR and NOT were used to specify searches.[2] From the initial pool of articles found through the search engine further documents were identified using the 'snowball technique' (Hepplestone et al., 2011; Webster and Watson, 2002).

2.2.2. Exclusion criteria

Given our primary interest in the use of delivery and passenger drones for commercial use, we made sure our selection of documents reflected this thematic angle. We excluded articles dealing exclusively with the sensory capabilities of drones, or their use for data acquisition, military purposes and surveillance. Furthermore, all articles dealing solely with private or recreational use of drones were excluded.[3]

2.2.3. Year

The starting point of the sampling period is 2013, linked to Jeff Bezos' famous announcement that Amazon would start to develop delivery drones (Streitfeld, 2013). Sampling ended in March 2019 and no papers published after this point were included in the analysis.

2.2.4. Language

We excluded articles written in any language other than English and German as only these two languages were spoken by all members of the research team.

2.3. Identification of documents: an extensive interdisciplinary study

2.3.1. Documents by thematic focus

We selected a total of 111 documents and grouped them into thematic categories (Table 1).[4] The distribution of documents across all categories (year of publication, author, etc.) is supplied in the Annex A.2.

2.3.2. Documents by authorship

The clear majority of publications (79.3%, 88) was written by academics, followed by those written by authors working in the private sector (11.7%, 13). Publications by authors working in the political sector (6.3%, 7) or in the civic sector (2.7%, 3) were identified less frequently.

2.3.3. Documents by year of publication

Looking at the analyzed publications from a chronological perspective it becomes clear that there is a steady upward trend indicating a more intense (especially academic) focus on the topic. While we were able to identify merely five publications dealing with urban cargo and passenger transport with UAVs in 2013 (4.5%), we included 38 publications from the year 2018 (34.2%).

Until the end of the document sampling period in March 2019 we sampled a total number of five relevant publications, indicating that the upward trend will likely continue throughout 2019 and beyond.

2.3.4. Coding

The selected documents were analyzed using qualitative content analysis. In total, three coders were involved in coding the documents. We started our coding procedure with a set of priorly determined categories, including:

- *expected benefits*: the benefit that drone technology is hoped to bring to specific interest groups, users, producers or society as a whole
- *anticipated barriers*: concrete obstacles preventing the mass use of drones in different commercial use cases

[2] The list of search items can be found in Annex A.1.

[3] We decided not to make the quality of the journal or the publication a sampling exclusion criterion. We took that decision because we wanted to include not only academic papers but also policy papers or private sector white papers and felt there was no objective quality standard that could be meaningfully applied to all these different kinds of data.

[4] It is important to note that we were not able to sample the exact same number of relevant publications for each topic area (e.g. publications on environment and sustainability or urban planning and infrastructure are underrepresented). The integration of various general surveys is intended to partly compensate for this circumstance.

Table 1
Distribution of documents according to their thematic focus.

Document by groups	in %	n	Document by groups	in %	n
Passenger Transportation	2.7%	3	Ethics and Technology Assessment	10.8%	12
Humanitarian Logistics	2.7%	3	Law and Regulations	11.7%	13
Political agenda/strategies	6.3%	7	Attitude and Acceptance Research	13.5%	15
Urban and Transportation Planning	7.2%	8	Logistics (general)	18.0%	20
Sustainability Assessment	8.1%	9	General Surveys	18.9%	21
				Total (N)	**111**

- *potential problems*: negative implications and challenges inherent to drone technology which would result from their development, introduction and use
- *proposed solutions*: concrete measures which allow to overcome anticipated barriers, mitigate potential problems and realize the expected benefits of drone technology

A set of contextualizing codes were created inductively (research gaps, stakeholder (-connections), future scenarios). Sub-codes, meaning thematic specifications of these categories, were added inductively by each member of the research team. Finally, small sub-sub codes were established to allow a precise understanding of the actual subject discussed at the smallest scale.

2.3.5. Codebook

As is generally recommended for content analysis we wrote a codebook (Ando et al., 2014). An excerpt of the codebook can be found in Annex A.3.[5]

2.3.6. Intercoder agreement analysis

Whenever documents in content analysis are coded by a group of different coders inter-coder reliability[6] becomes an issue (Gwet, 2014, p.7, Lombard et al., 2002, p.589). The most accepted approximation to inter-coder reliability is achieved by testing inter-coder agreement (Hayes and Krippendorff, 2007), measuring the extent to which two or more independent coders make the same coding decisions (Olson et al., 2016, p.29).

We conducted an inter-coder agreement analysis (ICA) to test the level of agreement within the research team. We discarded using measures like proportion agreement (Green, 1981, p.1069), Cohen's Kappa or the Holsti Index. The former because it tends to be too lax (Campbell et al., 2013, p.309), the latter two for being too conservative (Lombard et al., 2002). Instead we worked with Krippendorff's Alpha, which is generally agreed to be the strongest, most adaptive inter-coder agreement measure (Stevens et al., 2014, p.78, Hayes and Krippendorff, 2007). Following Hodson's recommendation (1999, p.29), we used a sample of 10% of our documents (11) for the analysis. Two coders independently coded the 11 documents using the four key code categories (*potential problems*, *anticipated barriers*, *proposed solutions* and *expected benefits*) while the third coder ran the ICA on atlas.ti.

Total inter-coder agreement across all 11 documents and all codes was $\alpha = 0.71$. In general, alpha values above 0.80 indicate a level of reliability which allows drawing quantitative conclusions, while levels between 0.67 and 0.79 are suited for drawing tentative conclusions (Mikhaylov et al., 2012, p.48). Our goal in this paper is to point to trends and set a wide variety of disciplines into perspective. Therefore, we judged this degree of inter-coder agreement to be satisfactory.

3. Results

3.1. Code category distributions

Of the total number of relevant quotations that were coded by the research team (2581), the majority accounted for the category of potential problems (40.2%, 1037), followed by proposed solutions (28.6%, 737) and anticipated barriers (16.5%, 426). Expected benefits are the smallest category with 381 quotations (14.8%).

3.1.1. Expected benefits

Nearly half of the 381 quotations in the category of expected benefits deal with **economic benefits** (49.3%, 188). Here, it is primarily expected that drone-supported logistics services will lead to lower costs for companies in the rapidly growing and price sensitive logistics sector. Roughly a fifth of the quotations focuses on **societal benefits** (20.2%, 77). Here, the emphasis is on drones' contribution to the improvement of (urban) traffic. Delivery and passenger drones could relieve the pressure on already congested streets and allow faster commuting in the air. This reallocation would also enable faster commuting on the ground. The third largest group of quotations contains **ecological and environmental benefits** (11.3%, 43).

We observed an increase in quotations looking at expected benefits within the sampling period. The peak of quotations (161) is in the year 2018.

3.1.2. Potential problems

The majority of the 1037 quotations in this category focuses on **legal aspects** (23.9%, 248). This includes the challenge of adapting the existing legal framework, to ensure a fair balance of interests and enforcement deficits. Another large group of quotations focuses on **ethical aspects** (22.7%, 235). Roughly half of these quotations discuss threats to privacy (50.2%, 118/235). Among the anticipated threats to **physical safety** (22.0%, 228), collisions, crashes, accidents and injuries make up roughly a third of the quotations. The threat of potential misuse of drones by criminals and terrorists also plays an important role. **Social issues** (12.8%, 133), **environmental interrelations** (7.5%, 78) and **economic problems** (6%, 62) are mentioned less frequently.

3.1.3. Anticipated barriers

Of the total number of 426 quotations coded as anticipated barriers, over half of the quotations refer to **technical aspects** (49.1%, 209). These issues encompass practical questions of autonomous flying and airspace integration as well as difficulties concerning battery capacity and data communication. About a quarter of anticipated barriers addresses **legal issues** (23.7%, 101). Here, central topics are concerns about the prohibitive effect of strict regulation and about the lack of legal standardization.

Another group of anticipated barriers addresses the **lack of acceptance for drones** among the public (15.7%, 67). Quotations mainly discuss invasions of privacy, safety concerns and noise levels as causes for a lack of public acceptance. Only 6.6% (28) of all quotations deal with **economic barriers** and 4.9% (21) are **infrastructural** in nature. Anticipated infrastructural barriers focus on the challenge of adapting existing infrastructure or constructing additional, physical and digital infrastructure in order to integrate drones into urban space.

3.1.4. Proposed solutions

The 737 quotations in this category address similar topics as those prevalent in the category of anticipated barriers. Solutions of a **legal** nature (27.6%, 204) discuss the future coordination of legislative processes, incorporating both hard and soft law. **Technical solutions** (27.0%, 199) focus on concrete approaches to issues such as navigation, communication and automatization of (delivery) drones.

Proposed solutions focusing on the **public acceptance** of drones are also represented quite strongly (14.0%, 103). Key to this group of solutions are suggestions to provide more public information and process transparency. Proposed solutions concentrating on **planning and infrastructure** (8.1%, 60) provide recommendations for the construction and adaptation of physical and digital infrastructure. In comparison, proposed solutions referring to **economic factors** (6.1%, 45), **safety and security** (4.7%, 35) and **environmental aspects** (3.0%, 22) play a minor role.

[5] Apart from this excerpt the full English translation of an abbreviated Codebook as well as the full German Codebook is available from the authors on request.

[6] In other fields and disciplines this is often referred to as inter-rater reliability, but in content analysis where data is explicitly generated through coding, the term 'inter-coder' agreement is prevalent (Gwet, 2014, p.7).

It becomes clear that the discourse is heavily characterized by technical and regulatory issues. In order to obtain a critical, holistic and interdisciplinary TA perspective the following section expands this narrow focus. To do so, a defined set of topics is analyzed along our main research categories.

3.2. Societal implications

The first impression of this topic area is rather ambivalent. On the one hand, societal benefits account for more than one third of all expected benefits (36.7%, 77). On the other hand, negative societal implications of using transportation drones form the dominating issue within potential problems (63.3%, 133).

The **expected benefits** for society (20.8%, 16) largely remain abstract or general. Drones are claimed to be "*definitely an advantage for societies*" (Bujak and Śliwa, 2017) or would have "*a considerable impact in the fields of academic, technological, business, and social development*" (de Miguel Molina and Santamarina Campos, 2018). The most frequently addressed societal benefit is the reduction of traffic congestion and the shortening of commuting times (22.1%, 17): "*UAVs could provide major relief for inner cities, taking traffic off the roads and into the skies*" (DHL, 2014). Further societal advantages include improved health care services (19.5%, 15), optimized parcel delivery for the benefit of customers (9.1%, 7), and improved search and rescue operations (6.5%, 5). In addition, drones are considered a possible tool for promoting social empowerment (9.1%, 7) and the sharing economy: "*where individuals borrow or rent assets owned by someone else*" (Kornatowski et al., 2018).

Occurrences of societal change are the major **problems** identified (18.8%, 25). The widespread use of delivery and passenger drones could divide (urban) society if "*the benefits of drones for some come with liabilities or concerns that impact others*" (Applin, 2016). Activism against drones and in particular against delivery drones could be a potential consequence (Lotz, 2015). Several authors point out that a permanent presence of drones could erode the current understanding of privacy (Schlag, 2013; Rao et al., 2016). This would be exacerbated if private companies were to use the data collected by drones for purposes beyond navigation (Jensen, 2016). Moreover, some authors caution that urban drone delivery will adversely change consumption and mobility patterns (Gulden, 2017; Applin, 2016). An almost immediate satisfaction of consumer wishes through instant deliveries could change behavioral patterns (Applin, 2016). Instant gratification of consumer wishes may be appreciated but may also lead to "*binge buying, increasing levels of consumer debt, the danger of excessive indebtedness, and finally insolvency*" (Nentwich and Horváth, 2018a).

The current implementation process of drone technology is regarded as another source of potential societal problems (15%, 20). According to the authors, policymaking about drone use in general and transport drones in particular usually consists of consultations with a small number of experts and stakeholders (Boucher, 2014). In the United States coordination between federal, state, and local government is currently increasing (West et al., 2019). In the German context, on the other hand, authors denounce a lack of awareness at the municipal level (Otto-Zimmermann and Roeßiger, 2017a; Otto-Zimmermann and Roeßiger, 2017b). Common to most articles is a shared perception that there is insufficient consultation of citizens or civic stakeholders (Otto-Zimmermann and Roeßiger, 2017b; West et al., 2019; Boucher, 2014). It is also emphasized that the call for stronger involvement of citizens (Boucher, 2016) may be opposed by the already established drone lobby (Otto-Zimmermann and Roeßiger, 2017b).

Additional potential problem areas of using drones for transportation purposes include negative effects of noise pollution (14.3%, 19) and the blurred boundaries between public and private spaces (11.3%, 15). Potential economic impacts include job losses, especially in the often precarious logistics sector (6.8%, 9). Authors also mention a lack of general information on drones (6.8%, 9). Moreover, authors claim that there is the possibility of growing social injustice linked to air taxis as a new form of elite mobility (3.8%, 5).

3.3. Safety and security

The topic of safety and security is characterized by a great problem awareness. This is already quite obvious when considering the key category of potential problems, in which drone-related risks for safety and security form the third largest group of quotations. In contrast, only 8.4% of the expected benefits and 4.7% of the proposed solutions are related to safety and security. Similarly, when looking at the internal ratio of quotations regarding safety and security, expected benefits (10.3%, 28) and proposed solutions (12.5%, 34) are clearly outnumbered by potential problems (77.2%, 210). The topic has gained increasing relevance over the years. From 2013 to 2015 it is mentioned only occasionally, but in 2018 safety and security was one of the most frequently discussed topics.

Regarding **expected benefits** related to safety and security issues it is striking that all refer to the use of drones as sensory devices and never to their use as a transportation technology. Obviously, the technology is not anticipated to make transportation more safe and secure.

Potential safety and security problems of drone use are perceived to be a major issue (32.8%, 75). Air collisions (Stöcker et al., 2017), crashes and malfunctions of soft- and hardware components (Department for Transport, 2016) could be especially relevant for urban areas (Clothier et al., 2015). The misuse of drones for criminal or terrorist purposes (25.4%, 58) is also discussed: drones could be used "*to smuggle weapons or drugs*" (Kitonsa, 2018) or "*hacked for consumer data*" (Bamburry, 2015). The latter aspect was held especially relevant as the inconspicuous nature of drones makes it *"difficult for the owner to detect the leak of information and ensure the security of the information as well as claims on ownership"* (Rao et al., 2016). Many options for potential terrorist abuse are described: drones could be "*weaponized and flown into any vulnerable infrastructure*" (Smith, 2015), manipulated to "*deliberately drop* [their] *payload to cause harm*" (Clarke, 2014), or to "*jam or spoof the Global Positioning System signals of other RPAS [remotely piloted aircraft systems], causing serious hazards to air safety*" (European RPAS Steering Group, 2013a). Notably, the possibility of using drones for criminal purposes is estimated to be much higher (58) than the possibility of combating crime with drones (7).

Proposed solutions offer to either reduce or prevent drones' potential damages. For instance, universal registration of drones in operation might "*allow better knowledge on who to prosecute in the event of an incident.*" Technical solutions involve geo-fencing and no-fly zones (20%, 7). These block certain areas, buildings or infrastructures from being overflown. The measures are implemented by drone sound detection (Alwateer et al., 2019), built-in transponders or software restrictions (Jensen, 2016). Possibilities of drone defense (20%, 7) range from interfering signals to launching interception devices to trained birds of prey (DFS, 2016).

3.4. Ethical issues/privacy violations

Ethical problems represent the second-largest group of all potential problems in the dataset (22.7%, 235). The concern of privacy violations is the key issue here (50.2%, 118). A second, though much smaller group addresses the lack of transparency regarding aims and purposes of drone operations (24, 10.2%). It is followed by issues of data privacy (19, 8.1%) and the potential of increased surveillance (15, 6.4%). The mention of potential privacy violations shows a rather stable development from 2013 to 2015 (11, 11, 7) and increases significantly from 2016 to 2018 (51, 39, 59). Given the relevance of privacy violations, this specific ethical complex will now be considered in more detail.

Potential problems regarding privacy violations stem from drones' "*combination of unfettered mobility and digital documentation* [that] *has the potential to violate personal privacy and private spaces, both of which help ensure anonymity*" (Nelson et al., 2019). Moreover, drones "*are often quiet and can fly at significant heights, often remaining invisible to the naked eye*" (Schlag, 2013), "*can also be used for monitoring purposes*" (DFS, 2016), or "*have the ability to collect, retain, use, and disclose personal information*" (Chang et al., 2017). Generally, drones are perceived as "*render*[ing] *fences*

and walls irrelevant to those seeking to keep out the unwanted eye" (Zwickle et al., 2019).

Even in cases where drones are exclusively used as transport devices, they need sensing and surveillance technologies. These prevent collisions and facilitate the landing/package drop-off and take-off process (Nentwich and Horváth, 2018a). As a result, delivery drones also bear the potential of (intentionally or unintentionally) causing privacy infringements when deployed close to private spaces.

Proposed solutions for mitigating potential privacy violations include technical and legal strategies. The most frequently discussed technological solution is to make UAVs identifiable through in-built remote identification systems (11.1%, 22). In addition, some authors suggest integrating preventative measures into drone designs (16.1%, 32). Such measures include algorithms as well as software designs for real time privacy impact assessments (privacy by design, privacy by default) (Pauner and Viguri, 2015; Kornatowski et al., 2018; Wang et al., 2016). Other technical approaches comprise geofencing or no fly zones (7.0%, 14). Exemplary for the width of approaches to prevent privacy violations, Wang et al. (2016) propose the following programmatic scheme: "(…) *making both the drones and their controllers more discoverable, approachable, and accountable; enabling communication between drone controllers and ordinary citizens/bystanders; making drone designs sensitive to local social and cultural norms*" (Wang et al., 2016).

Legal solutions comprise the establishment of a mandatory registration of drones (31, 15.2%), creating codes of conduct (17, 8.3%) and extending the regulatory frameworks to better protect privacy rights (15, 7.4%). These legal measures focus on creating a regulatory framework aimed at establishing "*rules on the data collected by drones instead just drone operation*" (Chang et al., 2017). This includes for example the need to remove or anonymize personal data, which is not strictly necessary for the drone mission. Further measures are the interdiction of storage and dissemination of personal data without knowledge of the person concerned.

3.5. Environment and sustainability

The topic of environment and sustainability is mostly characterized by a lack of solid scientific evidence and uncertainties about the environmental impact of drones. While environmental issues made up less than 1% of all expected benefits from 2013 to 2015, they made up 16.5% in 2018. Similarly, there are almost no proposed solutions concerning drones' environmental impact from 2013 to 2016, but they make up over 5% of all proposed solutions in 2017 and 2018. The number of quotations about potential environmental problems is slightly more constant, but there is still a notable increase from 7.1% of all citations addressed in 2015 to 10.8% in 2018.

The majority of quotations concerning **expected environmental benefits** describe drones as a more environmentally friendly technology for both logistics and passenger transportation. The main reason is the fact that drones are a fully electric transportation technology. This is either expressed in rather general terms (51.2%, 21) or in comparison to other (conventional) transportation technologies (48.8%, 14). 'Air taxis' are for instance considered to reduce carbon/noise footprint in comparison to fossil-fueled helicopters (European RPAS Steering Group, 2013d; Christen et al., 2018a; Nentwich and Horváth, 2018a).

Assessing the environmental benefits of delivery drones is complex and dependent on the respective deployment scenario. In a one-trip-per-item scenario where a drone transports a relatively light load, delivery drones have a significantly higher energy efficiency than, for example, diesel vans (Goodchild and Toy, 2018). However, as soon as several parcels have to be delivered conventional delivery methods remain more energy efficient, especially in cases where recipients can be grouped along routes (Figliozzi, 2017) or when service zones are distant (Goodchild and Toy, 2018). Goodchild and Toy (2018) therefore propose that *"a blended system would perform best (emit the least) with drones serving nearby addresses and trucks delivering to ones farther"* (Goodchild and Toy, 2018).

The two most frequently discussed **potential environmental problems** are dangers to wildlife (24.4%, 19) and the uncertainties regarding actual energy efficiencies and emissions of delivery drones (30.8%, 24). While some authors see drones as an opportunity for sustainable mobility (Kitonsa and Kruglikov, 2018; Koiwanit, 2018) for others they represent various uncertainties. As a result, authors caution that "*the impact of drone delivery system on the environment is still in question and the environmental sustainability should be assessed under widespread aerial transportation and through life cycle assessment*" (Shavarani et al., 2018). It is therefore criticized that only "*few scholarly analyses have been conducted to determine the actual CO2 reduction when drones are used in cities*" (Park et al., 2018).

The majority of **proposed environmental solutions** looks at very specific sustainability issues related to the use of drone technology and provides suggestions for improvements. These include the strategic construction of drone warehouses (Stolaroff et al., 2018; Lohn, 2017) or use of green energy to charge the drones (Park et al., 2018; Stolaroff et al., 2018). Interestingly, most solutions do not address the major issues identified in the context of environmental problems. In fact, only two quotations deal with the protection of wildlife (Chang et al., 2017; DLR, 2017) and none deal explicitly with the issue of providing more certainty about the positive environmental impact of drone technology.

3.6. Urban planning and infrastructure

The topic of planning and infrastructure has a fundamentally different character than most other topics. This is most clearly shown by the extent to which proposed solutions outweigh the problems and barriers addressed. While planning and infrastructure constitute 8.1% (60) of all quotations in the category proposed solutions, they make up a mere 4% (41) of potential problems and 4.9% (21) of anticipated barriers. What is more, the topic has increasingly come to the fore in recent years. Between 2016 and 2018 (107) the data analysis showed nine times more citations than in the previous three years (12).

Potential planning and infrastructural problems can be divided into two thematic areas. On the one hand, requirements for urban planning processes are formulated (19.5%, 8). Local planning authorities are considered unprepared for the challenge of integrating a third dimension of mobility into existing planning practice (Balac et al., 2018). It is unclear how both, an enabling planning practice as well as the reconciliation of conflicting interests can be ensured. Moreover, demands for participatory planning practices are expressed (Otto-Zimmermann and Roeßiger, 2017b). Aside those planning aspects, clearly defined requirements for physical infrastructure are lacking (Otto et al., 2018). For air logistics in urban areas the spatial distribution of charging and depot infrastructures is a key determinant of ideal delivery routes. This also influences further assessments of sustainability, efficiency and profitability (Balac et al., 2018; Murray and Chu, 2015; Shavarani et al., 2018; Otto et al., 2018). Regarding passenger transportation, a central question is how complementary infrastructure might enable links with existing road and transit networks (Balac et al., 2018).

On the other hand, a second, much larger topic area deals with the requirements for an Unmanned Traffic Management (UTM)/U-Space (80.5%, 33). It can be understood as a highly digitized, automated control system enabling safe and efficient access to lower airspace for a large number of drones (SESAR Joint Undertaking, 2018). The system requires small-scale planning of the lower airspace, taking into account terrain specifics and obstacles (DLR, 2017; Jensen, 2016). Further challenges to the U-Space are posed by the safeguarding of statically or dynamically defined no-fly zones and the establishment of flight corridors (DLR, 2017; Jensen, 2016). U-Space Management could be a crucial factor in minimizing the effects of drone traffic for the population and the environment (noise, visual pollution, etc.) (SESAR Joint Undertaking, 2018).

Examining anticipated **barriers** one finds a varying focus by authorship. Academic authors emphasize on the operational requirements for drone deployment. Infrastructure for parking, storage and charging would need to be expanded dramatically (Balac et al., 2018; Thipphavong et al., 2018). Private sector actors working on urban air mobility consider a well-

connected hub infrastructure a precondition for their business model (Uber, 2016).

Regarding **proposed solutions**, most quotations simply emphasize the construction of new infrastructure (26.7%, 169). Regarding logistic processes, many authors envision networks of small distribution hubs enabling last-mile delivery by drone (Stolaroff et al., 2018; Shavarani et al., 2018; Lohn, 2017). While delivery to suburban areas is considered a viable option (Airbus Blueprint, 2018; Nentwich and Horváth, 2018a), recommendations for dense urban areas are lacking. A repurposing of local parcel delivery stations may be feasible (DHL, 2014). To enable passenger transportation, authors suggest structural adaptations to existing buildings like business towers or parking decks (Airbus Blueprint, 2018). Other proposed solutions comprise platforms in close reach to highway junctions (Uber, 2016) or the utilization of existing railroad stations (Hoekstra et al., 2014).

Proposed solutions concerning a possible UTM/U-Space design involve the determination of flight routes in the urban environment (18.3%, 11). As a planning principle the fair sharing of societal burden and benefits is addressed as an important approach (Nentwich and Horváth, 2018b). To ensure this, a dialog and collaboration between planners and involved stakeholders (Balac et al., 2018; Otto-Zimmermann and Roeßiger, 2017b; Christen et al., 2018a; TATuP, 2018; Airbus Blueprint, 2018; Christen et al., 2018b) is proposed frequently (15%, 9).

3.7. Public acceptance

The topic of acceptance is mostly characterized by the importance it is given by the majority of publications. Most authors investigating the acceptance of commercial drone deployment agree that the (urban) population will be most exposed to the adverse effects of the widespread use of drones (Lidynia et al., 2017; Clothier et al., 2015). These adverse effects might negatively affect public acceptance, which is why across all publications acceptance is identified as one of the three major barriers to the use of drones for transportation (15.7%, 67), following technical and legal limitations. However, it is also possible to highlight possible solutions aiming to tackle the subject (60.6%, 103).

Acceptance as an **anticipated barrier** was - despite a temporary slump in 2017 - increasingly addressed from 2016 onwards (2016: 25.37%; 2017: 16.42%; 2018: 31.34%). Nearly one fifth (13) of the identified statements cite acceptance as a necessary basis for drone technology. However, 23.9% (16) of the quotes indicate that there is a lack of acceptance for certain use cases. The main reasons for the lack of acceptance identified are concerns about privacy (25.4%, 17), safety and security (17.9%, 12) and noise (9%, 6).

The majority of the **proposed solutions** aims to create public acceptance. In almost one third of all quotes, more information and process transparency (34.6%, 36) are considered important. Here, information is understood as a catalyst for a public debate (Otto et al., 2018; Du and Heldeweg, 2017; Europäische Kommission, 2014) and as a form of (legal) empowerment for citizens (Department for Transport, 2016; TATuP, 2018). Furthermore, various concepts of *good* jurisprudence are regarded necessary for establishing social acceptance, with the focus on regulations that safeguard public interests (19.4%, 20). Technical solutions form the third largest group of proposed solutions (14.7%, 15). These include technical safety measures (de Miguel Molina and Santamarina Campos, 2018) and the incorporation of privacy by design approaches (Anbaroğlu, 2017). Some authors propose to increase accountability by equipping drones with chips (Department for Transport, 2016). Other options are designing them in a more quiet (Uber, 2016; Kornatowski et al., 2018) and environmentally friendly way (European RPAS Steering Group, 2013d).

Yet another 11.7% (12) of all solutions for increasing public acceptance propose participatory approaches. A concrete goal of such public consultation processes is to reach a common understanding of (whether and) how urban airspace should be used in the future (Airbus Blueprint, 2018). It is stated that "*it would be high time to open up a debate now*" given that the technology is almost ready to be used commercially (Nentwich and Horváth, 2018a).

Finally, among others, the report of the European RPAS Steering Group in 2013 (European RPAS Steering Group, 2013d; European RPAS Steering Group, 2013a) advises to actively reframe the word *drone* from being associated with a foremost military device to a societally benefiting technology (7.7%, 8). However, studies do not show the negative effect of military associations on public acceptance (Boucher, 2016). Furthermore, some authors criticize the ethical principles underlying proposals to reframe (Boucher, 2015).

4. Discussion

Beyond summarizing the current socio-technical debate on the use of civil drones for transportation the objective of this literature review is to assess the possible consequences and provide a (critical) interim assessment of the central arguments characterizing this debate. In the following section, this assessment will be conducted by taking one step back and examining the rationale behind pushing the development of urban airspace use and accepting the risks associated with it.

As shown, the expectations of using drones for modes of transportation are dominated by economic benefits (49.3%). Private-sector and macroeconomic effects of technology introduction are highly relevant for a comprehensive technology assessment. From a mobility-oriented TA perspective however it should not be the main focus. We therefore turn to the benefits that are anticipated for the (urban) population (20.2%) and the environment (11.3%) by focusing on the three uniquely transportation related benefits: *traffic reduction*, *travel time savings* and *environmental relief*. These topics are discussed in a broader theoretical perspective of mobility research.

4.1. The promise of ground traffic reduction

Recognizing congestion as the prime negative side-effect of mass motorization, the ideal of achieving "smooth" and "seamless" traffic flows is one of the most paradigmatic policy aspirations (Mom, 2014; Habermas, 1992). Primarily sought through the construction of new (road) infrastructure however, strategies of providing extra road capacity often proved unsuccessful caused by the effects of 'induced traffic' (Goodwin, 1996). Further measures ensuring this long-standing dream of uninterrupted traffic flows include the reduction of densities, the enhancement of speed and the prioritization of certain transportation systems at the expense of others (Knoflacher, 2007). In addition, since the 1990s the rise of Information and Communication Technologies (ICT) has raised hopes for substituting substantial shares of physical transportation by means of telecommunication. This was expected to resolve existing traffic problems and to lessen the burden of commuting (Cairncross, 1997). However, anticipated ICT-related substitutional effects proved illusory because many physical processes were largely irreplaceable. What is more, ICT-induced complementary effects may sometimes generate an increased flow of physical goods (Mokhtarian, 2009).

Against this background, drone technology now seems to provide a new solution to this old problem, given that drones are able to use separate (air) space. From a technical standpoint, once airborne, passenger and delivery drones have the potential to either bypass ground-based traffic congestion or avoid congestion by lifting a share of ground transportation into airspace. Considering average payloads of up to 3 kg, about 80% of all domestic parcel deliveries are theoretically suited for air transportation by drones (McKinsey, 2016b). However, beyond delivery drones' technical capabilities there are various limiting factors that render the notion of actual ground traffic reduction questionable.

First, drones are not (yet) able to conduct complex multiple deliveries (Agatz et al., 2018) and therefore can hardly be considered a competition for conventional city logistics (Kunze, 2016). Instead, drone deliveries may rather become meaningful when employed in concert with delivery trucks (Murray and Chu, 2015). Other substitutional potential may unfold in cases of remote individual delivery or humanitarian scenarios. Both applications however account only for a marginal share of total traffic flows. This limits their potential for 'tangible' traffic reduction. Passenger drones

with their ability to transport a maximum of five passengers (or even less) per air taxi are equally limited by capacity (Uber, 2016).

Given the technical limitations of drones, significant reduction of ground transportation is currently only feasible by deploying immense autonomous drone fleets. Doole et al. (2018a) calculated that about 180.000 drone flights per hour would be necessary to shift 70% of all parcel deliveries in the metropolitan area of Paris into the air. It follows that individual parcel deliveries by drone will lead to substantial traffic flows in the skies. It is symptomatic that even before drones fly in urban airspace, authors consider traffic jams in the air a potential problem to be solved by efficient U-Space Management (DLR, 2017). Hence, even if drone fleet deployment were to substitute ground-based traffic it might come at the price of transferring traffic flows into a different dimension. From a planning point of view, traffic would not necessarily be reduced but rather redistributed. In short, the goal of solving traffic problems would have to be set off against the implications of great drone fleets. These may include unforeseeable problems and costs, which are intrinsic to any kind of traffic. As unveiled in our analysis, there are several authors that anticipate such problems in urban areas such as safety and privacy hazards for third parties (Anbaroğlu, 2017) or noise pollution in regard to citizens (Bendel, 2016; Du and Heldeweg, 2017; van Wynsberghe et al., 2018) as well as in regard to local fauna (Applin, 2016; Christen et al., 2018a; Bendel, 2016).

Secondly, substitution effects are known to only prevail under stable conditions of demand. Against the background of growing economies and current consumption patterns that fuel a fast-growing E-commerce business, the amount of parcel deliveries is anticipated to increase tremendously (Mordor Intelligence, 2019). This poses a challenge for urban space and logistics companies alike. In light of these projections, delivery drones may primarily slow down and compensate expected growth rates for ground-based urban transportation rather than actually reduce traffic flows. Hence, in the best case, the initial promise of traffic reduction may turn out to be a zero sum game. More critically, drones may indirectly facilitate the growth spiral of the E-commerce sector, especially if drones were to remove the critical pushback regarding problems of unreliable and expensive last mile delivery. Improved customer experience and cheaper delivery fees may increase online-orders by customers (PwC, 2016), which in turn may generate additional traffic flows.

Thirdly, a properly managed U-Space/UTM is proposed to provide highly dense and flexible drone flights. This could indeed facilitate further potential traffic reduction on the ground (DLR, 2017). However, economists have pointed to the phenomenon of rebound effects as a result of increasing efficiencies (Jevons, 1866; Greening et al., 2000). Studies show that it is the transport sector that is particularly prone to such rebound effects (Dimitropoulos et al., 2018; Frondel and Vance, 2013). Hence, given the experiences of transport-related savings acquired in energy, cost or traffic space there is reason to suspect that more efficient drone technology will induce the transportation of additional items. By that, drones may even lead to overcompensation ('backfire'), meaning an increase of both parcel and passenger transportation.

This interplay of logistics requirements and changing consumption patterns form a 'space-use-dilemma', in which drones may be able to substitute ground traffic but likely at the price of creating a new kind of (capacious) traffic flow in low-level airspace. Seen through the lens of a proposed "new transport planning paradigm" (Litman, 2013), this contradicts the aim to avoid, reduce and relocate traffic flows in more consolidated ways (Dalkmann and Brannigan, 2007). Notwithstanding, drones might contribute to this new planning paradigm because they support the general shift away from the primacy of car-based and fossil means of transportation.

The expectation of drone-induced traffic reduction appears an intuitive solution to existing problems but yet remains an open question. This calls for a deeper understanding of i) more precise substitution potentials of various drone application scenarios, and ii) drone-related (long-term) economic and behavioral effects. Future research would have to validate the substitutional effects of different drone scenarios and discuss them in the context of recently renewed transport planning strategies.

4.2. The promise of travel time savings

In the most general sense, travel time durations depend on the distance travelled in relation to speed. Transport planning conventionally considers travel times primarily a 'cost', which should be reduced by speeding up (Banister, 2008). Our analysis revealed that drones are clearly associated with the promise of travel time savings. Since airborne drones at first glance do not seem to require physical infrastructure they bear the advantage of operating in direct and uninterrupted line. Hence, drones will undoubtedly enable temporal advantages in comparison to ground-based transportation. However, a systematic assessment of real travel time savings would have to take into account the entire ecosystem of drone missions including all technical, processual and infrastructural aspects. In addition, a consideration of dynamic demand patterns might relativize the intuitive promise of travel time reduction.

Regarding infrastructural aspects, every transportation system needs a system of 'moorings' or infrastructural hubs to facilitate accelerated transportation (Urry, 2003). As drones need public vertiports or drone logistic hubs, their distribution density will be critical to the expected benefit of travel time savings. Door-to-door travel times will include transportation to and from such hubs as well as preparation time (e.g. transfers to and from the hub, security checks etc.). A German research team estimated that inner-city travel time savings of air taxis (compared to car transportation) are only likely if vertiports were deployed with a similar density as urban railroad stations (1 vertiport per square kilometer). Lower densities of vertiports may thus even result in higher door-to-door travel time compared to conventional means of transportation (BMVI, 2019) (Fig. 1).

Second, as travel time savings may more likely be realized with increasing flight distances, air taxis' limited battery capacities account for another setback regarding the central promise of time savings. Commonly anticipated concepts of intra-city passenger drones are projected to fly at speeds of up to 110 km/h and with a range of about 35 km before recharging (Volocopter, 2019). Time savings are thus even more dependent on the density of landing sites. Moreover, limited range capacities make travel time reduction likely only in the case of tremendous ground traffic congestion levels, in regions hard to access or with limited ground traffic infrastructure respectively.

Third, questions of how and where to implement the necessary facilitating systems remain unsolved, especially in areas where space is a limited resource (Stolaroff et al., 2018). In addition to these infrastructural limitations, insufficient air traffic management capacities are also known to drastically hamper time savings in aviation (Vascik et al., 2018).

Finally, given travelers' tendency to spend achieved time savings on additional or longer trips (Metz, 2008), there is reason to believe that this mechanism would also apply in the case of passenger drones. This may lead to a latent expectation that the system will be further sped up, which would increase traffic flows and increase environmental/energetic costs.

Altogether, travel time savings can only be evaluated against the density of supplementary infrastructure, speed levels, range and local congestion levels. While some application scenarios may be 'time-savers', others may actually become 'time-traps'. As a consequence, the generalizing nature of a 'faster' mode of transportation that was prevalent among our analyzed documents appears to be rather uncertain.

Only few studies have started to analyze and model demand sensitivity to technological and operational parameters (Balac et al., 2019). Further research should, therefore, deepen the understanding of influencing factors, in particular with respect to time savings (infrastructures, range, passenger/parcel handling procedures).

4.3. The promise of sustainable transportation

One of the world's key challenges today is to reduce the global CO2 footprint. This particularly concerns the transportation sector as it accounts for almost 25% of all global CO2 emissions (IPCC, 2014). Transportation is also considered critical because the sector's emission levels have continuously grown. While other sectors have achieved considerable CO2 reduction,

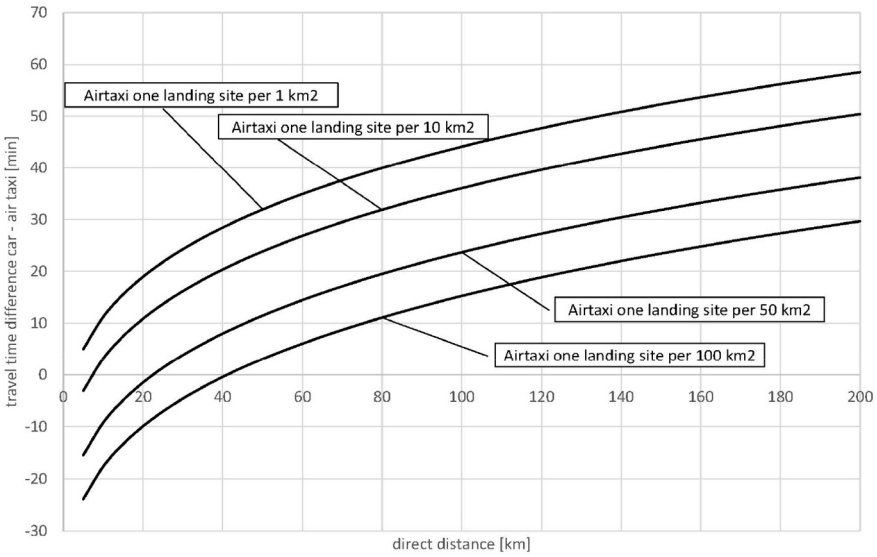

Fig. 1. Impact of Vertiports distribution on travel time by air taxi (BMVI, 2019).

e.g. industry, housing, or agriculture, a fast growing demand for passenger and freight activities "could outweigh all mitigation measures" (IPCC, 2014, 8).

The shift towards a sustainable future has to follow the three basic strategies of achieving efficiency, consistency and sufficiency (Huber, 2000). With respect to the transportation sector, strategies for a 'sustainable mobility paradigm' (Banister, 2008) range from renewed land-use policies and technological innovation to user participation. More precisely, a sustainable transportation future would mean to travel less, with shorter distances and using more eco-friendly modes of transportation.

The history of technology and transportation has demonstrated how the aim of sustainability was often accompanied by the promotion of innovative transport technologies (Edgerton, 2006; Kellermann et al., 2014). Our analysis unveiled that drones are by no means an exception (Uber, 2016; Airbus Blueprint, 2018). Reflecting a growing awareness for the need of 'green' transportation, environmental friendliness was identified as one of the key arguments in favor of the use of drones. More precisely, the key argument stressing drones' expected environmental benefit is the point that they are battery powered thus avoiding (local) pollution. Indeed, the technological development of (civil) drones almost uncontestedly focusses on battery powered movement. However, recent debates increasingly demand that the analysis of electrified mobilities takes into consideration electricity sources, use phase energy consumption, vehicle lifetimes, and battery replacement schedules (Hawkins et al., 2013). In short, if drones were to become a serious new means of sustainable transportation, they certainly will have to prove their feasibility against the paradigm of sustainable mobility.

In order to evaluate the sustainability of drones, a full life cycle assessment would need to be performed. Based on the estimated energy efficiency and environmental costs drones could then substitute traditional mobility offers wherever they are evidently more sustainable. A true assessment of the environmental friendliness of drones therefore needs to include a stronger comparative perspective, taking into account other modes of transportation. Based on the current research and available data such an assessment cannot yet be made.

In order to make drones a (more) environmentally friendly technology, the electric energy powering drones would have to be fully generated from renewable energy sources. Secondly, drones' batteries would need increased energy efficiency. However, propulsion and vertical mobility are generally more energy-intensive than ground-based motion. It is, therefore, unlikely that in the near future drones will prove to be a more energy-efficient option compared to existing transportation technologies. Thirdly, in order to reduce emissions effectively drones' batteries would need to be recycled or reused.

There is reason to believe that there will be attempts to compensate the energetic shortcomings of drones through technological innovation. However, even if drones' energy efficiency were to increase, this strategy may result in rebound effects. Therefore, it has been argued that "ultimately what is needed, to limit energy consumption, is to achieve energy sufficiency (or conservation) rather than energy efficiency" (Herring, 2006).

Given drones' difficult energetic framework conditions, further scientific evidence is needed to prove that they are an environmentally friendly technology alternative. Only very recently logistics research has started to conduct comparative studies on the energy efficiencies of conventional fuel-based versus drone-based electric transportation (Figliozzi, 2017; Park et al., 2018; Goodchild and Toy, 2018). The results suggest that substitution effects are possible where individual one-trip-per-item deliveries (express, medical care) have so far been realized with conventional vehicles. In contrast, drones are likely inefficient when it comes to delivering several packages that could be bundled on a route (Goodchild and Toy, 2018). However, findings from these pioneering studies remain partial and therefore may hardly permit a generalized assessment of the environmental friendliness of drones.

Future studies would have to develop a holistic assessment of the environmental effects of drones. This will have to include an appropriate life-cycle assessment of battery-powered drones, including the entire supply chain and further comparisons to other modes of mobility. Moreover, in order to conduct a comprehensive sustainability assessment the footprint of supplementary infrastructures (warehouses, charging stations, controlling stations) has to be put against possible savings on existing road infrastructure (Stolaroff et al., 2018).

5. Conclusion

Our analysis of 111 interdisciplinary publications examining the subject of drones revealed that since 2013 the discussion about a potential use of delivery and passenger drones has flourished, particularly in academia. Overall, we found that the current development is driven by a clear expectation of economic benefits, which is flanked less prominently by rather generalized expectations of societal and environmental improvements. More precisely, we found that the debate on the whole is characterized by the juxtaposition of rather definite economic expectations with quite complex and differentiated problems and concerns. This reflects the uncertainties still surrounding many of the technical particularities and potential impacts of drones on both societies and the environment.

It remains to be seen whether drones for transportation are a solution to the existing problems or a mere problem shift from ground to air. At first

glance, the vertical move into low level airspace appears to be an intuitive, simple, and, as shown, historically long-aspired move. However, such claims will have to prove themselves against the disillusions of former transportation innovations. That said, however, we have to be careful not to simply reproduce the problems and inequalities for the sake of progress. In this vein, it is debatable whether current transportation problems on the ground are the driver of drone technology developments or if such problems act as legitimation for the actual aim of exploring new market segments.

5.1. Limitations

We can not claim to have fully comprehended drone related debates within the respective time period. High information densities within the thematic fields of investigation did not allow us to cover the whole spectrum of articles related to the respective topics. Future research should address this and expand the focus of analysis based on the categories we established in this paper.

Moreover, despite a clear previous definition of codes and reasonable result of our inter-coder agreement analysis, a coding process involving three coders may have increased the risk of misinterpretation. This is also shown by the rather low Krippendorff's Alpha achieved in the ICA. At the same time, the collaboration between a team of researchers with different academic backgrounds and disciplinary expertise proved highly beneficial to the research process and allowed us to gather valuable interdisciplinary insights.

Finally, the boundaries between drones used for transportation or sensory purposes sometimes remain blurry as many studies did not fully separate these two main implementation scenarios. Since the assessment of drones can differ greatly from the implementation scenario, future research should make sure to clarify the relatedness of findings to the respective use case. This in turn would help professionalize the discourse on drones as a transportation medium. As a first terminological step to achieve better differentiation between logistics and passenger purposes we therefore propose to utilize the term Urban Air Logistics (UAL), which complements to the already well-established term of Urban Air Mobility (UAM) used for passenger transportation.

5.2. Relevance

The analysis provides an interim picture and discursive wrap-up within a highly dynamic field characterized by various uncertainties. As we have shown, these uncertainties are compensated (or reflected) by often oversimplified promises and premature evaluations. This calls for an intensification of research efforts and further interdisciplinary inquiry. These inquiries would have the task to promote more comprehensive discussions on expected positive and negative effects of the technology. The results could then support an informed social and legal discourse on which sustainable economic development can be based. Technology assessment and mobility studies do not yet seem to have fully realized the topics' potential relevance. This review therefore calls to sensitize for drones as a new subject for the social sciences engaging with emerging transportation technologies in general as well as for disciplines of transport and urban planning or the civil society in particular.

5.3. Outlook

As delivery and passenger drones may soon come closer to real life implementation they will become more ‘tangible’ to wider parts of society. Thus, the critical moment might come where public acceptance will be of vital influence. We found that, so far, the subject of drones is mostly debated within a small circle of technical, economic and legal stakeholders. Due to that, societal perspectives of civil drone deployment have so far played a comparatively marginal role. As the public acts as a central stakeholder in this innovation process, drones' various potentials can only unfold if their development is in line with demands for the benefit of society. In order to avoid potential societal conflicts in the near future, the debate on drones would have to leave the circles of engineers, academia and legislative bodies solely discussing the future of drones in public space. This will involve a stronger consideration (and recognition) of drones' potentials and risks and a realistic evaluation of drone-related promises. In this context, this review may have come at just the appropriate time.

Authors' contributions

Robin Kellermann: Conceptualization, Project Administration, Supervision, Funding Acquisition, Writing - Original Draft.

Tobias Biehle: Formal analysis, Data Curation, Writing - Review & Editing.

Liliann Fischer: Methodology, Validation, Writing - Review & Editing.

Availability of data and materials

The datasets used in the current study are available from the corresponding author on request.

Declaration of competing interest

The authors declare that they have no competing interests.

Appendix A. Annex

A.1. Search items of document sampling

	German keywords	English keywords
General key words		
	zivile Drohnen	Civil drones
	UAV, UAS, RPAS	UAV, UAS, RPAS
	kommerzielle Drohnennutzung	Commercial drones
Thematic clustering of key words		
Passenger transportation	Passagierdrohne	Passenger drone
	Flugtaxi	Drone AND passenger transport
		Urban Air Mobility OR UAM
Drone Delivery	Drohnen UND Güterverkehr	Drones AND delivery
	Drohnen UND Logistik	Drones AND logistics
	Drohnen UND Pakete UND Lieferung	Drones AND parcel delivery
Sustainability	Drohnen UND Nachhaltigkeit	Drones AND sustainability
	Drohnen UND Umwelt	Drones AND environment
Ethics	Zivile Drohnen UND Ethik	Civil drones AND ethics
	Drohnen UND Ethik OHNE Militär	Drones AND ethics NOT military
Infrastructure and planning	Drohnen UND Infrastruktur	Drones AND infrastructure
Attitude and acceptance research	Drohnen UND Gesellschaft	Drones AND society
	Drohnen UND Akzeptanz	Drones AND acceptance

A.2. Documents displayed per document group

Selection criteria	Document group	Number of documents
Year	2013	5
	2014	9
	2015	12
	2016	20
	2017	22
	2018	38

(continued on next page)

(*continued*)

Selection criteria	Document group	Number of documents
	2019	5
Author	Politics	7
	Private sector	13
	Academia	88
	Civil society	3
Geographic area	All except EU and US	8
	Germany	8
	EU (without Germany)	18
	EU (with Germany)	26
	US	18
Research design	Empirical/experimental	36
	Theoretical/conceptual	75
Thematic	Logistics	22
	Humanitarian Logistics	3
	Sustainability	9
	Passenger transport	3
	Law and regulation	13
	Political and programmatic aspects	7
	Urban planning	8
	Overview	21
Area of use	Rural	5
	Urban	16
	Not specified	92

A.3. Codebook excerpt

(*continued*)

Code	Definition	Example
Potential problems (legal)	These codes identify different types of problems connected to the legal framework. On the one hand, these are ways in which **drones conflict with the existing legal framework** which might not be suited to cover law infringements by drones. These are problems resulting from the fact that the **existing legal framework is not designed to effectively regulate drones**. On the other hand, these codes identify **problems resulting from newly created laws** or laws that were adapted to drones. The code covers both the long existing and the newly created legal framework.	"Currently, there are **gaps in the laws** that cover drones and these gaps may enable drones to **take advantage of 'hackable space'** within the system" (77:53)
Expected benefits (environment/sustainability)	Has various dimensions. On the one hand, this includes the hope that drones will be a **sustainable alternative** to existing technologies and thereby will have a positive influence on the environment. On the other hand, these expected benefits are formulated as scenarios in which drones take on **environmental protection tasks**.	"When the comprehensive environmental impact was evaluated after adding nine impact categories and normalizing and weighting the data, the **environmental impact of drones was found to be one-twelfth that of the motorcycle**" (14:12)
Anticipated barriers (acceptance)	On the one hand, these quotations describe the general fact that **public acceptance is necessary** for drones to ever be used commercially (and in great numbers) and that **acceptance is still lacking** in many cases. On the other hand, they identify **particular factors** which result in a lack of acceptance - factors that provoke **public resistance** to drones.	"Autonomous air traffic must be able to solve current problems concerning **noise generation and the intrusion of privacy to win the acceptance of customers and regulators**." (45:47)
Proposed solutions (legal)	This code family has two dimensions. One includes **solutions for specifically economic problems** posed by the use of drone technology. This could be proposals for overcoming barriers to profitability which prevent investments in drone technology. On the other hand, it also encompasses proposals which include **economic actors, processes or mechanisms** but describe solutions for problems which are themselves not economic in nature.	"The **concept** gives **incentives for (unmanned) aircraft manufacturers and operators to invest** in performance relevant technology, but **doesn't exclude airspace users** with low levels of equipment from entering the U-space airspace." (17:22)

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