Lifting healthcare to the sky: Drones for improving medical infrastructure

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Abstract

- Remote communities often rely on weak infrastructural connections, which complicates access to essential medical supplies.
- Drones provide a green window of opportunity as a leapfrog technology to overcome infrastructural challenges. There is large potential in the medical sector to complement existing infrastructure in a decentralized healthcare system.
- Future implementation of drone technologies requires extensive consideration of societal (mis)perceptions and concerns relating to drone technologies. Inclusion and involvement of remote communities in the implementation process is fundamental to future projects.
- National regulatory frameworks need to facilitate the implementation of medical drones by providing clear guidelines on use of medical drones, as security concerns remain difficult to navigate.
- Although future trajectories of medical drones can differ based on a multitude of factors, widespread implementation of medical drones is most feasible through public-private partnerships.

Infrastructure is considered a prerequisite for development[1], and subsequently necessary to narrow global disparities. Yet, infrastructural weaknesses remain a challenge for many regions in the Global South[2]. These challenges especially affect remote communities and hard-to-reach areas, as geographical barriers exacerbate problems for the construction of adequate infrastructural networks[3]. Lack of transport infrastructure like roads, railways, bridges, and ports, complicate the delivery and mobility of goods and people, and subsequently contributes to the perpetuation of regional inequalities[2] between hard-to-reach and better-connected communities. Approximately one billion people – about one third of the global, rural population – live more than two kilometers away from an all-season road that connects them to essential services[4].

The infrastructural challenge for such remote communities is particularly pressing for the medical sector, as poor transport infrastructure fails to secure medical supply chains[5]. The current dependency on traditional modes of ground transport, such as motorbikes, trucks, or boats[2,3] does not allow for accurate, timely responses to the communities' medical needs, and furthermore poses security risks as the existing infrastructure's functionality can be unreliable[6] or weather dependent. These issues already prove difficult to overcome and are likely to be exacerbated by the consequences of climate change on extreme weather conditions[7]. The implementation of unmanned aerial vehicles (UAVs) in the medical sector can have a lasting impact on remote communities' access to medical supplies. Access to this technology, however, has so far complicated the implementation and widescale utilization of medical drones. This brief discusses the synergies and trade-offs that emerge when increased access to drone technologies for the transport of medical supplies to hard-to-reach communities in the Global South is promoted. An analysis of different application scenarios informs the recommendations for policymakers in the field of infrastructure and healthcare to facilitate these future pathways.

Current state of medical infrastructure

Countries with a high number of remote communities are pushed to decentralize healthcare facilities, which can have major adverse consequences. Decentralization results in many remote communities having only basic healthcare facilities at their disposal, as there are often no financial resources to provide each individual community with a fully-fledged hospital. For example, many hard-to-reach Pacific Islands with fewer than 1000 inhabitants rely on primary health care services, often delivered on an informal basis by community members and occasional visiting staff[8]. Decentralized healthcare facilities furthermore result in a decentralized stock of medical supplies, such as a decentralization of blood storage. This consequently results in increased wastage of supplies, like expired blood units[9]. In contrast to centralized hospitals, individual small-scale healthcare facilities cannot benefit from the economies of scale to process the supplies[10]. However, a centralized healthcare system requires sufficient performance of the aforementioned medical infrastructure, which often lacks in many countries of the Global South that are currently dependent on poorly maintained ground

transport. To improve performance, frontier modes of transport can complement the infrastructure that is currently in place.

Drones for medical infrastructure: a 'green' mode of transport?

UAVs, better known as drones, have increasingly been used as a complementary mode of transport, especially for medical purposes[11]. Battery-powered cargo drones can fly up to 150 kilometers at 90km/h and can carry up to 10kg of cargo depending on the type of UAV. As they do not require on-board personnel[11] and can be remotely operated under a wide range of weather circumstances[12], drones can easily transport medical supplies to and from remote areas[13], such as medicines and blood units (see annex 5 for an extensive list of medical supplies that can be transported by drones). They furthermore could provide a sustainable alternative to initiating large-scale infrastructural improvements. The discussion on drones as a green alternative to other types of transport is very complex. Measuring CO2 emissions for medical drones is incredibly complicated, since they are highly dependent on the production type of the power used. When powered by solar panels for example, drones have a very different CO2 balance than coal power plants. Additionally, the weight of transported goods, as well as wind resistance, type of drone, and type of battery, all affect the CO2 balance[14].

"Drones make sense when you have to carry things that are light, that need to go over challenging terrain very quickly – or almost immediately"[6]

Still, studies have shown that drones generally have a better CO2 balance than trucks, which are often used for the delivery of medical goods to hard-to-reach communities in the Global South. Especially for shorter distances, drones are more CO2 efficient than trucks[15]. This is in line with the findings from the College of Engineering[16], that found drones to be the second most efficient, just behind E-cargo bikes (Fig 1). Although these case studies relate to specific instances, the multitude of similar findings suggest that drones do indeed produce fewer emissions than other forms of transport[17–19].

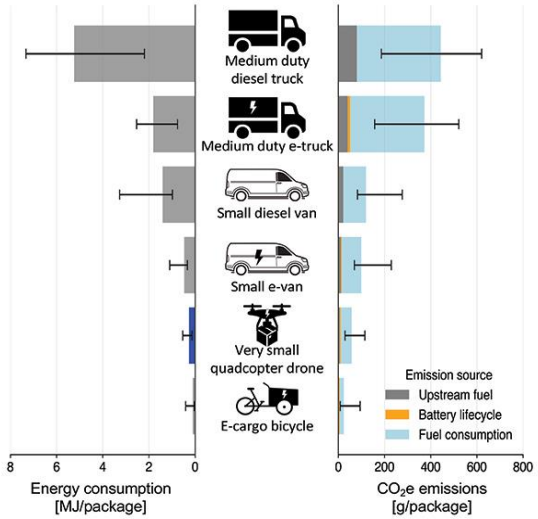

Figure 1. Source: Carnegie Mellon University, College of Engineering

A comparative scenario approach

As there is no single trajectory for the future implementation of medical drones, thematic scenarios will explore the synergies and trade-offs of future pathways. The scenarios assume that prerequisites for implementation (the framework) are adhered to and explore how different driving forces affect future trajectories (axes and driving forces). In this policy brief, trade-offs and synergies of all four scenarios will be explained briefly. For a more elaborate analysis on each scenario, see annex 4.

Framework: prerequisites for future pathways

There are several factors that are integral to successful implementation of drone technologies in the healthcare sector. These prerequisites are community inclusion, understanding of existing healthcare infrastructure, and (national) regulations.

"There is a lot of informal communication that needs to take place – a lot of relationship building"[20]

Community inclusion is essential for successful implementation of drones for the transport of medical supplies in the Global South. This can be done through analytical approaches like a community perception study, results of which can then inform Community sensitization campaigns. Stakeholder engagement and reciprocal education between the government, implementing entity and the community is needed[5,20]. Additionally, existing healthcare infrastructure needs to be respected and implemented into the drone project. Questions like how the medicine gets onto the drone, who puts it in, what qualifications are required to operate the drone, how patient confidentiality is treated, and the starting point of the drones' journey, all need to be addressed[21]. Therefore, implementation of drones in the healthcare system needs to be

addressed to ensure successful and sustainable implementation.

"The drone technology [...] is there but how to integrate it into a healthcare system is [...] the more challenging change management question"[20]

The implementation of drone technologies is furthermore dependent on the regulatory framework in aviation security and navigation. Regulations can ensure that technological concerns, such as surveillance issues[12] and safety limitations are clearly defined and addressed, but a lack of regulations similarly facilitates the implementation of drones[22]. As such, our scenarios assume that the regulatory framework is permissive of the implementation of medical drones. Furthermore, it is assumed that mutual public-private cooperation allows actors, both public and private, to develop their projects[9,23]. That is to say, it is assumed that privately initiated projects are enabled by the public sector, and vice versa.

A more elaborate explanation of the framework can be found in annex 1.

Driving forces

The outcome of implementing medical drones is affected by the following two overarching factors:

Technological nature: the outcome of medical drone projects is affected by the projects' overarching goal of adapting or innovating existing medical drone technology. Adaptive projects look to implement readily available drone technologies in existing medical infrastructure and aim to adapt to the most urgent medical needs of the respective remote communities. Innovative projects, on the other hand, focus on improvement of drone technologies to make them more versatile and efficient.

Economic incentive: economic incentive of those initiating medical drone projects affects how the project is implemented, as profit versus non-profit driven projects will prioritize different considerations.

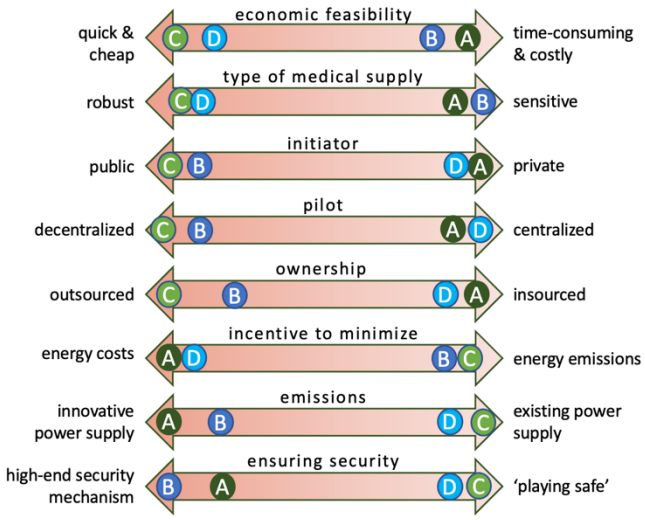

Figure 2. Micro-scenarios' driving forces

The outcome of drone technologies' implementation is, thus, dependent on the economic incentive with which it was initiated. Based on these axes and the frameworks' assumptions, the following four scenarios illustrate future trajectories and explore the impacts that the driving forces have (see Figure 2 and Annex 2).

Scenario A – Someday innovation will pay off

Profit driven and innovative

Although **standing out with innovation** is a profit-driven business model for a private initiative aiming for a **high economic comparative advantage** in the field of drone technologies, countries of the Global South will benefit from the developments in terms of **diversified types of medical supplies** that can be transported and **high-end security mechanisms**. Additionally, the environment will benefit from **more efficient power units** that are initially developed to reduce costs. However, a significant trade-off of this profit-driven innovation is the **large amount of financial resources** needed, as well as the **time-consuming** nature of the development projects. In other words, innovative drones are **not readily available** to adapt to urgent medical issues in countries of the Global South. Additionally, there is a risk that jobs will be lost due to **centralized pilots** or **autonomous drones**. Lastly, **insourced ownership** of the drones means that the national government has less control over the project.

Scenario B – High-tech, small scale

Non-profit driven and innovative

With scenario B, a **public initiative** is realizing the **long-term transport** of medical supplies, with **high-tech** drones supplying a variety of medical supplies to remote communities. As research about innovative drone techniques inevitably takes time, the initial implementation will take longer and is going to be more **costly** due to the procurement costs. However, the drone technology will be much **safer** and **energy efficient**. The projects will utilize autonomous drones, which can be centrally operated by the public initiative itself. Hard-to-reach communities will be able to receive more **sensitive medical supplies** like blood samples, however, because of the high costs fewer communities will be part of this drone network.

Scenario C – Ready for take-off

Non-profit driven and adaptive

This scenario allows for **existing** medical drone technologies to be implemented within a **short timeframe**, facilitating accurate emergency responses as well as **decreased delivery time** of medical supplies. This results in **fewer casualties** and can reduce the amount of medical waste[24]. **Low investment costs**, due to outsourcing the procurement and logistics[25], and **reduced emissions** positively off-set comparisons to larger investments in traditional ground transport infrastructure. Conversely, outsourcing the technology procurement and logistical services results in **dependency** on external providers and higher costs long-term. The **limited carrying capacity** requires more frequent deployment of medical drones, and the subsequent **replacement of batteries** is both costly and environmentally unfriendly.

Scenario D – Don't reinvent the wheel

Profit driven and adaptive

The initiating, most likely private, organization in this scenario developed a business model to generate **quick revenues** by implementing **medical drones that already exist**. For this, the operating organizations go to places that need medical infrastructure improvement **most urgently**, and the technology will be **rapidly deployed**. The existing drones with **decentralized pilots** operate drones within visual line of site which will result in **fewer regulatory challenges** and security concerns. It can be seen as a 'green' synergy that companies invest in drones as **energy efficient modes of transport**, although the incentive behind this is the reduction of costs. This synergy however would be much bigger with innovative drones that run on newer energy efficient power supplies. The **stagnant innovation** in this scenario can thus also be seen as a trade-off. Other trade-offs in this scenario are the **low economic comparative advantage** of the existing drones, as well as the **limited variety of robust medical supplies** that can be transported by existing drones. Last, the national government has little control over the project since **ownership of the drones is insourced** by the commercial organization.

Upwards & Onwards: what now?

UAV technologies have a lot of unused potential in the field of medicine. Although they will not fix fundamental problems with existing infrastructure, drones provide both short-term and long-term solutions for hard-to-reach communities' medical supply chains where this is currently failing[5].

The previous scenarios illustrate what extreme pathways of implementation can look like. Where prioritizing the rapid inclusion of remote communities in the medical supply chain is the goal, governmental actors in health agencies should take immediate action in the procurement of drone technologies. However, when long-term implementation of medical drones is desired, the environmental externalities involved in the development of ground infrastructure can be more adequately addressed through deployment of more energy-efficient drones. It is therefore in the hands of actors in infrastructure and health areas to identify which synergies and trade-offs take priority, and which concessions subsequently need to be made.

Despite these considerations and potential future pathways, it is necessary to consider a 'moderate' scenario, that suits the application case, in which public and private actors not just enable, but collectively support and encourage improving accessibility to medical drones. Securing the financial funds for the development of these projects is most feasible through an elaborate collaboration between public and private actors. Strong collaborative efforts should, thus, take priority in any considered scenario as a way to close potential resource gaps[26].

Future pathways: recommendations

Nonetheless, there are a variety of actors that can implement, contribute, and benefit from widespread accessibility to drone technologies. Actors in the public and private sector in the field of infrastructure and healthcare should consider the following aspects when embarking on different trajectories.

Regardless of the chosen pathway, there should be careful consideration of the following aspects:

- Involvement of affected communities in the process of implementing medical drones. Those overseeing drone projects should develop *sensitization strategies* to uncover, address and mitigate societal misconceptions of drone technologies through community engagement. Local leadership can provide essential lines of communication to mitigate societal anxiety relating to the misuse of medical drones.
- Ensure that (supra-)national regulatory frameworks enable drone technologies to be implemented in the field of healthcare. Policy makers must include specific surveillance and safety precautions in (supra-)national legislation, to ensure that privacy, security, and safety concerns are addressed.
- There should be a shift from public-private cooperation to extensive collaboration. Increased accessibility to medical drones is most feasible through extensive public-private partnerships, which means executives from the public and private sector should collaborate in their efforts to introduce drones in the medical field. Informative events for public and private actors in the field of drone technologies should emphasize the value of collaboration in the field. Commitments and subsequent obligations should be contractually defined to ensure long-term viability of these projects.

Scenario	Key considerations
A) Someday, innovation will pay off	• In order to financially benefit most from a high comparative advantage of innovative drone technologies with long-term development processes, private companies should jump into the niche of the drone market as soon as possible. • Commercial companies should prioritize the development of more efficient power units in their drones, as this will reduce both energy costs and emissions.
B) High-tech, small scale	• Public actors should start investing in drone projects now, to keep up with the private sector and be able to have a comparative advantage through high-tech drone technologies. • To reduce CO2 emissions and the usage of fossil fuels, public actors should start using electrically powered cargo drones to transport medical supplies instead of motorbikes or trucks, within the next 5 years.
C) Ready for take-off	• Actors should prioritize the delivery of emergency medical supplies. • Public actors should clearly define the contractual obligations and expectations necessary for the outsourcing of medical drones.
D) Don't reinvent the wheel	• In order to achieve successful implementation as quickly as possible, profit-driven companies should deploy their drones in places that need medical infrastructure improvement most urgently. • To accelerate this process, governments of countries that urgently need this infrastructural improvement should actively recruit private actors that aim to deploy their drones as quickly as possible.

Annex 1 – Explanation of the framework

In order to research the synergies and trade-offs of making drones for medical transportation more accessible in four different scenarios, a basic frame was established. This frame lays the groundwork for all scenarios discussed, as it not only accounts for the focal points of this brief, but also aims to justify the assumptions that were made.

All four scenarios are focused on drones to transport medical supplies to and from hard-to-reach communities in countries of the Global South. Although the definition of 'hard-to-reach communities' is one of utmost complexity[27], numerous scholars point to the absolute geographical distance between these communities and the closest health facility, measured in both kilometers and time[28,29]. In addition, factors as terrain, nomadic movement, political turbulence are also seen as drivers of community isolation in a healthcare context[27]. With regard to the actual medical supplies, the focal point of this research is on medical supplies that are both lacking in the aforementioned hard-to-reach communities, as well as suitable to be transported by drones that are either existing or planned for future innovation. Within this framework, medical supplies can entail vaccines, medicines, blood units, laboratory samples, automated external defibrillators (AEDs), organs, mouth masks and a plethora of other possibilities[9,13,25,30,30]. The particular supply that can be transported by drones, however, also depends on the actual type of drone being utilized. This, respectively, is strongly related to the distinction between pioneering drones for future innovation and existing drones for quick adaptation to urgent matters.

Additionally, increased access to drones for medical transportation will also be inherently subject to the regulatory system that is in place. Even though findings of multiple expert interviews point to a regulatory pattern that indicate a difference between drone regulations on the European continent versus drone regulations on the African continent[9,22], it is clear that this regulatory system varies by case. Therefore, the regulatory context cannot, and should not, be generalized over the entire Global South. This framework acknowledges that the implementation of drones is always subject to such a regulatory context;

albeit the actual regulatory facet of implementation is still heavily dependent on a multiformity of drivers, such as the initiator and the profit versus non-profit nature of the project. The acknowledgment of a regulatory context is in line with the assumption that mutual public-private cooperation allows actors, both public and private, to develop their projects[9,23]. That is to say, it is assumed that privately initiated projects are commonly allowed by the public sector, and vice versa.

As a final cornerstone of the research framework, inclusivity plays an important part in all four scenarios. In this research, it is assumed that projects in the field of medical drone transportation are implemented in an inclusive and equitable manner. By including local knowledge and opinions in the respective hard-to-reach communities, development projects in the health sector are considered relatively effective and innovative[5,6]. These practices are considered the most people-centered, and can contribute to increased community acceptance. Therefore, inclusivity is not a driver within the four scenarios, but merely a given from which all scenarios were developed.

Annex 2 – Methodology

For this brief three main methods were used to conduct research. The first method is literature research, secondly expert interviews and lastly scenario building.

Literature research was first used to get an overview of the topic, at this stage both academic papers and news articles were studied. Through this research the research question and the sub-questions were identified. Each sub-question was derived from a relevant topic identified in literature research.

Based on these sub-topics, a set of questions per topic were defined, which were then used amongst different experts. The expert identification was informed by the sub-topics. The answers of the different experts were then categorized by sub-topic and analyzed, to draw conclusions for each topic. The intel from the interviews both decided the scenarios we picked in the scenario analysis, as well as the conclusions of these scenarios and the general structure in terms of chapters of the brief. Later, multiple experts reviewed the draft policy brief and added their opinions and feedback on the research. Their concerns were implemented as needed.

Figure 3. Visual representation of the methodology

In order to build the scenarios, multiple micro scenarios were established. These micro scenarios are in line with the two overarching axes (technological nature and economic incentive) and can be seen as driving forces of the eventual scenarios. The micro scenarios used in this research are listed below.

1. **Economic feasibility:** feasibility of the technology in terms of required time and financial means. Some strategies may result in a rather *quick and cheap* implementation, whereas other strategies result in a *time-consuming and costly* implementation.
2. **Type of medical supply:** the carrying capacity of the drone, related to the maximum sensitivity of the medical supplies that can be transported. Medical supplies can for example be very vibration sensitive, or regulation sensitive. Depending on the technique being used, the carrying capacity of a drone ranges from robust to sensitive medical supplies.
3. **Initiator:** the type of actor that takes the initiative to implement drones for medical transportation, which can either be from the public sector or the private sector. An example of a public initiator is a national government, whereas an example of a private initiator is a commercial company.
4. **Pilot:** the location of the pilot that controls the drone. Centralized pilots control the drone from a central operation center; decentralized pilots on the other hand are on site.
5. **Ownership:** the actors initiating drone projects can either develop and/or own the drone themselves (insourcing), or outsource the procurement, maintenance and ownership of the technology.
6. **Incentive to minimize:** the incentive to minimize energy usage, from either sustainable or commercial concerns. Respectively, the goal is to reduce energy emissions (sustainability concern) or to reduce energy costs (commercial concern).
7. **Emissions:** the emission of greenhouse gases, which depends on the development of the drones' power supply. Innovative power supplies are expected to have fewer and cleaner emissions, whereas existing power supplies are expected to be relatively polluting.
8. **Ensuring security:** the way security concerns are dealt with, for example with the use of technology. Some strategies may focus on high-end security mechanisms to ensure security, whereas other strategies prefer to 'play safe' with existing materials that come along with less security concerns.

An analysis on the scenarios that resulted from these micro scenarios can be found in annex 4.

Annex 3 Interviews

Name	Title	Affiliation
Adam Klectasky	Researcher	Czech Technical University in Prague
Anna Straubinger	Researcher	ZEW
James Middleton	Business Developer	AVY
Lammer Kooistra	Professor	WUR
Mina Carolina Baumgarten	Project Manager MV|LIFE|DRONE	Universitätsmedizin Greifswald
Nicolas Brieger	Head of Drone & Vertical Mobility Academy	Féderation International l'Automobile (FIA)
Pim Stevens, Vries Strookman	Project Leader, Communication Strategist	Amsterdam Drone Lab
Sandy Lee	Project Manager Drone Transport Initiative	The University of British Columbia
Simon Prent	Manager Drone Operations	ANWB Medical Air Assistance Services
Gabriella Ailstock & Olivier Defawe	Manager Health Systems & Director Health Systems	Village Reach

Annex 4 – Scenario analysis

Scenario A – Someday innovation will pay off

Profit driven and innovative

In this scenario, drones are made more accessible for developing communities by **profit-driven organizations** that are focused on the **innovation** of existing medical infrastructure in countries of the Global South. As an example, this could be a **multinational company** with sufficient **financial means**. Typically, a drone delivery project in this scenario stems from a private initiative and is **large-scale** and **long-term**[6] in nature. Because of the spacious time frame and financial possibilities, the initiating organization of the project is able to focus on technological innovation. To cope with security concerns, the project in this scenario typically focuses on technological advancements such as **high-end security mechanisms**. Other innovative improvements of the drones entail: (1) more **efficient power supplies**[31] to reduce costs; (2) **increased flight ranges**; (3) larger and more **diverse carrying capacity** of both robust as well as sensitive medical supplies[21]; (4) **centralized pilots** that operate Beyond Visual Line of Sight[9], or ultimately; (5) **autonomous flights** that do not require pilots at all[12]. Having these innovative technologies incorporated in the drones, the drones have a **high economic comparative advantage**, compared to drones that already exist in the market. This in turn is likely to result in the commercial company **keeping ownership over the drones** insourced. In turn, national governments are likely to have just little project control, implying that they will not be involved in development processes.

Synergies:

The private, innovative initiative results in **highly advanced** drones that can cover **long distances** due to improved power units. The incentive to drive down costs will result in these power units being **more energy efficient**, ultimately mitigating negative environmental externalities. The move towards autonomous drones results in **less man-power** needed for the eventual deployment of the technology. Additionally, the drones are developed to carry **more sensitive and larger medical supplies** and will be able to adhere to stricter safety and security regulations due to the high-end security mechanisms.

Trade-offs:

Due to the innovative nature of the project, the new technologies will **not be readily available**. The implementation process of the innovative projects will **take more time**, as the project is not driven by specific societal [needs]. Therefore, extensive, additional research and mitigation has to be done to address and counter societal misconceptions and concerns. Furthermore, the innovative nature requires **large amounts of funding**.

Scenario B – High-tech, small scale

Non-profit driven and innovative

A **future-focused public actor**, for example a publicly funded university, conducts **long-term** research on **small-scale** pilot studies to make medical drones more accessible for developing communities. Although these projects are a public initiative, they can get decent funds from both the government as well as from private companies. Because of the **wide time frame** and **large financial means**, the initiating entity is able to focus **on technological innovation**, having **autonomous drones** in the back of its mind. To cope with security concerns, the research group focuses on more technological advancements, such as **high-end security mechanisms**. This is only enforced by the fact that the research is largely public funded and stems from a public initiative. Also, these innovative technologies are focused on **low emission power supplies** to make transport via drones greener than it is currently. With all these innovative technologies incorporated in the drones of the study, these drones are likely to have a **high economic comparative advantage**, compared to drones that are already in the market.

Synergies:

Greater **protection against cyber-attacks** and other security risks. A variety of **different medical supplies** can be transported, such as blood units, blood sample and other vibration sensitive supplies. The drones are **autonomous**, which reduces the costs of the operation as **fewer pilots** are required to monitor and operate the drones. Sufficient internet connection and electricity networks are less of a problem than for other scenarios, as the **improved technologies** in this innovative scenario will use **satellite connections** for drone piloting. Due to the increased battery longevity, the drone needs to be charged less frequently and is therefore not as reliant on a stable electricity network for recharging[6]. Because it is a public initiative, the implementation country's guidelines regarding climate change actions are adopted and accordingly it will be attempted to make a drone that is **less carbon intensive** in its manufacturing and charging.

Trade-offs:

There needs to be **extensive infrastructure**, entailing, regulations, air traffic control, take-off, and pick-up stations[12]. All these factors, as well as the time and money invested in the innovation of drones themselves, will drive up the **costs** tremendously. Therefore, **fewer communities will be able to access this technology**, at least in its beginning phase. The business model for these types of drones is questionable since they are specially designed to be able to carry all kinds of sensitive medical supplies. Because of this specialization, other types of deliveries like e-commerce, will not be possible, which is **unattractive for private businesses** that could improve drone infrastructure in general[5].

Scenario C – Ready for take-off

Non-profit driven and adaptive

This scenario assumes that non-profit driven initiatives focus on adapting **existing** drones into current medical infrastructure. This means that the project will deploy **automated** drones that are **remotely piloted**. The project will be initiated by the **public sector** – such as governments or health facilities – and aims to **rapidly** facilitate delivery of urgent, **robust** (meaning insensitive to vibrations) medical supplies to remote communities. As there are financial limitations to the implementation of medical drones, deployment needs to occur at the **lowest price-point** possible and serves to **complement existing ground-transport** of medical supplies. To minimize costs, the procurement and logistical services of deployment will be **outsourced**[25], meaning companies will be hired to operate the drones. The drones will be powered by existing energy sources, such as lithium batteries.

Synergies:

Adaptive, non-profit driven initiatives allow for drones to be implemented in a **relatively short timeframe** (less than 15 months) [5], as actors in the **public** sector have an accurate understanding of both the infrastructural and medical shortcomings that remote communities are affected by. There is a clear understanding of the social perceptions and concerns regarding the implementation of drones. The implementation of the technology will be relatively **cost-friendly** short-term as there is no procurement of the technology itself[25] and it is thus cheaper than investing in improving ground-transport infrastructure. This subsequently means that public initiators **save resources on extensive training** and maintenance of the drones. Medical drones can be rapidly used for **targeted, efficient** delivery of **robust medical supplies**[13], such as blood units and medical tools. As the drone technologies use lithium-batteries for the power supply, they have **lower CO2 emissions** than improvements of existing infrastructure would produce.

Trade-offs:

Conversely, outsourcing the procurement and logistical services of the medical drones will result in **dependency** on external partner. In case of technical failure of the medical drone, e.g., external knowledge and assistance is necessary to regain functionality. Additionally, hiring these service providers will be more **expensive** in the **long-term** when medical drones are implemented for a longer period of time. Current drone technologies furthermore have potential security weaknesses as there are **few protection mechanisms** against security risks such as hijacking. The **limited carrying capacity** moreover requires medical drones to be **deployed more often** to deliver similar quantities of supplies to remote health facilities & communities than compared to traditional ground transport.

Scenario D – Don't reinvent the wheel

Profit driven and adaptive

In order to make **quick revenues**, private businesses can make the choice to implement **existing drone techniques** with **existing power supplies** in communities where health infrastructure problems concerning the transportation of medical supplies are pressing. As an example, drones from the Chinese drone company DJI can be bought and deployed, as DJI already has a major stake in the drone market[31]. In this case, the business model is to **adapt to the urgent with existing materials**, leading to **quick responses** and rapid revenues.

Synergies:

On the plus side of this strategy, **less financial means** are necessary to enter the market in comparison to innovative projects that require years of research. The biggest expense for innovative drone projects is the manpower to test the drones, pilot the drones and put the drones into service[9]. The only investment for a rapid business model in this scenario on the other hand, is the one-time expense of the drone itself. In addition, **investment in existing drones is generally less speculative** than an investment in drone innovation. After all, there is already a lot more knowledge about the technique when the technique already exists.

Many of the existing drones in the current market contain a box that carries medical supplies and includes a sensor to determine whether the temperature inside the box stays within set margins[9]. Therefore, **medical supplies that require steady temperatures** can be transported, which is an important medical facet. The existing drones used in this scenario are often **controlled by decentralized pilots and typically operate one drone at a time, sometimes within VLOS**, whereas innovative drone projects put their focus on centralized pilots who can **operate multiple autonomous or semi-autonomous drones BVLOS.** It is however widely assumed that these innovative autonomous drones have higher risks, resulting in the situation that autonomous drones are currently forbidden in many countries. It is widely assumed that these innovative autonomous drones have higher risks, resulting in the situation that autonomous drones are currently not used in many countries[12]. Organizations that implement existing drones with decentralized pilots on the other hand are expected to face **fewer regulatory**

challenges and **security concerns**. This again contributes to the fact that implementation of existing drones in this scenario will generate quicker profit than innovative drones will do.

As a synergy of aiming on quicker profit, the implementation of existing drones for medical transportation also implies **rapid deployment**. To generate quick profit, it is to be expected that operating organizations go to places that need medical infrastructure improvement **most urgently**. Although this is a profit-driven and market-driven strategy, those countries in urgent need will profit from rapid deployment.

As the main focus in this implementation scenario is on profit, investors in this scenario are not incentivized by philanthropic reasons, nor by sustainability concerns. However, since energy efficient modes of transport also result in **lower energy costs**, sustainable synergies are likely to arise. Drones are relatively energy efficient[6] in comparison to the diesel fueled lorry trucks and ferries that currently transport medical supplies to hard-to-reach communities. Besides, the required electricity is much cheaper than fossil fuels like petrol and diesel. As this will reduce costs, profit-driven companies are incentivized to invest in this relatively energy efficient and electric mode of transport. In addition, sustainable modes of transport reflect well on the company's image. Fortunately, this results in a sustainable synergy, as **drones will emit less carbon** than currently operating modes of transport that run on fossil fuels.

Trade-offs:

Making use of existing drones with existing power supplies also comes along with certain trade-offs. As the goal is to make profit as quickly as possible, **innovation of drone technologies is rather stagnant**. In turn, **economic comparative advantage of the drones is relatively low**, as there are already a lot of comparable and equal techniques in the market. This also translates to the applicability of the implemented drones, since **vibration sensitive medical supplies** such as organs are more difficult to transport with currently existing drones. For this to happen, innovative developments of the boxes that carry supplies under the drone would be necessary[21]. Secondly, stagnant innovation of drone technologies translates to **stagnant innovation of their power supplies**. In turn, the aforementioned sustainable synergy of utilizing drones as being relatively energy efficient modes of transport could be significantly stronger if more innovative power supplies would have been used.

As mentioned before, the main investment in this scenario is the one-time expense of the drone itself. After purchasing, the commercial company is likely to **insource ownership** over the machine. In that case, the government of the respective country in which the drone system is deployed will have **little control** over the project. The predominant power of the private sector that follows can be seen as a severe trade-off when making drones more accessible in this manner.

Annex 5 – Medical supplies that can be transported by drones

Medical supply	Sources
Blood units (for transfusions)	Nyaaba & Ayamga (2021) Interview Simon Prent, ANWB Medical Air Assistance Interview Nicolas Brieger, FIA UNICEF, Drones in Supply Chains Stokenberga & Ochoa (2021)
Automated external defibrillators (AEDs)	Nyaaba & Ayamga (2021) Interview Nicolas Brieger, FIA UNICEF, Drones in Supply Chains
Medicines	Nyaaba & Ayamga (2021) Interview Simon Prent, ANWB Medical Air Assistance Interview Nicolas Brieger, FIA UNICEF, Drones in Supply Chains Stokenberga & Ochoa (2021)
Vaccines	Nyaaba & Ayamga (2021) UNICEF, Drones in Supply Chains Stokenberga & Ochoa (2021)
Laboratory test samples	Nyaaba & Ayamga (2021) UNICEF, Drones in Supply Chains Stokenberga & Ochoa (2021)
Food for health facilities	Nyaaba & Ayamga (2021)
Antibiotics	Nyaaba & Ayamga (2021)
Antivenom	Nyaaba & Ayamga (2021)
Human body parts / organs	Nyaaba & Ayamga (2021) Interview Simon Prent, ANWB Medical Air Assistance
Social distance inspection	Nyaaba & Ayamga (2021)
Personal Protective Equipment (PPEs) (e.g., gloves and facemasks)	Nyaaba & Ayamga (2021) UNICEF, Drones in Supply Chains
Condoms	Nyaaba & Ayamga (2021)
Pathology specimens	Nyaaba & Ayamga (2021)
HIV therapies	Nyaaba & Ayamga (2021)
Micronutrients	UNICEF, Drones in Supply Chains
Lab results	UNICEF, Drones in Supply Chains
Medical wastage	UNICEF, Drones in Supply Chains
Reports and other documentation	UNICEF, Drones in Supply Chains

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