White Paper

Tip of the Iceberg: Economic and Environmental Impact of the Vaccine Cold Chain

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Introduction

Vaccines are undoubtedly among the most effective healthcare innovations of the 20th century, with an estimated 154 million lives saved to date as a result of global immunisation programmes[1]. The rapid development and mass vaccination campaigns seen during the COVID-19 pandemic were a case in point. In the 21st century, modern vaccine technologies push the boundaries of what is possible in terms of speed of development, but major challenges remain in the management of the cold chain between the point of vaccine manufacture and the point of vaccine administration to patient, regardless of location. Whilst we all remember the requirements for hospitals to procure large ultra-low temperature freezers for the storage of some COVID-19 vaccines, it is true that refrigerated or frozen storage is needed for all vaccines administered across the globe. The reliance on the pharmaceutical cold chain adds significant complexity to an already convoluted network of different stakeholders working together to ensure the maintenance of temperature control along the supply chain. This additional barrier is well-recognised in Low and Middle-Income Countries (LMICs) due to poor infrastructure. However, the considerable impact of the vaccine cold chain in high-income countries — including Europe and the United States — is often underappreciated.

In this white paper, we present an evidence-based approach to understanding the economic and environmental impacts of the vaccine cold chain in Europe, focusing on the UK, Germany and Spain, and provide in-depth analyses on the respective contributions of transportation, storage, and waste management.

Hidden difficulties in cold chain management

The pharmaceutical cold chain encompasses the entire supply chain with an uninterrupted temperature control using cold rooms, shipping containers, refrigerators, and vehicles to maintain the integrity and efficacy of biological medicines, including vaccines[2,3].

Most vaccines require constant refrigeration between 2-8°C, whilst some biologics must be stored at -20°C, and certain mRNA vaccines necessitate Ultra-Low Temperatures (ULT) as low as -80°C.

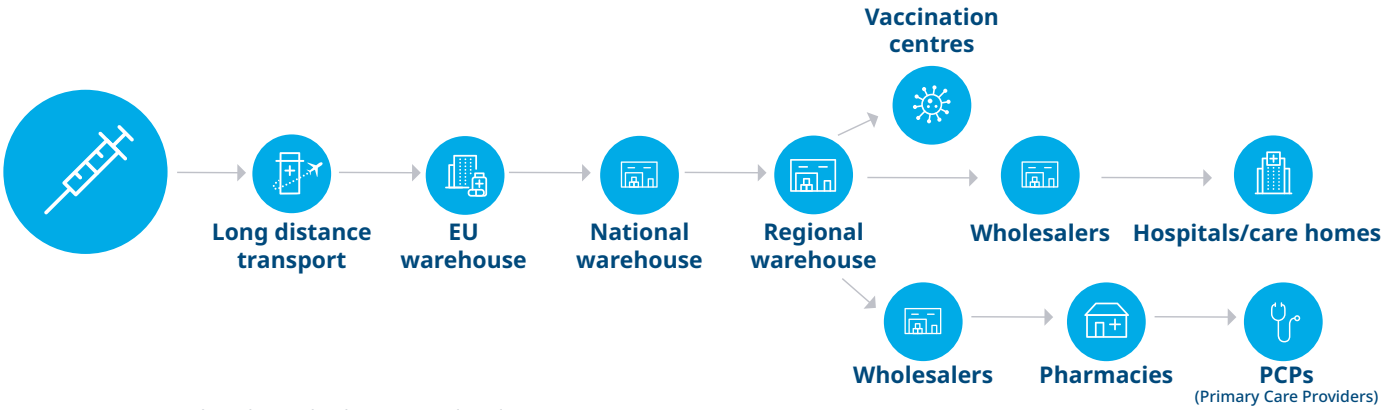
Strict temperature control is crucial, as most vaccines contain toxoid-based protein antigens that require precise structural integrity to elicit an effective immune response. Exposure to elevated temperatures can cause these proteins to unfold, aggregate, and degrade[4], whereas freezing temperatures can result in the formation of ice crystals[5], disrupting the protein structure and leading to irreversible denaturation.

Beyond antigen stability, adjuvants — such as aluminium salts — play a key role in enhancing immune responses by promoting antigen-presenting cells' activation and proliferation. Storage outside the specific temperature recommendations (typically 2-8°C) can drastically alter the physicochemical properties of an adjuvant, resulting in a loss of immunogenicity and rendering vaccines sub-potent.

The pharmaceutical cold chain encompasses the entire supply chain with an uninterrupted temperature control using cold rooms, shipping containers, refrigerators, and vehicles to maintain the integrity and efficacy of biological medicines, including vaccines.

Vaccines constitute a substantial portion of the global cold chain volume, with approximately five billion doses administered annually[6]. The logistical challenges of vaccine cold chain management arise due to the expansive supply network that typically incorporates multiple intermediary points, such as regional distribution centres and biopharmaceutical wholesalers (Figure 1). This complexity is further compounded by rigorous regulatory guidelines and vaccine-specific storage and handling requirements. While extensive efforts — including robust temperature monitoring systems, infrastructure improvements and comprehensive training — have been implemented, temperature excursions remain a considerable challenge in global cold chain management, with these incidents taking place across higher-, middle-, and lower-income countries.

Figure 1: Vaccine supply chain — illustrative



Source: IQVIA EMEA Thought Leadership; Kurzweil et al. (2021)

The management, maintenance, and investment in the pharmaceutical cold chain represents a substantial economic cost due to both the capital expenditure and operating costs relating to cold chain infrastructure, with UNICEF alone procuring $105.9 million of cold chain equipment and services in 2023[7]. According to IQVIA, the global cold chain market accounted for 38% market share of all pharmaceuticals, up from 26% in 2017, and expenditure on cold chain logistics was estimated to be around $21.3 billion in 2024[8,9].

Temperature excursions

Temperature excursions — instances where vaccines are stored outside the stipulated storage temperature requirements — may result in sub-potent or entirely non-potent vaccines. Consequently, these vaccines fail to provide adequate protection against targeted diseases.

Temperature excursions typically arise due to a combination of human error, equipment failure, and logistical challenges. A common cause of temperature excursions is the use of storage and transportation practices which expose vaccines to freezing temperatures. Freezing typically occurs due to an overemphasis on heat protection, driven by the misconception that vaccines are more susceptible to damage from heat than freezing. This may lead to the excessive use of ice packs during transportation of vaccines which require storage at 2-8°C.

Furthermore, the use of non-medical-grade refrigerators may cause temperature fluctuations and non-uniform cooling, resulting in the freezing of some or all of the fridge contents. Indeed, a 2017 literature review of freezing within the cold chain, spanning both higher- and lower-income countries, suggested that freezing of vaccines remains a widespread issue[10]. Vaccine storage data indicated that exposure to temperatures below the recommend guidelines were observed in 33% and 37% of higher- and lower-income countries respectively. Similarly, vaccine transportation data indicated that exposure to temperatures below those recommended occurred across studies in 38% of higher-income and in 19% of lower-income countries.

It is also well known that vaccine exposure to excessive heat can result from mechanical failure of cold-storage units as well as power outages. These issues are exacerbated in lower-income countries where cold chain infrastructure is often less reliable, and power outages are more frequent. However, human error — such as inadequate temperature monitoring and improper vaccine handling during transport — remains a key contributing factor to temperature excursions throughout the cold chain.

33%

Vaccine storage data indicated that exposure to temperatures below the recommended guidelines was observed in higher-income countries at a rate of 33%.

Implications of cold chain failure

Regulatory bodies — for example the UK MHRA — provide detailed guidance on incidents relating to errors in vaccine storage, handling, and administration, which informs decisions on whether to discard products[11] or not. Specific storage and handling protocols based on the precise formulation and resultant temperature sensitivity of each vaccine are typically provided by manufacturers. Any deviation from these recommended temperature control instructions necessitates disposal and destruction to ensure patient safety.

The WHO estimates that the vaccines wastage rate is a combination of three types of wastage:

- Closed vial wastage (Wc): due primarily to inefficiencies in the supply chain, including temperature control, temperature monitoring, and stock management during storage and transportation. According to the WHO, a maximum of 1% wastage rate can be attributed to each storage facility.
- Avoidable open vial wastage (Wao): usually attributable to immunization workers' practices, however, this likely only accounts for 5% of wastage.
- Unavoidable open vial wastage (Wuo): a key source of vaccine wastage, it includes discarded doses from unused doses of multi-dose vials, taking into consideration vial size, session size and discard time. These estimation can vary significantly across vaccine types and healthcare systems. For example, in Italy, 25% of total doses of the DTPa-HBV-IPV/Hib vaccine were discarded due to temperature excursion according to a study conducted by Silvestri et al. This number could be significantly higher for low income countries where temperature excursion equipment and data is not available.

In addition to economic losses, there is a significant environmental impact due to the substantial energy investment in the manufacturing, packaging, storage, and transport of wasted vaccines.

Temperature excursions which are not identified, and result in the use of sub-potent vaccines, pose a significant risk to public health campaigns. The Herd Immunity Threshold (HIT) varies by disease transmissibility. For highly contagious diseases including measles and polio, estimated HITs are 95% and 80%, respectively[12]. The administration of sub-potent vaccines can result in much reduced immunity resulting in increased frequency of outbreaks in unprotected populations. Although widely perceived as a challenge faced by lower-income countries, these events have also been observed in higher-income countries. For example, the Sydney Local Health District Public Health Unit recently identified an incident in which patients of a Sydney clinic were potentially administered sub-potent vaccines — due to storage outside the stipulated temperatures — resulting in the need to revaccinate over 1,000 patients[13]. Revaccination not only poses an unnecessary risk to individuals but damages public confidence in immunisation programmes, with vaccine hesitancy identified by the World Health Organization (WHO) in 2019 as one of the top ten threats to global health[14].

Towards sustainable solutions

The healthcare sector is estimated to account for approximately 4.4% of Global Greenhouse Gas (GHG) emissions[15], with the cold chain alone contributing 55% more GHG emissions (per dollar of revenue) than the automotive industry[16]. With an increasing emphasis on reducing GHG emissions — highlighted by the NHS UK's commitment to becoming a net zero national health service by 2040 — the importance of reducing supplier emissions is considerable. The increasing number of biologics in development further exacerbates these challenges. As per IQVIA data, over 50% of clinical-stage assets are biologics with the majority requiring temperature control[17]. Reducing global reliance on the cold chain is therefore crucial to mitigate the environmental impact of GHGs and ensure ambitious net-zero targets are met.

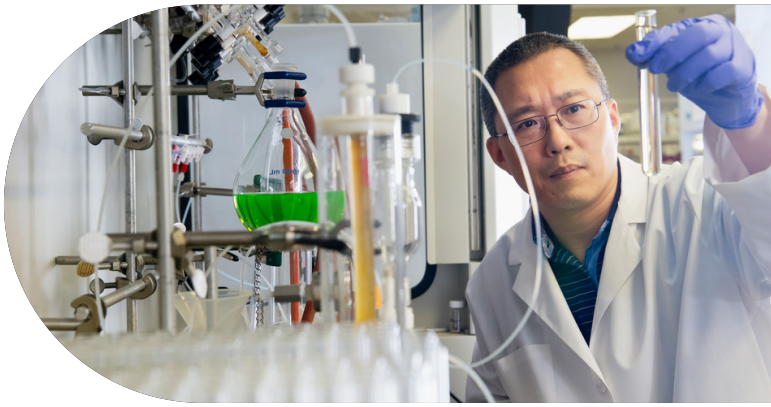
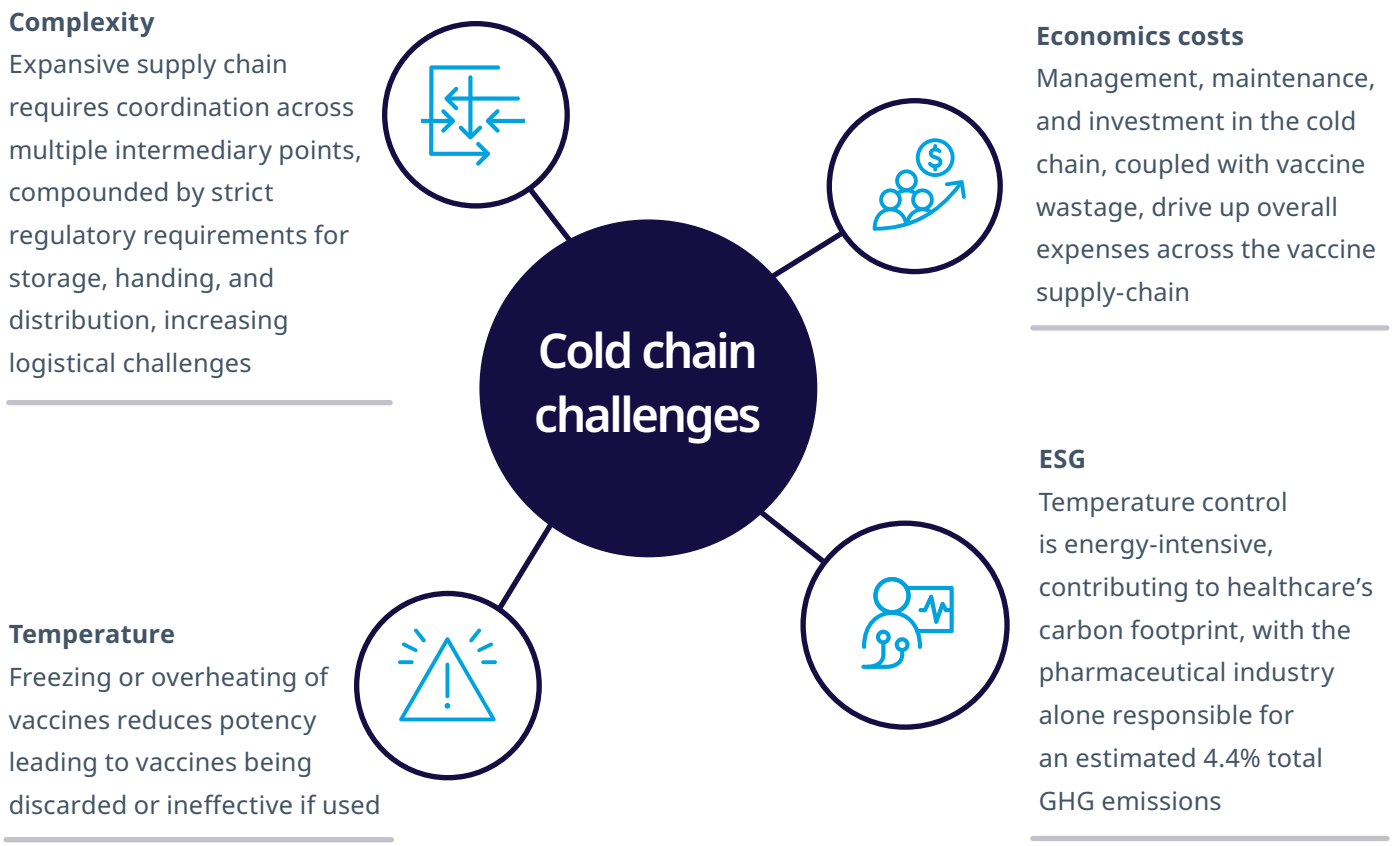


Figure 2: Vaccine cold chain challenges — not exhaustive



Source: IQVIA EMEA Thought Leadership

Through the simultaneous adoption of sustainable practices and the implementation of innovative thermostable vaccines and novel technologies, the pharmaceutical industry can play a significant role in achieving global emission reduction targets, promoting environmental sustainability, and ensuring access to safe and effective vaccines for all.

A promising solution to addressing problems surrounding the cold chain is the implementation of thermostable technologies into modern and existing pharmaceuticals. A hypothetical thermostable vaccine — as considered in this paper — would not require any cold chain transportation or storage and would be fully stable at a storage temperature up to 30°C (climate zone IVb conditions). This would remove all logistics surrounding cold chain management and bring storage and transportation requirements in line with those of small molecule drugs such as paracetamol tablets.

The total economic and environmental impact of thermostable vs. cold chain vaccines remains elusive. Here, we present a data-driven approach to understand the total economic and environmental costs of cold chain vaccines in Europe, compare them to thermostable vaccines and identify the major cost drivers using three different vaccine types as examples.

Methodology

We took a stepwise approach, as illustrated in Figure 3, to develop the white paper, which included hypotheses generation, and an extensive Targeted Literature Review (TLR) to understand and collect existing insights, data points and analyses that would help quantify the extent of the economic and environmental impact of cold chain requirements of vaccines.

For the TLR, a total 1,008 publications were identified by title from the OVID database which provides access to a range of journals, e-books and other databases and is referenced by clinical trials, bibliography searches and HTA websites. This total figure was reduced to 89 publications through screening of the abstract during the insight consolidation phase, and further reduced to 12 through a full publication scanning for relevance. These provided the data points required and informed the subsequent analyses. Furthermore, we conducted additional secondary research to support the data gathering for the planned analyses.

Our analyses focused only on certain stages of the vaccine lifecycle. As data on vaccine manufacturing and administration was either unavailable or varied significantly depending on the vaccine, we decided to focus solely on cold chain vaccine transportation, storage, and wastage (Figure 4), as well as the environmental impact. We focused on the economic and environmental impact across transport, storage, and wastage, using three representative vaccine types as case studies:

1. **Campaign vaccines** that are routinely administered, e.g., influenza
2. **Booster vaccines** for adolescents or adults based on national immunisation recommendations, e.g., Td-containing booster vaccines
3. **Stockpile vaccines** which are procured and stored as part of pandemic or security preparedness, e.g., H5N1 (bird flu)

Figure 3: Stepwise approach to understand vaccine cold chain economic and environmental impact

Literature review

Conducted literature review against pre-specified criteria

Existing insights consolidation

Identified key insights which would either support/disprove our hypotheses around the economic and environmental impact of cold chain vaccines

Analyses planning

Planned analyses to quantify the economic and environmental impact of cold chain vaccines

Additional research

Identified gaps in our inputs library from secondary research

Conducted analyses

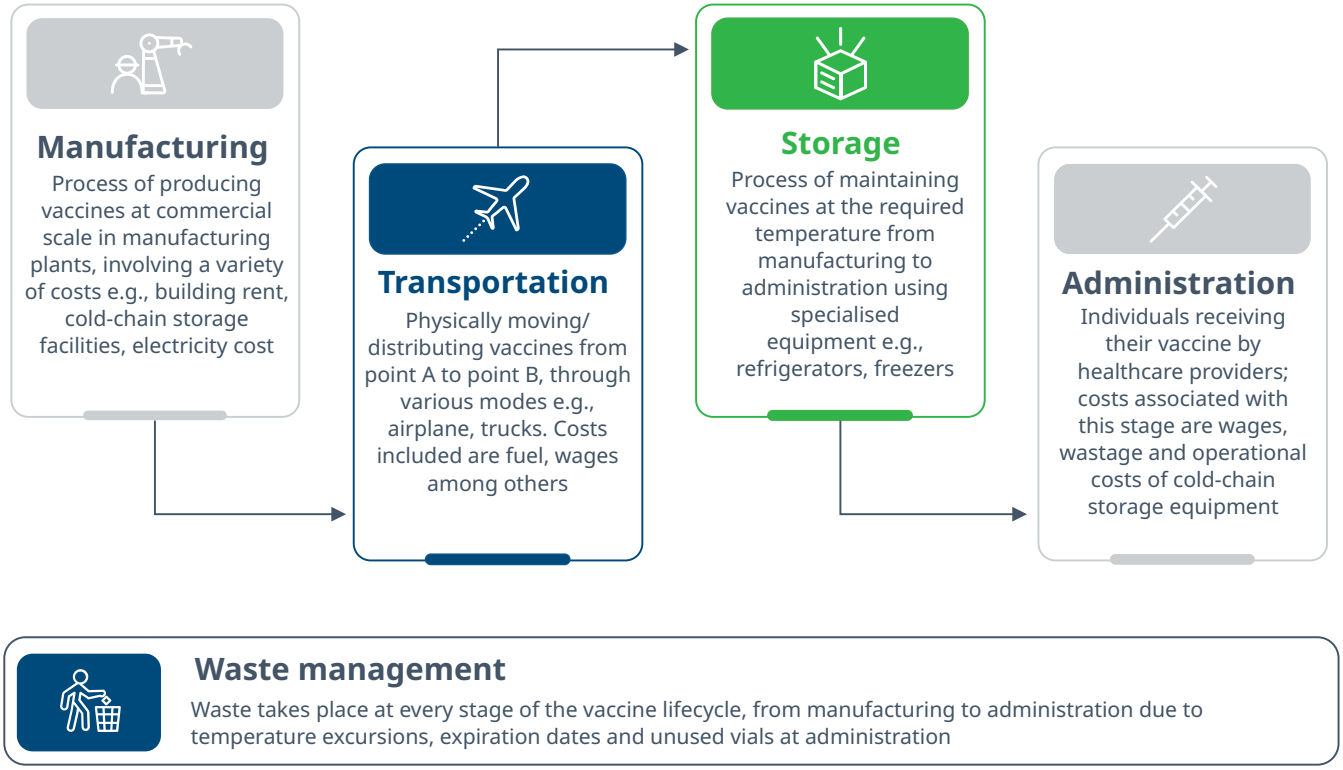
Using insights from existing literature, additional research conducted

Conclusion

Developed key conclusions

Source: IQVIA Strategy Consulting; IQVIA EMEA Thought Leadership

Figure 4: Economic and environmental impact analyses collection across the vaccine lifecycle



Source: IQVIA Strategy Consulting; IQVIA EMEA Thought Leadership

Transportation

To calculate the total transportation costs per dose of cold chain vaccine, we firstly looked at the total transportation costs for the 2023 UK influenza campaign, as calculated by Ibrahim et al.[18], which then allowed us to calculate the total transportation cost per dose by dividing the total transportation costs per week by the average number of doses administered per week. We assumed that transportation costs in Germany and Spain are likely to be similar to those in the UK, therefore the transportation cost per dose, per week in UK was applied to Germany and Spain as well. To obtain the total number of doses administered in the UK, Germany and Spain for adults over 65 years old, we leveraged figures reported by the OECD[19]. This number is likely an underestimation of total influenza doses administered, given that individuals eligible for an influenza vaccination comprise other higher-risk groups beyond the 65+ years population.

Subsequently, the total, yearly, transportation costs for influenza vaccines were calculated by multiplying the number of doses with the costs per week.

To interrogate the transport costs associated with booster and stockpiled vaccines, Td-containing booster vaccines and the H5N1 vaccine were selected as representative examples. Given the lack of available data on these costs, the cost per dose of influenza vaccine was extrapolated from the Ibrahim et al. figures and applied to both vaccines.

The total yearly doses administered of Td-containing booster vaccines in UK, Germany and Spain were quantified using publicly available information and IQVIA MIDAS data, whereas the H5N1 vaccine doses were obtained from publicly available information on the recent procurement agreed between the UK and European governments with CSL Seqirus.

Storage

To quantify the total storage costs, we broke down the costs into two main components: fixed costs and variable costs. The fixed costs accounted for the installation of supply chain assets including storage devices and building infrastructure, while variable costs were defined as the costs for operating the equipment and building where the vaccines are stored. Ibrahim et. al have calculated the total storage costs for the duration of the 2023 influenza campaign, broken down into these two cost components[18].
We calculated the total fixed and variable costs for storing an influenza vaccine in refrigerated units per week. Using this, along with the average influenza doses administered per week in the UK, we quantified the fixed and variable costs of influenza vaccine storage per dose per week. The total yearly storage cost across the three vaccine types in focus for this whitepaper was calculated using the total weeks of storage required and the total doses administered per year as described above.

Wastage

The WHO reported vaccine wastage of 1% per intermediary point in the vaccine supply chain due to temperature excursions. We mapped out a typical vaccine journey (Figure 1), identifying approximately seven intermediary points before administration, resulting in a minimum total wastage of 7% from transportation and storage. We understand that this number can be higher, as reported by Silvestri et al. where 25% of total doses of the DTPa-HBV-IPV/Hib vaccine were discarded due to temperature excursions[20]. Therefore, we assume that there must be a range of vaccines discarded due to temperature excursions along the supply chain. Expiration dates also contribute to wastage, varying by vaccine type. To calculate annual vaccine wastage, we used the total volume of vaccines administered per year, assuming 16% wastage due to temperature excursions, an average between 7% and 25% based on data from both the WHO and a Silvestri et al[20,21]. Wastage from expiration dates was estimated assuming that 13% of non-campaign vaccines are discarded due to expiration[22]. Stockpiled vaccines with a one-year shelf life, like H5N1, are assumed to be 100% discarded after 12 months. The total economic impact of wastage was quantified by multiplying the total doses wasted by the average list price for each vaccine type in the UK, Germany, and Spain[23].

Environmental impact calculation

We leveraged Patenaude et al.'s Greenhouse Gas (GHG) emissions estimates for AstraZeneca's COVISHIELD® as the assumption for all vaccines which require the same temperature control range, i.e., between 2-8°C. This publication focused on nine markets, including the UK and Spain[24]. To estimate the GHG emissions for Germany, we took the average of the UK's GHG emissions and Spain's GHG emissions. The total yearly GHG emissions from the three vaccines in focus were calculated by firstly quantifying the emissions per dose and then multiplying that figure by the total amount of doses administered per year. Similarly, the European GHG emissions were calculated by multiplying with the dose estimates described above.

Furthermore, we calculated the financial costs corresponding to the environmental impact of the cold chain vaccines in focus for this whitepaper by applying the carbon prices as published by the World Bank for 2024 for UK, Germany, and Spain. For Europe, we used an average carbon price.

Estimating economic and environmental impact of vaccine administration in Europe

At a European level, to quantify the economic and environmental impact, we firstly estimated the total vaccine doses administered in one year using the WHO reported global total and then multiplied this by 29%, as this represents the proportion administered in High-Income Countries (HIC). We further applied the total European population as a percentage of the total population of HIC to arrive at the estimated doses administered in Europe (~523 million doses in 2022). Using this figure, we were able to calculate the transportation, storage and wastage costs associated with cold chain vaccines, using the same inputs as discussed above.

For the cost comparison between a cold chain vaccine and a thermostable vaccine, we examined two different scenarios for the thermostable vaccine: the base case scenario and the best case scenario, each with different assumptions regarding storage and wastage. We assumed that transportation costs will remain the same, given that the modes of transportation and costs associated with them will likely be the same. On the other hand, storage and wastage costs are likely to differ substantially between cold chain and thermostable vaccines due to the limited need for temperature control equipment and risks of temperature excursions and expiration dates.

Results

In this section we will show the total annual economic and environmental impact of cold chain vaccines. We analysed the overall economic impact, compared the cost of cold chain vaccines to thermostable vaccines, and discussed the individual components across three representative vaccine types in Germany, the U.K., and Spain. Additionally, we quantified the total environmental impact of cold chain vaccines in Europe, as well as for the same three vaccine types and countries.

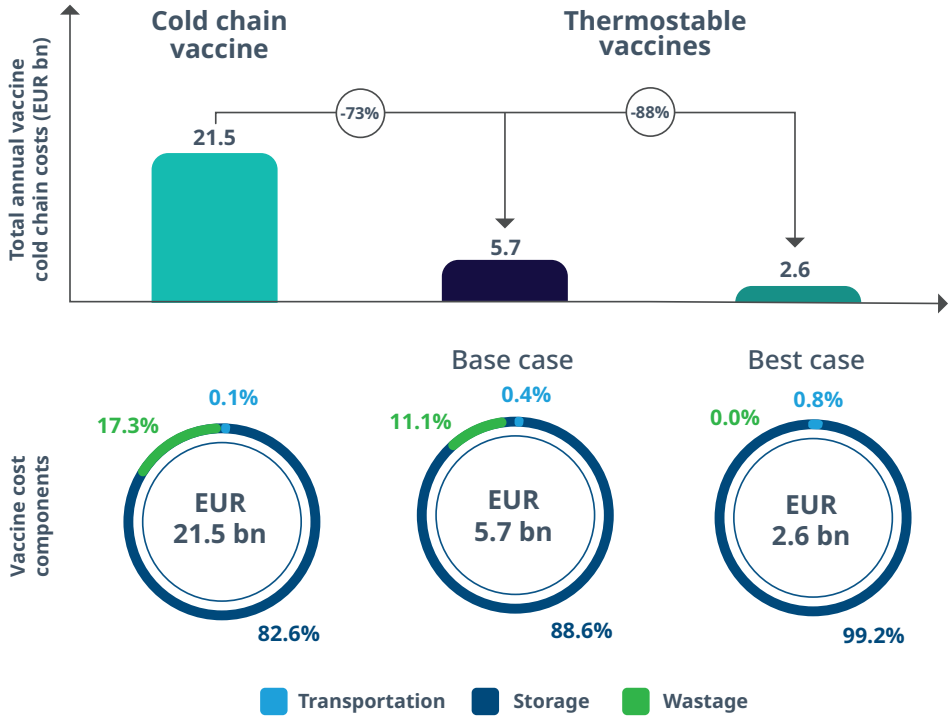
The cold chain has a significant economic impact

First, we looked at the combined economic impact of the cold chain on vaccines from transportation, wastage and storage in Europe. The total costs were significant, estimated at €21.5 billion per year. Storage costs accounted for most of these costs, with a share of 82.6%, followed by wastage with 17.3% (Figure 5). Transportation costs in contrast were almost negligible at around 0.1%. This was not surprising as costs for refrigeration were part of vaccine storage cost calculations. The actual cost of the cold chain might be even higher, considering that in future there may be a higher proportion of mRNA vaccines, requiring ultra-low temperature storage. Overall, the cold chain has a significant economic impact, with total costs comparable to the combined pharmaceutical expenditures of Poland and Austria[25].

Economic cost comparison of cold chain vs. thermostable vaccines

Next, we wanted to understand potential cost savings in Europe when switching cold chain vaccines to a hypothetical thermostable vaccine that does not require temperature control. In our base case scenario, we estimated a reduction in storage costs to 29%, while the best case scenario projected a reduction to 14%. Warehouse and storage costs typically account for 10-20% of the total costs associated with cold-chain logistics, including transportation[26]. Transportation costs were assumed to remain constant, as the mode and costs of transportation were expected to stay the same. Additionally, we assumed a 50% reduction in vaccine wastage, lowering it to 6.5% down from 13%, due to expiration only, with no wastage from temperature excursions. In the best case scenario, we assumed no wastage at all.

Figure 5: Comparison of the total economic impact of cold chain vaccines to thermostable vaccines



Thermostable vaccines assumptions

Base case

- **Transportation costs:** same as cold-chain vaccines
- **Storage costs:** 71% lower than those of cold-chain vaccines
- **Wastage costs:** 50% lower than those of cold-chain vaccines, assuming no wastage from temperature excursions

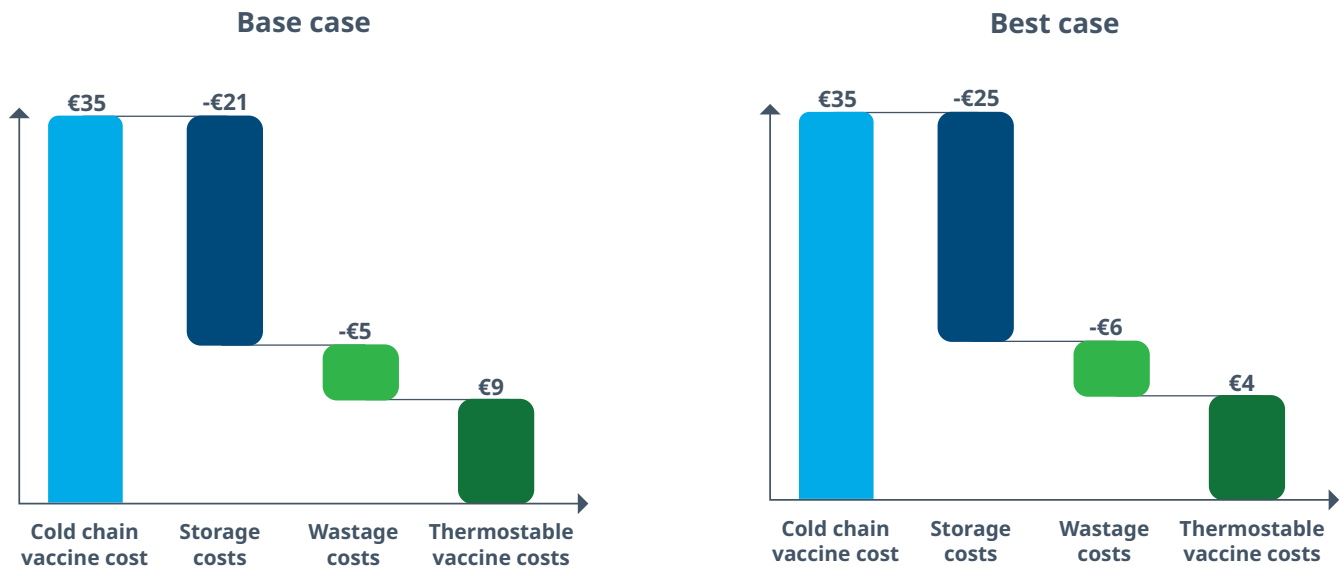
Best case

- **Transportation costs:** same as cold-chain vaccines
- **Storage costs:** 86% lower than those of cold-chain vaccines
- **Wastage costs:** none assumed vs. cold-chain vaccines

Source: IQVIA Strategy Consulting; IQVIA EMEA Thought Leadership

A thermostable vaccine significantly reduced total annual vaccine cold chain costs, ranging from €5.7 billion for the base case to €2.6 billion in the best case scenario, representing a total cost reduction between 73% and 88% annually (Figure 5). These potential cost reductions are likely underestimated. Depending on the manufacturing location, thermostable vaccines could use slower and cheaper transportation modes like container ships instead of expensive air transport. Additionally, would allow manufacturers to manufacture fewer batches, further reducing overall costs.

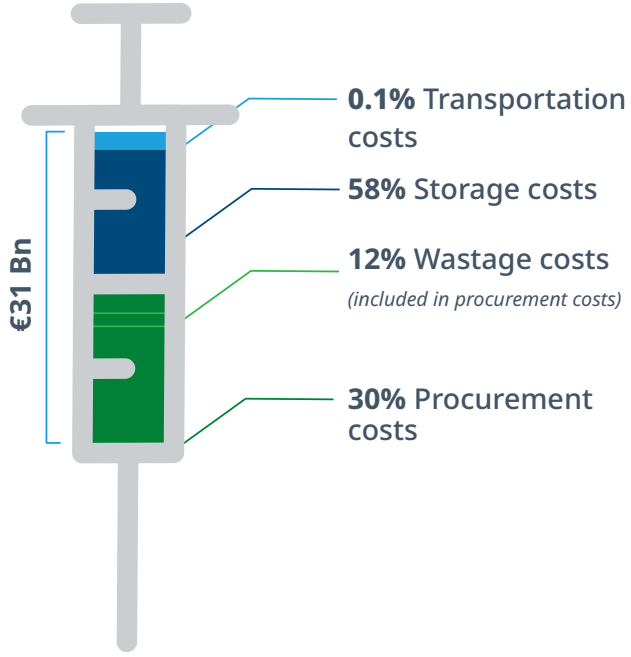
Figure 6: Cost difference per dose of a cold chain and a thermostable vaccine in terms of transportation, storage and wastage



Source: IQVIA Strategy Consuting, EMEA Thought Leadership

We also looked at estimating the cost savings per dose for a thermostable vaccine vs. a cold-chain vaccine. In our base case for a thermostable vaccine, the per unit costs decreased by €26, dropping from €35 to €9, which include transportation, storage and wastage costs. Storage and wastage cost reductions accounted for €21 and €5, respectively. In the best case scenario, the per unit costs were further reduced by €31 per unit, with cost reductions from storage at €25 and wastage at €6. (Figure 6).

Figure 7: Cold chain adds significant costs to vaccines



Source: IQVIA Strategy Consulting; IQVIA EMEA Thought Leadership

Vaccine procurement costs are a crucial consideration for healthcare systems when deciding which vaccines to purchase. To contextualise the procurement costs, we assumed an average per dose price of €15 based on the average price across vaccines for UK, DE and ES, as calculated by IQVIA. In fact, procurement costs only accounted for 30% of the total costs, with storage and transportation accounting for 58% and 0.1% respectively (Figure 7). Wastage costs alone accounted for 12% of total costs with these being part of the initial procurement costs.

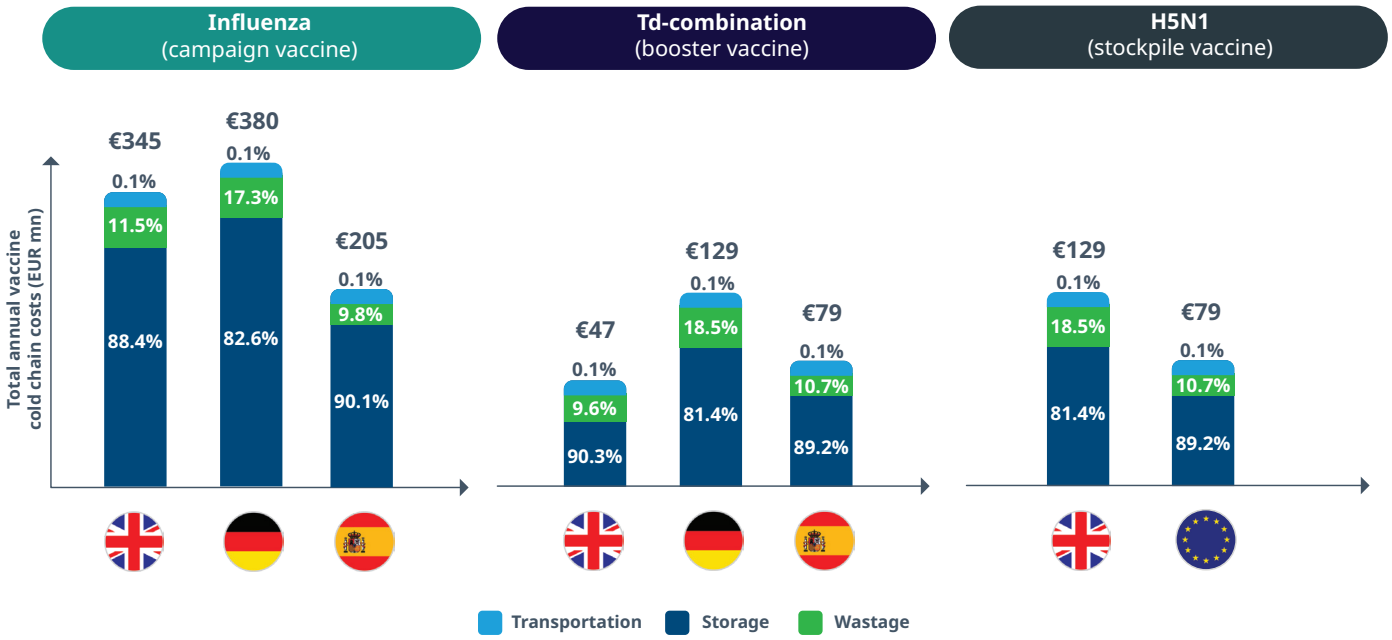
Overall, a full transition to thermostable vaccines could result in significant cost reductions in the European healthcare system, potentially saving between €26-31 in economic costs per dose. This translates to total annual cost savings ranging from €13.6 to €16.3 billion in Europe — more than vaccine procurement costs.

Cold chain vaccine cost comparison for different vaccine types

Acknowledging that total cold chain vaccine costs — excluding procurement — differ across different vaccine types, we have chosen to quantify the economic impact of a representative campaign, booster and emergency use-only stockpiled vaccine in Germany, Spain and the United Kingdom. Based on our literature review, vaccine volume data availability and public health interest, we decided to look at influenza, Td-containing and H5N1 vaccines below.

The **influenza vaccine** is updated annually based on the WHO Global Influenza Surveillance and Response System (GISRS)[27], thus ensuring that the vaccine is effective against the most current strains of the virus, which is crucial for public health. Storage cost was the main cost factor ranging from 82.6% to 90.1% of the total costs in the three countries in scope. Wastage was the second largest factor with wastage occurring mostly during transport and storage whilst expiration e.g., due to shelf-life is not relevant given the vaccine's seasonality. The relative costs associated with wastage differed by country. They are highest in Germany with 17.3% and lowest in Spain with 9.8%. This difference can be largely explained by the list price of the influenza vaccine in each respective country. Transportation costs accounted for only 0.1% of the costs in all three countries (Figure 8 left panel).

Figure 8: Economic impact of influenza, Td-containing booster and H5N1 vaccines



Td-containing booster vaccines (Td, Tdap, Td-IPV) are typically recommended for adolescents and adults in every 10 years. Consequently, the total number of doses required annually is lower compared to a campaign vaccine. Storage costs ranged between 81.4% and 90.3% of total annual vaccine cold chain costs. Vaccine wastage costs ranged between 9.6% to 18.5%. Besides wastage occurring mostly during transport and storage, Td-containing booster vaccines also expire within 2-3 years, contributing to higher relative proportions of economic costs associated with wastage. Costs related to transportation were generally low for Td-containing booster vaccines at 0.1% across countries (Figure 8 middle panel).

The **H5N1 vaccine** is a stockpile vaccine designed for emergency use and intended to protect against the H5N1 avian influenza virus in the event of an outbreak. It is procured by the UK government and the European Union. Due to the unavailability of list price data for the

H5N1 vaccine, we made assumptions regarding its cost, estimating it at €10 per vial based on pricing insights from similar vaccines[28]. The total annual costs due to the vaccine cold chain was split almost 70/30 between storage and wastage. This is not surprising as such a stockpile vaccine experiences wastage across the life cycle and must be discarded at the end of its 12-month shelf life. Transportation costs were again negligible with just 0.1% of the total annual vaccine cold chain costs (Figure 8 right panel).

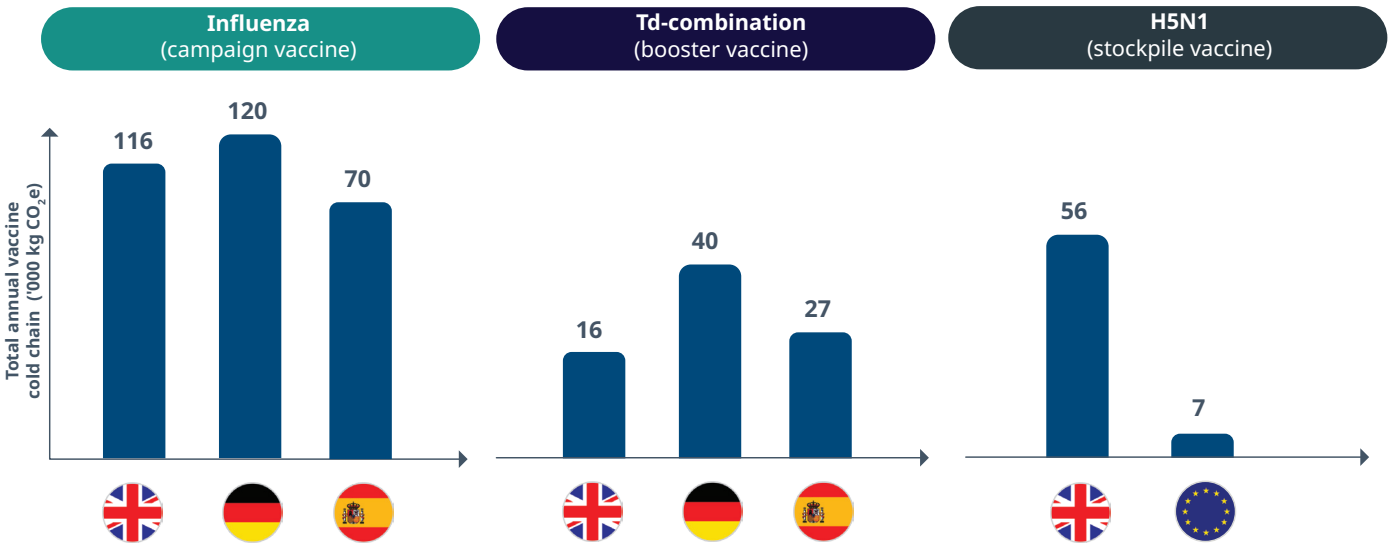
Environmental impact

The carbon footprint of medicines becomes an increasingly pressing topic for stakeholders across the pharmaceutical industry and healthcare systems. The exact contribution of cold chain vaccines has been elusive. To calculate the total annual carbon emissions from cold chain vaccines in Europe, we again used the total vaccine dose estimates and multiplied that with our kg CO_2 equivalents per dose value needed for refrigeration. We found that collectively, cold chain

6.7 million
kg CO_2e
Or the equivalent of driving an average car for 39.4 million kilometers

vaccines account for 6.7 million kg CO_2e per year in Europe or the equivalent of driving an average car for 39.4 million kilometres[29]. The true impact might be even higher as some countries rely more on fossil fuels for energy production. Moreover, as more mRNA-based vaccines reach the market, the total energy consumption will likely increase. The external costs of Greenhouse Gas (GHG) emissions can also be quantified by using carbon prices. The total annual costs from cold chain vaccines' environmental impact added up to €32.3 million in Europe[30]. A hypothetical thermostable vaccine would avoid refrigeration across the life cycle and could significantly reduce the carbon footprint.

Figure 9: Environmental impact of the vaccine cold chain



To understand the GHG emissions required to refrigerate the influenza, Td-containing booster and H5N1 vaccines in our countries of interest, we used the country-level dose estimates to calculate the total annual kg CO_2e. Unsurprisingly, the high-volume influenza campaign vaccine had a higher carbon footprint than booster or stockpile vaccines (Figure 9).

Conclusion

Our results demonstrate that the total economic and environmental impact of cold chain vaccines are considerable, and a transition to thermostable vaccines would lead to significant cost savings from the storage and wastage components. Further elucidation of the vaccine supply chain highlighted the multiple stakeholders involved — spanning from manufacturers to primary care providers. Whilst previous research has indicated the importance of novel technologies to combat cold-chain mismanagement in lower-income countries, the impact of the cold chain in higher-income countries has, to date, been largely overlooked. These data points highlight the unmet need for novel thermostable technologies globally, providing essential information to stakeholders across the pharmaceutical, logistics and healthcare industries.

With rising healthcare costs — and a demographic shift towards an ageing population — health systems in Europe are under increasing financial pressure. Our analysis demonstrates that the introduction of thermostable technologies could significantly reduce cold chain associated costs — freeing up critical resources and enhancing healthcare standards. Moreover, the assured potency of thermostable vaccines ensures consistent immunisation coverage and strengthens public confidence in such programs. This will ultimately lead to further long-term cost savings from avoiding vaccine-preventable diseases.

When considering the costs of vaccines, procurement is typically the focus of stakeholders — however, the cost of a vaccine is only the tip of the iceberg, with far greater expense hidden below the surface. Cold chain logistics and wastage of vaccines drive up costs and, accounting for 70% of total costs.

Thermostable vaccines would not only be cost — effective to healthcare systems but also for vaccine manufacturers. The avoidance of strict regulatory requirements around vaccine supply and storage would reduce complexity, wastage, and avoidance of any penalties around non-compliance. Reliable, potent vaccines would also enhance public confidence in vaccines and their manufacturers.

In addition to the economic impacts and considering the ambitious net-zero targets set by national health service across Europe, sustainable procurement is increasingly vital to contributing to reducing GHG emissions whilst moving towards more sustainable practices. Vaccine manufacturers, as suppliers to healthcare systems, will be directly impacted once they are required to provide for example a carbon reduction plan for all emissions as stated in the NHS' net zero supplier roadmap.

The solution to decreasing reliance on the cold chain is likely to be multipronged, combining advancements in thermostable sterile formulations — such as Stablepharma's novel thermostable vaccines — and novel delivery mechanisms for instance microarray patches. Moreover, alternative preservation methods — such as protein engineering, plant-based or bacterial expression systems, and synthetic stabilizers — offer promising ways to develop thermostable vaccines.

Healthcare systems and decision-makers need to fully understand the transparency of all costs related to vaccines, recognising that a significant portion of the true impact is often hidden, much like the tip of an iceberg.

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Stefan Lutzmayer has over 8 years of experience working in academia and life sciences. He joined the Thought Leadership team in 2021 where he creates novel materials on emerging next-generation biotherapeutic platforms like the microbiome or gene-editing, new developments across therapeutic areas, including central nervous system or cardiometabolic diseases as well as vaccines and cold chain pharmaceuticals.

Stefan is considered a subject matter expert in these areas. He frequently engages with senior client stakeholders, speaks at conferences, and supports consulting projects.

Stefan has prior experience working as an IT consultant advising healthcare and life sciences clients. He holds a PhD degree from the University of Vienna, is trained in molecular biology and data analysis and has published multiple peer-reviewed articles in internationally-renowned journals.

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Elina Osoianu has over 6 years of experience working in life sciences, both in strategy consulting and in industry. As a member of the EMEA strategy consulting team, she advises life sciences companies on commercialising innovative products by developing access & launch strategies for therapeutics and vaccines to optimize their long-term success beyond market entry.

In consulting, Elina has worked across a range of therapeutic areas & commercial topics but has a specialist focus and interest on developing commercial strategies for assets in vaccines, oncology and infectious diseases. Here, she uses her industry experience to enrich her advisory efforts so that they best translate into client success.

She has used her collective experience to lead thought leadership efforts on the challenges & opportunities faced by life science companies, incl. the role of AI in optimizing pharmaceutical supply chains and the role of EU HTA as a strategic opportunity for PharmaCos.

Her prior experience working in the pharmaceutical industry, for a global biopharmaceutical company, spanned across different functions, from supply chain to brand strategy. Prior to this, she completed a BSc in medicinal chemistry from University College Dublin and a MSc in Business Management from UCD Michael Smurfit Graduate Business School.

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Tom Rosenfeld joined the Stablepharma team in 2024 where he works across business development, strategy, and finance to support Stablepharma's mission to revolutionise vaccine stability and accessibility.

Tom has experience working across healthcare and life science projects, particularly in oncology, in both professional and research settings including as a bioinformatic researcher at a global, AI-driven, medical research company.

He holds an MSc in Bioinformatics from the University of Edinburgh, where he focused on leveraging genomic data for use in colorectal cancer research. Prior to this, he completed a BSc in Biology at the University of Bristol.

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