Sustainability in the Operating Room

Environmental Life Cycle Assessment for Kliniek voor de Hand

Environmental Life Cycle Assessment (NWI-FMT032 KW2)
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1. Introduction

Healthcare has improved significantly in recent decades, resulting in increasing human life expectancy by 23 years (Kaplan et al., 2019). Nevertheless, this progress also comes at an environmental cost. The health sector has a substantial environmental impact, being a major source of pollution and emissions through factors such as (medical) waste, transport and energy use (Lenzen et al., 2020). Consequently, healthcare's climate footprint accounts for 4.4% of global net emissions (Karliner et al., 2020). Operating rooms (ORs) within hospitals are the largest contributors to emissions due to their high resource use and waste generation. They consume three to six times more energy than other hospital areas and are responsible for an estimated 50–70% of total hospital waste, of which only 20–50% is recyclable (Guetter et al., 2018; Sullivan et al., 2023).

In the Netherlands, the health sector is responsible for around 7% of national greenhouse gas emissions (RIVM, 2023). Kliniek voor de Hand (KvdH), a practice specialized in hand and wrist surgery, is at the forefront of efforts to make the OR more sustainable. They use Xlite plasters, which are biodegradable, as a sustainable alternative to plastic plasters and gypsum for stabilizing and protecting the hand after surgery. Furthermore, they use washable surgery caps instead of disposable caps and a different air ventilation system, a HEPA filter in combination with a Verfris system, compared to conventional ORs (Kliniek voor de Hand, 2024). A HEPA filter is a diffuser specifically designed for hospitals or clean rooms (Halton, 2024). Verfris is a unit that maintains a well-ventilated healthy indoor climate and has been developed for extra ventilation in education, healthcare and office spaces (*VERFRIS – Orange Climate*, n.d.). KvdH is the first independent practice in the Netherlands to introduce this innovative air system in an OR. Both clinics feature a standby mode at night to minimize energy consumption. However, during the day, a conventional OR can only use a class 1 system, which provides cleaner air but consumes more energy. At KvdH, class 2 that uses less energy can also be used, allowing for switching between the two classes to reduce energy consumption. Additionally, the clinic is powered entirely by 100% renewable energy through the use of solar panels.

These different implementation steps could enhance the sustainability of the OR. Donahue et al. (2024) conducted a Life Cycle Assessment (LCA) comparing the use of reusable surgical caps to disposable caps in an OR, in which reusable caps had lower total lifetime CO_2

emissions across multiple scenarios. Nevertheless, no LCAs have been done about the impact of biodegradable plasters or an alternative air ventilation system in an OR. Therefore, it is unclear to what extent these implementations are more sustainable. This study aims to compare the human health and environmental impacts of plasters, surgical caps, and the air ventilation system in the OR of KvdH with those of a conventional OR. This will be done by performing a LCA, in line with the work of Baumann and Tillman (2004). The insights of this study are shared with KvdH in order to provide the clinic with a clear insight into their sustainability practices. Furthermore, this paper will conclude with recommendations, which will further improve the sustainability goals of the clinic and provide additional suggestions for conventional clinics.

2. Methods

This research is conducted in line with the ISO standards (*ISO 14044*, 2006) on LCAs, which requires defining a clear goal, functional unit and system boundaries. As stated above, the primary goal of this research was to analyse the environmental impacts of the reusable surgical caps, the HEPA filter in combination with Verfris and the XLite plasters used in KvdH's OR and compare this to the materials used in conventional ORs. Additionally, the aim of this research was to uncover how these three different implementations relate to each other and which had the highest impact.

2.1 Functional unit

For this paper, the following functional unit was used: *the use of an OR for 10 patients per 24 hours*. Although each of the three OR implementations includes different materials and processes, the chosen formulation of the functional unit enabled the combination of these three implementations into one LCA study (figure 1).

2.2 System Boundaries

The system boundaries vary depending on the analysed components, in order to ensure that our analysis is focused on the most impactful stages of each component's lifecycle. For both the surgical caps and the plasters, the system boundaries were 'cradle to grave', excluding some processes that concern the production of industrial machines. For example, the manufacturing of equipment used to process the different materials into the final product were not taken into account. Considering that the average lifespan of these machines is over 10 years, the impact contribution to the final products was assumed to be minimal (Erumban, 2008). This assumption was also applied to the production of the washing machine needed for the reusable surgical caps, which has an average lifespan of 12 years (Hennies & Stamminger, 2016).

The system boundary used for the air ventilation systems was 'cradle to gate'. However, production of the air ventilation system was not included, since the system has an average lifespan of around 15 years ('How Long Do Commercial HVAC Systems Last?', 2023). The assumption was that the overall impact of these processes was negligible, seeing as our functional unit consists of only 24 hours.

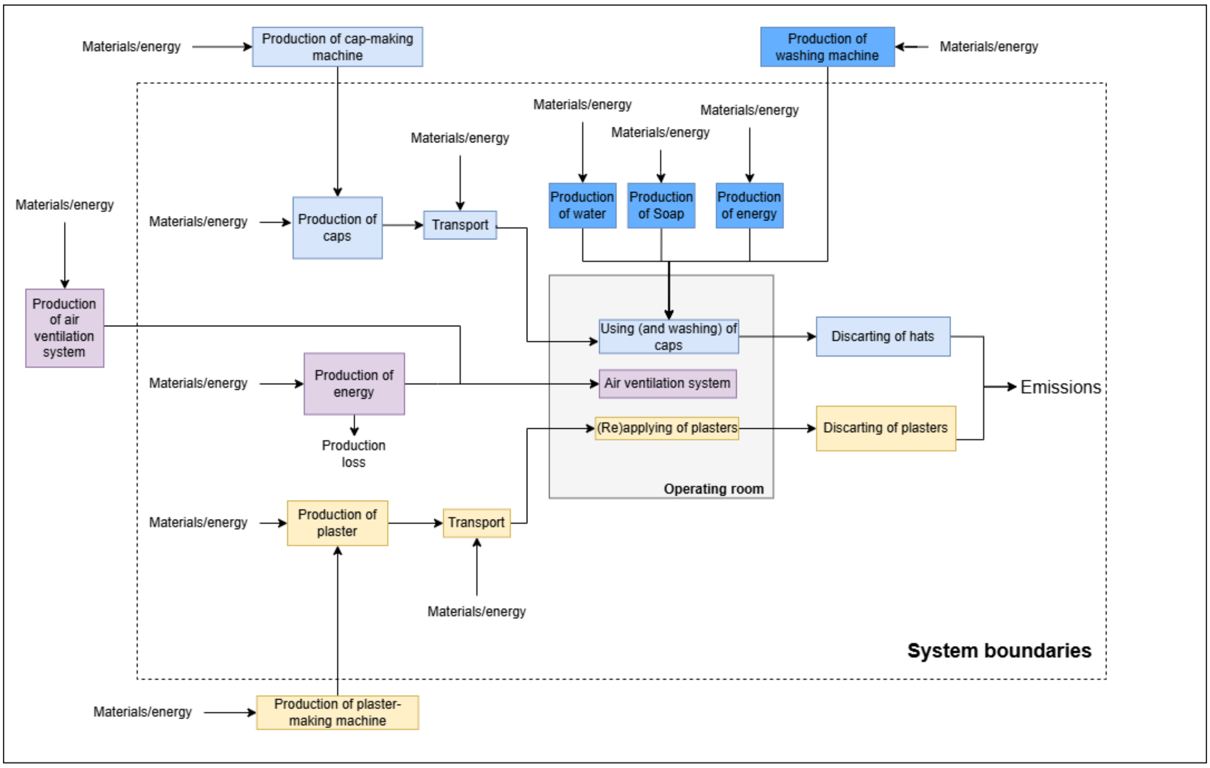

Figure 1 | Graphical overview of the system boundaries for this study. The dotted line visualises the system boundaries, and the grey area represents our functional unit. The blue processes belong to the surgical caps, the purple to the air ventilation systems, and the yellow to the plasters. The deep blue colour represents the addition of the washing process of the reusable hats used by KvdH.

2.3 Inventory - data collection and assumptions

Data for all three components – surgical caps, air ventilation systems, and plasters – was collected through information provided by KvdH and literature. Assumptions were made for both KvdH's and a conventional OR by taking averages, based on this collected data. KvdH provided us with the information that on average, 10 patients are treated per day in the OR, for each of which 5 people are needed as personnel. This means that 15 surgical caps are needed per day, 10 for patients and 5 for personnel, who keep the same cap for the whole day. Furthermore, roughly half of all patients need a cast after their treatment, leading to 5 plasters per 24 hours.

2.3.1 Surgical caps

The disposable surgical caps were assumed to consist of the same composition of materials and methods as the disposable caps examined in the paper by Donahue et al. (2024) (Appendix Table 1.1). This means that the caps were made of 80% polyester and 20% polyisoprene. In addition, the thermoforming of plastic sheets was included to account for the processing needed for the polyester. The disposal of the caps is also taken into account, for which we chose the waste scenario *Municipal solid waste* in the Netherlands, since the caps belong to the general waste. As the same material was selected for disposable caps as in Donahue et al. (2024), we assumed the same transport methods, by ship and lorry. Since the distances traveled in our study differ from their study, we assumed a value of 0.3857 tKm for sea transport and 1.1439 for land transport. This is based on the Ecoinvent 3.9.1 database, where for similar products these transport distances are used, based on the US BTS Commodity Flow Surveys of 1993, 1997, 2002, 2007 by the US Department Of Transportation and Bureau of Transportation Statistics.

KvdH provided the information for the reusable surgical caps, which consisted of 99% polyester and 1% carbon (Appendix Table 1.2). Since the thermoforming of plastic sheets was included in the LCA of the disposable caps, it was decided to also include this step for the reusable caps, seeing as both kinds of caps include polyester. As a proxy for the 1% carbon in the hats, the material carbon black was used in SimaPro. KvdH also provided the information on the longevity of the reusable caps, which was concluded to be 200 days with the caps being washed every day. In accordance with our functional unit that only considers 24 hours, the production and materials needed for the reusable caps were divided by 200, since 1/200 of the reusable cap was needed per day. To account for the washing of the caps, we decided the same amount of water and (solar) energy was needed per cap as concluded by the paper of Donahue et al. (2024), which is respectively 0.41 kg and 0.023 kWh. In addition to these inputs, soap was also included in this process, which was weighed to be 10 g per washing. As for the disposal for this process, we chose the same waste scenario for the reusable surgical caps as for the disposable ones. Additionally, the same amount of water that was chosen as input for the washing of the caps was also chosen as an output of unpolluted wastewater. Lastly, transport of the reusable caps was assumed to be the same as that for the disposable caps, also divided by 200.

2.3.2 Air ventilation systems

For the inventory assessment for the air ventilation system, two aspects were most relevant: the difference in power use for each airflow (class 1, class 2 and standby) and what kind of energy is used.

To gather the data of the different airflows, the clinic helped in providing contact with the air system company (called Orange Climate) monitoring the energy use of the HEPA and Verfris systems. This resulted in precise data on which airflow and corresponding energy was used on average in the KvdH's OR per 24 hours (Appendix Table 2.2). Furthermore, the company also provided relevant comparison data of energy used in a conventional air system, which uses - as mentioned in the introduction - only a class 1 and standby mode (Appendix Table 2.1). Not only does the conventional system lack an energy saving class 2, the overall energy used in the other two settings is higher, as it lacks the new innovative efficiency of the systems used in KvdH. Within 24 hours, KvdH makes use of the class 1 system for 4 hours, while class 2 is used for 8 hours. For the remaining 12 hours per day, energy save mode is used.

After describing the different energy modes, it is important to analyse the source of the energy, which differs between KvdH and conventional clinics. The 'Landelijk Netwerk de Groene OK' reported that KvdH uses 100% renewable energy, which according to the clinic consists of solar energy (Barometer Groene OK, 2023). While the same report mentioned how conventional clinics use only 53% renewable energy.

2.3.3 Plasters

In a conventional OR setting two plasters are normally used after hand surgery. The first plaster is directly used after the operation and consists of cotton and calcium sulphate (the gypsum). After one week, this is replaced by a polyester cast (Appendix Table 3.1) We received the specific weight and size of regular plaster bandage after contacting the medical company 'Merkala' and calculated the average weight for a single use for one person (Merkala, n.d.). We allocated 20% of the weight to the cotton (27 g) and 80% to the gypsum material (108 g), which is an assumption based on a range through literature (Schmidt et al., 1973; Wytch et al., 1991). The Xlite plaster that was used in KvdH consists of 100% cotton with a thermoplastic resin (Appendix table 3.2). The thermoplastic resin was excluded from the analysis as it was only a very small part of the Xlite plaster. According to KvdH, the Xlite plaster weighed 17 grams. We assumed the same weight for the polyester cast in a conventional OR. For the heating process of both casts, we assumed the same water and energy consumption. Since we considered this contribution to be negligible, the process was excluded from the analysis.

The disposal for the normal plasters were also included, for which we chose the same waste scenario as the caps, *Municipal solid waste* in the Netherlands. Nevertheless, for the Xlite plasters, *Biowaste* was chosen as these plasters are biodegradable. The transport of both plaster types was assumed to be the same distance as for the reusable and disposable caps, involving transport by ship and lorry.

2.4 Impact analysis

The LCIA in this study was conducted using the software SimaPro 9.6.0.1 and the life cycle inventory database Ecoinvent 3.10, as well as the life cycle impact assessment methods ReCiPe 2016 Endpoint (H) V1.09 and ReCiPe 2016 Midpoint (H) V1.09. These databases were accessed via SimaPro. We compared the OR of KvdH with a conventional clinic in SimPro and evaluated the endpoints human health impact (reported as DALYs), environmental impact (reported as species extinct per year) and resource impact (reported as USD 2013). The impact categories that were relevant for our case and found to have the highest impact, such as global warming potential, fine particulate matter, human (non-)carcinogenic toxicity, eutrophication and land use, were further analysed for KvdH through midpoint analysis.

In addition, several scenario analyses were done to gain more insight into how each sustainability element implemented by KvdH affects the endpoint impacts. For the first scenario analysis, each sustainability element individually replaces a conventional method or material. For the second scenario analysis, we compared a conventional OR, which generally uses 53% green energy, to a conventional OR that would use 100% green energy and a conventional OR that would use 100% green energy in combination with a HEPA filter and Verfris system.

3. Results

3.1 Environmental life cycle assessment

To study the differences between the ORs and identify which impacts (human health, environmental- and resource impacts) are highest, a comparison was done on endpoint level, leading to an indication of the midpoints that are most affected in both situations (Figure 2). In general, it can be seen that on all endpoint levels (human health, the environment and resources), the OR of KvdH has lower impacts than an OR of a conventional clinic. On the human health endpoint level, KvdH's OR has lowered its impacts by 58% in comparison to a conventional clinic. On the environmental endpoint level, this percentage is 40% and on the resource endpoint level 71%.

Looking further into these endpoints, it can be seen that for both OR scenarios global warming, fine particulate matter, human carcinogenic toxicity and human non-carcinogenic toxicity together account for the largest part of the impacts. Furthermore, looking at the environment, again global warming is shown to belong to the highest impact categories as well as land use and marine eutrophication.

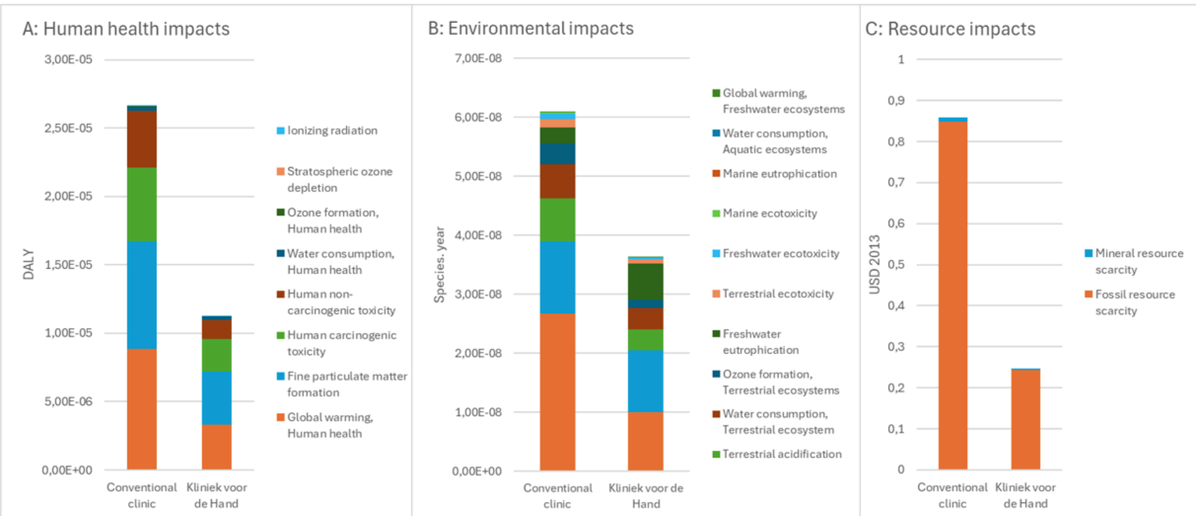

Figure 2 | Endpoint comparison between a conventional clinic and Kliniek voor de Hand. The comparison is based on plasters, surgical caps and air ventilation systems used in an operating room in 24 hours. The coloured bars show the different midpoint categories. A: Human health impacts categorized by midpoints for both clinics, expressed as Disability-Adjusted Life Years (DALY). B: Environmental impacts categorized by midpoints for both clinics, expressed as species lost per year. C: Resource impacts categorized by midpoints for both clinics (x-axis), expressed in USD.

To further look into these highest impact categories in the light of the OR used in KvdH, we examined the previously mentioned categories on midpoint level to identify the main drivers behind these impacts (Figure 3). Looking at the categories that are identified as highest impact categories for human health (figure 3A-D), it can be seen that the reusable surgical caps have the lowest contribution to all of these categories. The highest contributor to global warming and fine particulate matter formation, in contrast, is the XLite plaster and to human (non-) carcinogenic toxicity is the HEPA filter in combination with Verfris. This contribution of the air ventilation system to human (non-) carcinogenic toxicity can mainly be attributed to the installation of the solar panels. Noticeably, the HEPA filter in combination with Verfris is the smallest contributor in the environmental categories (figure 3E-F). Instead, XLite plaster is again shown to be the largest contributor to both of these environmental impacts. Overall, the XLite plasters show to be the largest contributor to the endpoints.

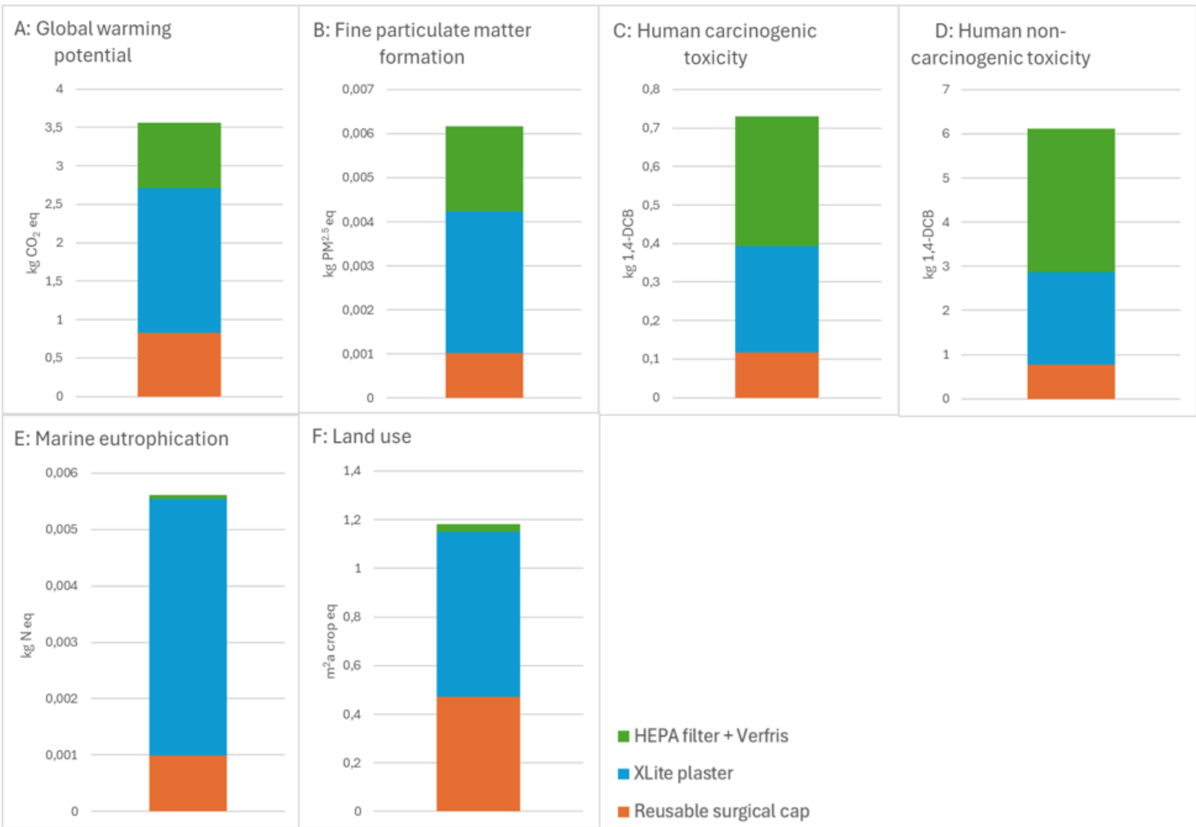

Figure 3 | Midpoint analysis on the highest impact categories for Kliniek voor de Hand. This analysis is based on plasters, surgical caps and air ventilation systems used in an operating room in 24 hours.The green bars represent the HEPA filter + Verfris, the blue bars represent the Xlite plaster, and the orange bars represent the reusable surgical cap. A-D display the highest impact categories at the human health endpoint level. A, E, and F show the highest impact categories at the environmental endpoint level.

3.2 Scenario analyses

To get a more in-depth view of how each sustainability element implemented by KvdH affects the total human health and environmental impacts of a conventional clinic, a scenario analysis was done where each element individually replaces a conventional method or material (Figure 4). Looking at the different scenarios, it can be seen that the implementation of the HEPA filter in combination with the Verfris system reduces the impacts on both human health and the environment the most. This reduction in impact can mainly be ascribed to the reduction in effects on global warming, which is almost halved. This is followed by the implementation of XLite plasters instead of conventional plasters, which also mainly reduces the effects on global warming. Reusable surgical caps also reduce the impacts on human health, however, they increase the impacts on the environment. This increase in impacts on the environment can mainly be attributed to the increased impact that the reusable caps have on land use and freshwater eutrophication. Looking further into the causes of the impacts on land use, it can be seen that the washing of the reusable surgical caps is the main contributor, which can be attributed to the production of palm oil that is needed for the laundry detergent.

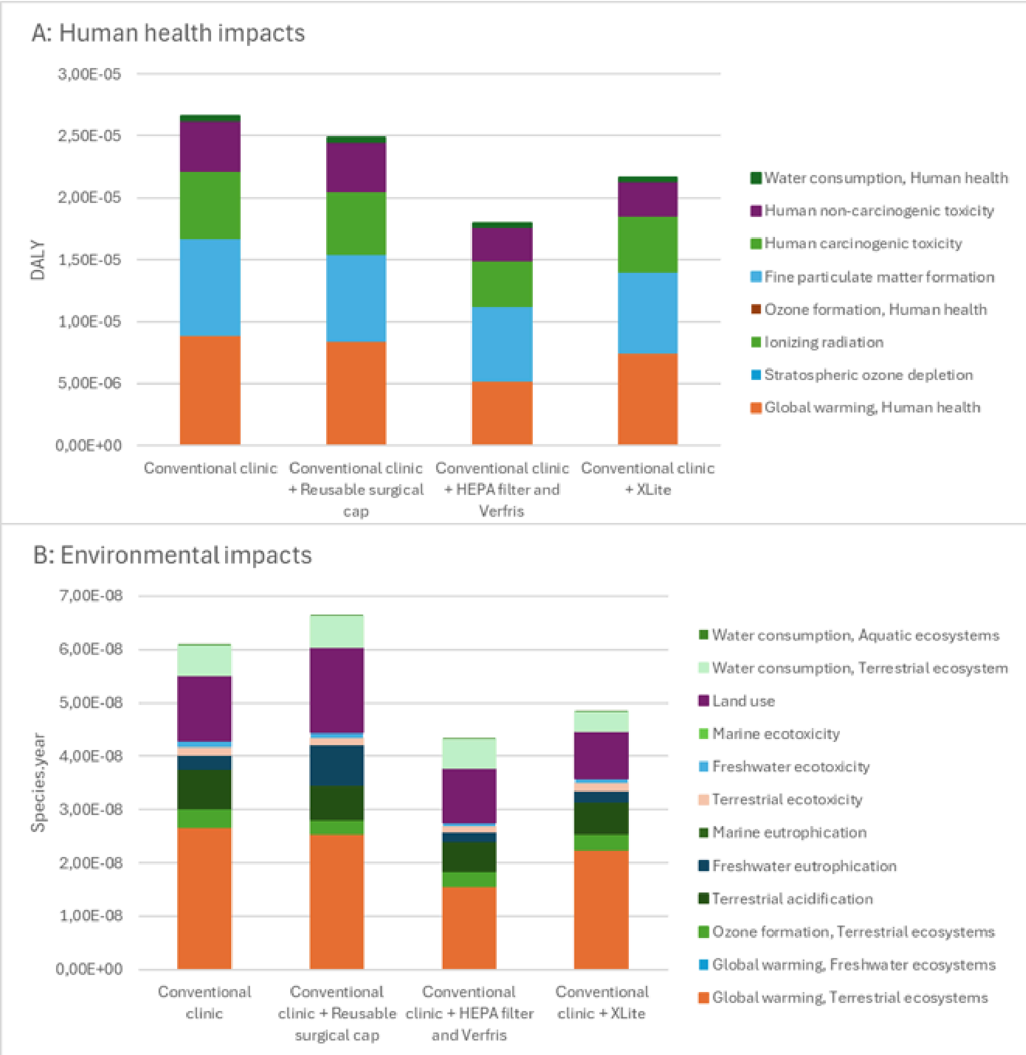

Figure 4 | Scenario analysis on sustainability implementations of Kliniek voor de Hand. This scenario analysis is based on the endpoint categories human health (A) and the environment (B). Every scenario is set in an operation room of a conventional clinic within 24 hours, with only one sustainability implementation of KvdH. The different colour bars show the different midpoint categories.

Since the HEPA filter in combination with the Verfris system seems to contribute the most to a reduction in impacts on human health and the environment, we looked further into electricity usage through a scenario analysis (figure 5). In this analysis, a conventional clinic with different energy scenarios was considered, meaning that this analysis makes use of conventional plasters and disposable surgical caps. Making use of 100% green energy (solar) instead of the conventional 53% already shows a reduction in impact on both the human health and the environmental level. Adding the HEPA filter in combination with the Verfris system further reduces the impacts, with a reduction of 32% in human health and 29% in the environment, relative to a conventional clinic. These reductions can mainly be attributed to a reduced impact on global warming for both endpoints. Doing a midpoint analysis on both clinics and looking at global warming potential, it can be seen that a conventional clinic's air ventilation system has an emission of 4.82 kg CO_2 per 24 hours, while KvdH's air ventilation system has an emission of 0.85 kg CO_2 per 24 hours (Appendix Figure 1). This is a reduction of 82% in carbon footprint.

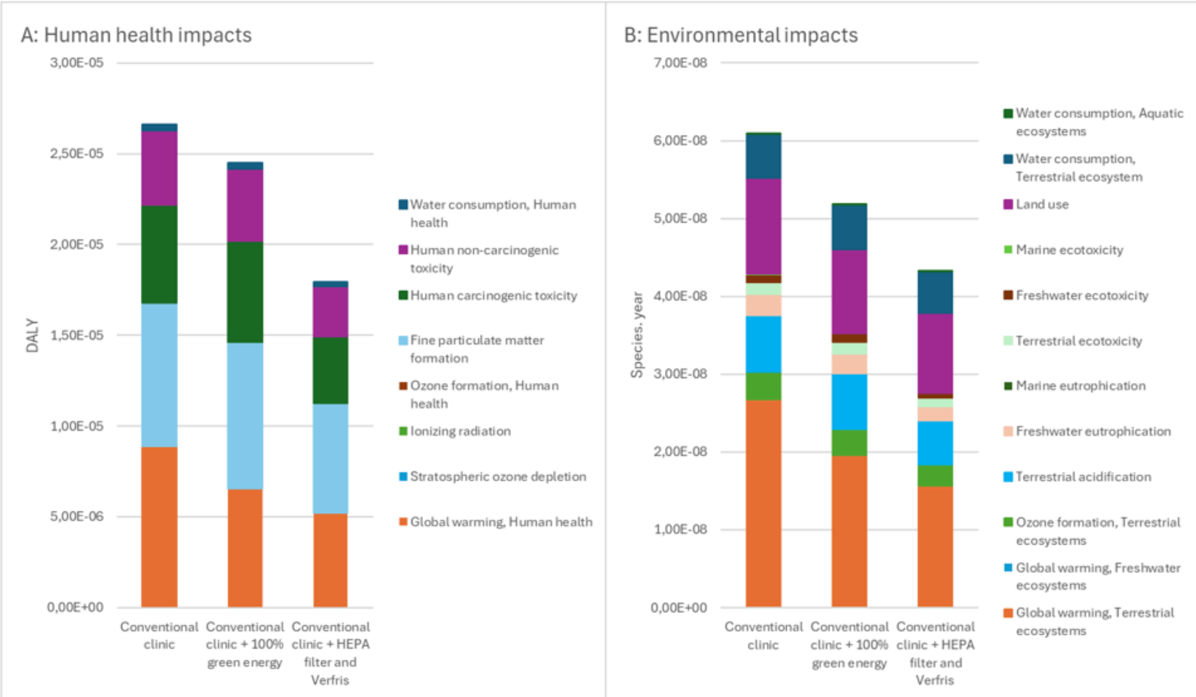

Figure 5 | Scenario analysis on different energy sources. This scenario analysis is based on the endpoint categories human health (A) and the environment (B) and is set in the operation room in a timespan of 24 hours. A conventional clinic uses 53% green energy (solar energy) and 47% grid energy, while in the other two scenarios 100% green energy (solar energy) is used. The last scenario also includes the HEPA filter in combination with the Verfris system. The different colour bars show the different midpoint categories.

4. Discussion

From this LCA, it can be concluded that the Xlite plasters, air ventilation system and reusable hats used by KvdH are sustainable alternatives. These implementations taken by KvdH significantly reduce the impacts caused by its operation room on human health, environmental and resource level compared to a conventional clinic. On human health endpoint level, its impact is lowered by 58%, on environmental endpoint level by 40% and on the resource endpoint level by 71%. The impacts caused by KvdH's alternatives at the midpoint level, are primarily attributed to the XLite plasters and in case of human toxicity to the HEPA filter in combination with the Verfris system. However, the scenario analysis also reveals that, overall, this air ventilation system leads to the highest reduction in impact on the endpoint levels of human health and the environment.

4.1 Advice KvdH

Since KvdH has a significantly lower impact on human health, the environment, and resources compared to a conventional clinic, we recommend KvdH to continue using these alternatives. However, there is still potential for further improvements to make it even more sustainable than it is now.

As previously mentioned, the reusable surgical caps used by KvdH have a significant impact on land use change, due to the production of palm oil that is used in the soap for washing the caps. Although palm oil is often more cost-effective than other crops, its production has several negative environmental impacts, such as deforestation and peatland draining (Meijaard et al., 2020). Therefore, using laundry detergent that does not contain palm oil could reduce this impact on land use change. A more sustainable alternative for palm oil is stearic sunflower oil (Anushree et al., 2017), which could be considered when choosing soap for washing. Further research could be done to find the impact change when using a more sustainable detergent.

Furthermore, the midpoint analysis shows that Xlite plasters have the greatest impact across most midpoints, except for human (non-) carcinogenic toxicity. This could be due to the type of cotton that is used in the Xlite plaster, as water consumption and pesticide use during cotton production can have a substantial negative impact on the environment (Kooistra et al., 2016). The use of an alternative fibre or organic cotton could potentially reduce this impact

(Delate et al., 2020; Zhang et al., 2023). Further LCIA research on these alternatives is needed, to examine the change in impacts when using these more sustainable alternatives instead of non-organic cotton.

Lastly, the HEPA filter and Verfris unit seem to have the biggest impact on human (non)carcinogenic toxicity. This appears to result from KvdH's use of green energy through the installation of solar panels, rather than the HEPA filter and Verfris unit itself. Solar panels are a more sustainable alternative to fossil fuels, nevertheless, they contain hazardous chemical elements like lead, tin, cadmium, silicon and copper (Bang et al., 2018). While solar cells are designed to minimize leaching, environmental disasters or improper disposal in landfills could release these harmful substances (Kwak et al., 2020). Therefore, more research is needed on safe usage and waste management of PV solar panels in the future.

4.2 Advice conventional clinic

For a conventional clinic, implementing all three alternatives of KvdH would enhance the overall sustainability of the operating room. The biggest reduction in impacts is caused by the introduction of the HEPA filter in combination with the Verfris system and the switching of air ventilation classes that this system allows for. Therefore, our advice to clinics that use a conventional OR would be to invest first in this air ventilation system if they want to reduce their impacts the most. Further research should be done into the feasibility of implementing this innovative air ventilation in conventional OR settings, in order to determine how realistic this implementation would be in larger clinics or hospitals.

4.3 Limitations

A limitation of this paper was the specific timeframe of 24 hours with regards to the functional unit. Broadening this frame would also make the production and discarding of the factory machines producing caps, air systems and plasters more relevant. However, this would also increase the resources needed to complete the LCIA. Although our assumptions are substantiated, the data remains an assumption with a certain bandwidth and gaps, which will have affected the final results. Furthermore, it should be acknowledged that ReCiPe is not a perfect model as, for example, the leakage of microplastics (from washing the reusable caps) is not included.

4.4 Conclusion

In conclusion, the sustainability implementations in KvdH's operation room significantly reduce the clinic's impacts. Therefore, we recommend that KvdH continue using the reusable surgical caps, the innovative air ventilation system, and the XLite plasters. To further improve on sustainability, KvdH could look at the use of more sustainable alternatives for laundry detergents using palm oil. The use of organic cotton instead of non-organic cotton in plasters would also further reduce the clinic's impacts, however, this might be outside of KvdH's control. Since the air ventilation system of KvdH shows the largest reduction in the clinic's impacts, clinics with conventional ORs are recommended to implement this first as a step towards sustainability.

5. Literature

Anushree, S., André, M., Guillaume, D., & Frédéric, F. (2017). Stearic sunflower oil as a sustainable and healthy alternative to palm oil. A review. Agronomy for Sustainable Development, 37(3). https://doi.org/10.1007/s13593-017-0426-x

Barometer Groene OK 2023 — Kliniek voor de hand. (2023). Landelijk Netwerk de Groene OK.

Bang, Y. Y., Hong, N. J., Sung Lee, D., & Lim, S. R. (2018). Comparative assessment of solar photovoltaic panels based on metal-derived hazardous waste, resource depletion, and toxicity potentials. International Journal of Green Energy, 15(10), 550–557. https://doi.org/10.1080/15435075.2018.1505618

Baumann, H., & Tillman, A.-M. (2004). LCA in a nutshell. In *The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application* (pp. 19–41). Studentlitteratur AB. http://dx.doi.org/10.1065/lca2006.02.008

Donahue, L. M., Petit, H. J., Thiel, C. L., Sullivan, G. A., Gulack, B. C., & Shah, A. N. (2024). A Life Cycle Assessment of Reusable and Disposable Surgical Caps. J Surg Res, 299, 112-119. https://doi.org/10.1016/j.jss.2024.04.007

Delate, K., Heller, B., & Shade, J. (2020). Organic cotton production may alleviate the environmental impacts of intensive conventional cotton production. *Renewable Agriculture and Food Systems*, *36*(4), 405–412. https://doi.org/10.1017/s1742170520000356

Erumban, A. A. (2008). Lifetimes of Machinery and Equipment: Evidence from Dutch Manufacturing. *Review of Income and Wealth*, *54*(2), 237–268. https://doi.org/10.1111/j.1475-4991.2008.00272.x

Guetter, C. R., Williams, B. J., Slama, E., Arrington, A., Henry, M. C., Möller, M. G., ... &

Crandall, M. (2018). Greening the operating room. *The American journal of surgery*, *216*(4), 683-688. https://doi.org/10.1016/j.amjsurg.2018.07.021

Hauschild, M. Z., Goedkoop, M., Guinée, J., Heijungs, R., Huijbregts, M., Jolliet, O., Margni, M., De Schryver, A., Humbert, S., Laurent, A., Sala, S., & Pant, R. (2013). Identifying best existing practice for characterization modeling in life cycle impact assessment. *The International Journal of Life Cycle Assessment*, *18*(3), 683–697. https://doi.org/10.1007/s11367-012-0489-5

Hennies, L., & Stamminger, R. (2016). An empirical survey on the obsolescence of appliances in German households. *Resources, Conservation and Recycling*, *112*, 73–82. https://doi.org/10.1016/j.resconrec.2016.04.013

HEPA diffuser. Halton Vita VHT. With foamed polyurethane (PUR) gasket. (2024, December 11). Halton. https://www.halton.com/products/vht-hepa-diffuser/

How Long Do Commercial HVAC Systems Last? (2023, October 30). *PROAC Corporation*. https://proaccorp.com/how-long-do-commercial-hvac-systems-last/

ISO 14044:2006 (Version 1). (2006). https://www.iso.org/standard/38498.html

Kaplan, R. M., & Milstein, A. (2019). Contributions of health care to longevity: a review of 4 estimation methods. The Annals of Family Medicine, 17(3), 267-272. https://doi.org/10.1370/afm.2362

Karliner, J., Slotterback, S., Boyd, R., Ashby, B., Steele, K., & Wang, J. (2020). Health care's climate footprint: The health sector contribution and opportunities for action. *European Journal of Public Health,* *30*(Supplement 5), ckaa165.843. https://doi.org/10.1093/eurpub/ckaa165.843

Kliniek voor de hand. (2024, July 3). In onze kliniek werken we steeds duurzamer. Voor De Hand. https://voordehand.nl/duurzaamheid/

Kooistra, K. J., Termorshuizen, A. J., & Pyburn, R. (2006). The sustainability of cotton:

Consequences for man and environment (No. 223). Wetenschapswinkel Wageningen. https://edepot.wur.nl/17214

Kwak, J. I., Nam, S. H., Kim, L., & An, Y. J. (2020). Potential environmental risk of solar cells: Current knowledge and future challenges. Journal of Hazardous Materials, 392, 122297. https://doi.org/10.1016/j.jhazmat.2020.122297

Lenzen, M., Malik, A., Li, M., Fry, J., Weisz, H., Pichler, P. P., ... & Pencheon, D. (2020). The environmental footprint of health care: a global assessment. *The Lancet Planetary Health*, *4*(7), e271-e279. https://doi.org/10.1016/S2542-5196(20)30121-2

Meijaard, E., Brooks, T.M., Carlson, K.M. et al. (2020). The environmental impacts of palm oil in context. *Nat. Plants* 6, 1418–1426 . https://doi.org/10.1038/s41477-020-00813-w

Merkala. (n.d.). *Romed plaster bandage*. Merkala. Retrieved December 19, 2024, from https://www.merkala.nl/romed-gipsverband.html

RIVM. (2023). Het effect van de zorgsector op het milieu: Verduurzaming van de zorgsector. In https://www.rivm.nl/sites/default/files/2023-03/De%20impact%20van%20de%20zorgsector%20op%20het%20milieu.pdf

Schmidt, V. E., Somerset, J. H., & Porter, R. E. (1973). Mechanical properties of orthopedic plaster bandages. *Journal of Biomechanics*, *6*(2), 173–185. https://doi.org/10.1016/0021-9290(73)90086-9

Sodhi, M., Banaszek, L., Magee, C., & Rivero-Hudec, M. (2022). Economic Lifetimes of Solar Panels. *Procedia CIRP*, *105*, 782–787. https://doi.org/10.1016/j.procir.2022.02.130

Sullivan, G. A., Reiter, A. J., Hu, A., Smith, C., Storton, K., Gulack, B. C., Shah, A. N., Dsida, R., & Raval, M. V. (2023). Operating room recycling: opportunities to reduce carbon emissions without increases in cost. Journal of Pediatric Surgery, 58(11), 2187–2191. https://doi.org/10.1016/j.jpedsurg.2023.04.011

VERFRIS – Orange Climate. (n.d.). Orange Climate. https://www.orangeclimate.com/producten/luchtbehandelingskasten/energiezuilen/verfris/

Wytch, R., Ashcroft, G. P., Ledingham, W. M., Wardlaw, D., & Ritchie, I. K. (1991). Modern splinting bandages. *The Journal of Bone & Joint Surgery British Volume*, *73-B*(1), 88–91. https://doi.org/10.1302/0301-620X.73B1.1991785

Zhang, Z., Huang, J., Yao, Y., Peters, G., Macdonald, B., La Rosa, A. D., Wang, Z., & Scherer, L. (2023). Environmental impacts of cotton and opportunities for improvement. Nature Reviews Earth & Environment, 4(10), 703–715. https://doi.org/10.1038/s43017-023-00476-z

6. Appendix

Table 1.1 - Inventory of 1 disposable cap (Conventional)

Process	*Amount*	*Database process name*
Production polypropylene	2.4 g	Textile, nonwoven polypropylene {RoW}| textile production, nonwoven polypropylene, spunbond | Cut-off, U
Processing polyester	"	Thermoforming of plastic sheets {GLO}| market for | Cut-off, U
Production polyisoprene	0.6 g	Synthetic rubber {GLO}| market for | Cut-off, U
Transport by land	0.3857 tKm	Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U
Transport by sea	1.1439 tKM	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Disposal caps	3 g	Municipal solid waste (waste scenario) {NL}| treatment of municipal solid waste, incineration | Cut-off, U

Table 1.2 - Inventory of 1 reusable cap (KvdH)

Process	*Amount*	*Database process name*
Production polyester	127.71 g /200	Textile, nonwoven polyester {GLO}| market for textile, nonwoven polyester | Cut-off, U
Processing polyester	"	Thermoforming of plastic sheets {GLO}| market for | Cut-off, U
Production carbon black	1.29 g /200	Municipal solid waste (waste scenario) {NL}| treatment of municipal solid waste, incineration | Cut-off, U
Transport by land	0.3857 tKm	Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U
Transport by sea	1.1439 tKM	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Water use (laundering)	0.41 kg	Tap water {RoW}| tap water production, conventional treatment | Cut-off, U
Production electricity (laundering)	0.023 KwH	Electricity, low voltage {NL}| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Cut-off, U

Production soap (laundering)	10 g	Soap {GLO}| market for soap | Cut-off, U
Creating wastewater (laundering)	0.41 m³	Wastewater, unpolluted, from residence {RoW}| market for wastewater, unpolluted, from residence | Cut-off, U
Disposal caps	129 g	Municipal solid waste (waste scenario) {NL}| treatment of municipal solid waste, incineration | Cut-off, U

Table 2.1 - Inventory air system per 24 hours (Conventional)

Air system	*Energy*	*Database process name*
Conventional 'standby'	3.72 KwH	(53%) Electricity, low voltage {NL}| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Cut-off, U **AND** (47%) Electricity, low voltage {NL}| market for electricity, low voltage | Cut-off, U
Conventional 'class 1'	15.84 KwH	"

Table 2.2 - Inventory air system per 24 hours (KvdH)

Air system	*Energy*	*Database process name*
KvdH 'standby'	1.44 KwH	Electricity, low voltage {NL}| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Cut-off, U
KvdH 'class 2'	2.56 KwH	"
KvdH 'class 1'	3.28 KwH	"

Table 3.1 - Inventory of 1 plaster (Conventional)

Process	*Amount*	*Database process name*
Production cotton	27 g	Textile, woven cotton {GLO}| market for textile, woven cotton | Cut-off, U
Production calcium sulphate	108 g	Gypsum, mineral {RoW}| market for gypsum, mineral | Cut-off, U

Production polyester	17 g	Municipal solid waste (waste scenario) {NL}| treatment of municipal solid waste, incineration | Cut-off, U
Transport by land	0.3857 tKm	Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U
Transport by sea	1.1439 tKM	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Disposal plaster	152 g	Municipal solid waste (waste scenario) {NL}| treatment of municipal solid waste, incineration | Cut-off, U

Table 3.2 - Inventory of 1 Xlite plaster (KvdH)

Process	*Amount*	*Database process name*
Production cotton	17 g	Textile, woven cotton {GLO}| market for textile, woven cotton | Cut-off, U
Transport by land	0.3857 tKm	Transport, freight, lorry, unspecified {GLO}| market group for transport, freight, lorry, unspecified | Cut-off, U
Transport by sea	1.1439 tKM	Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U
Disposal plaster	17 g	Biowaste {CH}| market for biowaste | Cut-off, U

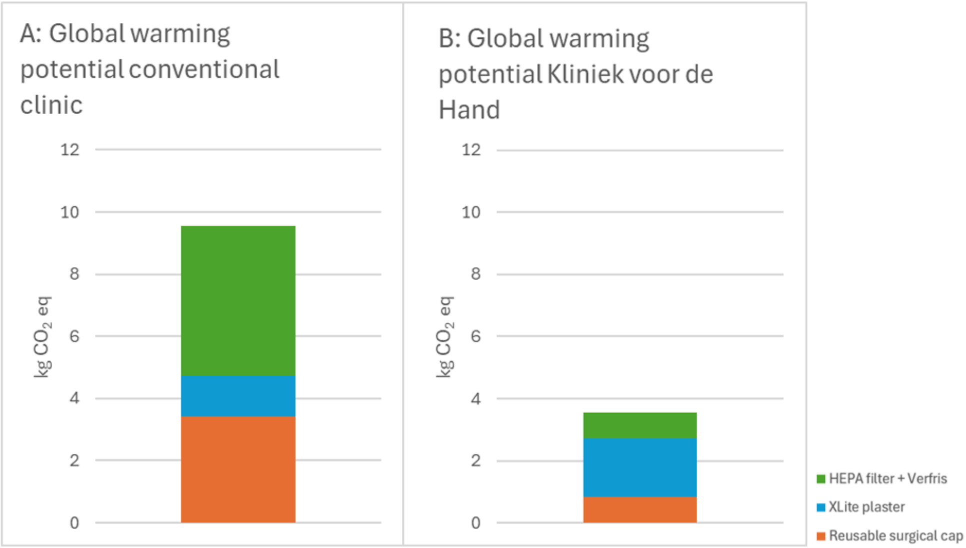

Figure 1 | Midpoint comparison of global warming potential for both clinics. This analysis is based on plasters, surgical caps and air ventilation systems used in an operating room in 24 hours.The green bars represent the HEPA filter + Verfris, the blue bars represent the Xlite plaster, and the orange bars represent the reusable surgical cap.