Environmental Hotspot Analysis of Laboratory Consumables in a University and University Medical Center

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1. Introduction

Laboratories within healthcare and research institutions play an essential role in diagnostics, patient care and scientific discovery. Nonetheless, the broader healthcare sector also presents a considerable environmental footprint, with recent estimates indicating that the global health-care industry contributes between 1% and 5% of total global environmental impacts, and potentially more in specific countries (Lenzen et al., 2020). Research on hospital sustainability has increased, yet much of this work concentrates on direct energy- and water-use, building design and clinical waste streams (McGain & Naylor, 2014). As the supply chains behind health-care goods dominate indirect (scope 3) emissions, procurement and single-use products have become increasingly recognized as priority areas (Lenzen et al., 2020). However, despite this growing awareness, assessments specifically focused on laboratory consumables (such as single-use plastics, pipette tips, tubes and common chemicals) remain scarce, leaving a critical knowledge gap in sustainability planning for hospital and research laboratories.

We define "laboratory consumables" as a collection of commonly used disposable materials such as pipettes, pipette tips, tubes, and other single-use plastics, as well as essential chemicals and reagents including ethanol, phosphate-buffered saline (PBS), extraction kits, and cell culture media. These categories combine high unit volumes with material and chemical diversity, meaning that aggregate environmental impacts can be large even when individual item footprints are modest. Because such consumables are typically classified within institutional procurement systems rather than in clinical waste streams, their environmental footprint is often hidden in scope 3 accounting and thus under-prioritized in sustainability policy and procurement decisions.

Recent national initiatives, most notably the Dutch Federation of University Medical Centers (UMCNL) analysis of medical disposables across UMC hospitals, have demonstrated the value of procurement-based hotspot analyses for identifying intervention targets. In this project, we aim to identify the laboratory-specific items that are the largest contributors to procurement-related CO_2 emissions, as well as the circular or lower-impact alternatives that could achieve the greatest reductions in emissions and resource extraction. Addressing these questions requires harmonized procurement data, lifecycle-informed footprint assessment methods, and transdisciplinary collaboration with procurement specialists, laboratory staff, and circular-economy experts.

The present study addresses this gap by analyzing 2023 procurement records from two complementary institutional settings: University Medical Center Utrecht (UMCU), a university medical center with both research and diagnostic laboratories (approximately 16,000 total employees, including an estimated 2,000-3,000 laboratory personnel) and Wageningen University & Research (WUR), a research university focused on life sciences and sustainability (approximately 7,700 employees). Using these data, we aim to identify laboratory consumable hotspots and prioritize a switch to lower-impact alternatives of these product categories. To achieve this, we collected procurement data and applied filtering criteria to select the most frequently used products in laboratories. We then estimated carbon dioxide equivalent (CO_2e) footprints for these categories to generate a ranked hotspot list. Throughout the analysis, we engaged procurement officers, laboratory technicians, and circular-economy consultants to validate categorizations, refine CO_2e assumptions, and identify candidate alternatives, such as reusable, biodegradable, or reformulated products.

This study presents a spend-based hotspot analysis, comparing procurement patterns between hospital and university laboratories to identify the laboratory consumables that contribute most to scope 3 carbon emissions. By quantifying and ranking these hotspots, the analysis provides an evidence-based foundation for understanding the climate impacts of laboratory operations and highlights potential areas for circularity and lower-impact alternatives. We also address methodological challenges, including data completeness and footprint uncertainty, and discuss the implications for Circular Safe Hospitals and the Green Deal Sustainable Healthcare 3.0 targets, as well as opportunities for scaling this approach across institutions. The outcomes aim to raise awareness of the footprint of laboratories in hospitals and universities, inform future research, and support data-driven decisions for sustainable laboratory management.

2. Material and methods

2.1 Study design and scope

This cross-institutional, procurement-based study analysed common laboratory consumable and chemical purchases made in year 2023 at UMCU and WUR. The objective was to (1) map each purchased laboratory item to a harmonised category and subcategory, (2) estimate CO_2e footprints per item, (3) relate financial expenditure to footprint metrics, and (4) identify procurement hotspots for circular interventions. A schematic overview of the approach is displayed in **Figure 1**.

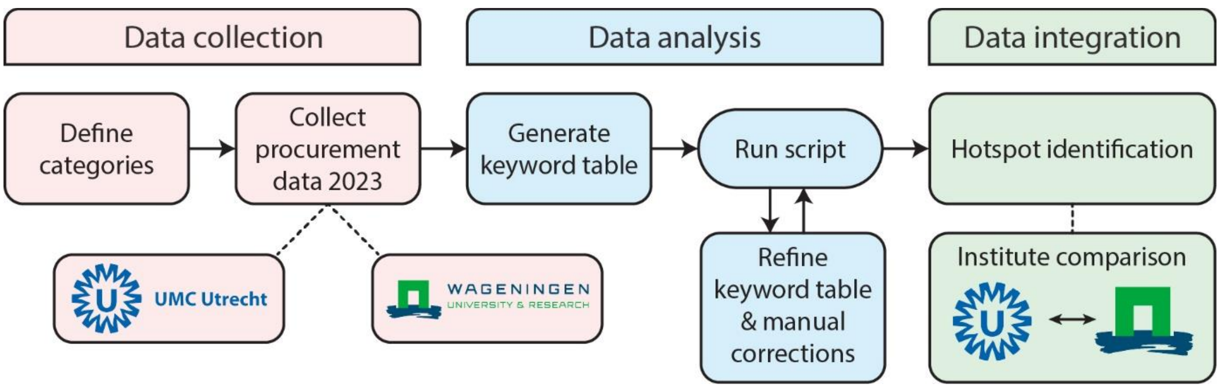

Figure 1. Schematic overview of the methods, including data collection (left), data analysis (middle) and data integration (right).

2.2 Data collection

Procurement data for the calendar year 2023 were obtained directly from the procurement systems of UMCU and WUR. Procurement policy of both WUR and UMCU involves placing orders through this procurement system. The datasets differed in structure and variable naming. The UMCU dataset contained information on goods group, procurement group, supplier name, SAP item description and number, item description, supplier item number, division, cost center, Global Trade Item Number (GTIN), unit price, currency, quantity ordered, and total amount excluding and including VAT. The WUR dataset included information on order number, supplier, line number, requester, ledger account, cost center, internal article number, supplier article number, article name, currency, price per unit, quantity, unit, total excluding VAT, total including VAT, order date, delivery date, status, project, entity, request type, product group, article ID, price per unit, quantity ordered, and quantity received. All data were used in their original exported form. These data provided the basis for subsequent categorization, keyword assignment, and CO_2e footprint estimation. A contract manager enriched the WUR data with a separate column, defining whether products were attributed as lab products.

2.2.1 Data selection and exclusion

To focus on laboratory products with annual procurement cycles, items typically purchased in multi-year batches, such as "Fetal Calf Serum" and "Basement Membrane Extract", were excluded from the analysis. Laboratory equipment was also excluded. This ensured that the analysis reflected the environmental footprint of products regularly procured within a single calendar year.

2.3 Classification framework and NACRES mapping

To enable reproducible, cross-institutional categorization, we developed a hierarchical classification of consumables and chemicals, structured into main types (disposables, kits, chemicals and reagents), categories, and subcategories, with each subcategory accompanied by an internal description to ensure consistent interpretation. For example, within the "Disposables" type, category 1 (plastic tubes) is subdivided into four subcategories: falcon tubes (a), centrifuge tubes (b), cryotubes (c), and disposable cuvettes (d). Each subcategory was assigned to the corresponding NACRES procurement code, which is a French coding system for research institutes and universities to classify procurement data. Each procurement category within the NACRES database has a spend-based emission factor that was used for the analysis in this work to estimate CO_2e emissions based on expenditure data. The complete list of categories, together with the corresponding NACRES-related codes and additional attributes, is provided in **Supplementary Table 1**.

2.4 Keyword lists and matching logic

For every subcategory a curated set of keywords was created to capture the lexical variability observed in procurement descriptions (e.g., "p1000 tip", "pipette tip 1000 µL", "filter tip p1000"). Keywords were formulated as regular expressions and could include logical operators and wildcards to capture variation (for example, pipet* would match both "pipette" and "pipettes"). Company names were occasionally included as keywords, to categorise products that would otherwise be challenging to match to a specific subcategory. Each keyword was assigned to a specific subcategory, which in turn was linked to a NACRES code. This structure allowed the keyword lists to serve as an intermediary between the product names in the procurement data and the NACRES categorization via our internal classification. Note that the keyword list in combination with the footprint results described in this report contains sensitive information about suppliers for both institutes. Therefore, the keyword table is not published as supplemental material to this report.

2.5 Python script and manual verification

A dedicated Python script was developed to process each row of the dataset. For every entry, the script combined the product description with the supplier's name and attempted to match it against the curated keyword list. Multiple candidate matches were allowed for a single procurement entry; however, the most appropriate match was later manually selected. Given the variability in procurement descriptions, the automated pipeline was executed iteratively. After each run, all products that were assigned to multiple categories were manually reviewed by two team members with laboratory experience to identify common misclassifications and gaps in keyword coverage. Feedback from these checks led to progressive refinements of the keyword lists and matching rules. The script was re-run after each refinement; subsequent manual checks focused on previously problematic classes. Syringes were subsequently excluded from the UMCU analysis because they are primarily used in healthcare settings and cannot be distinguished from laboratory use. Finally, all rows that were eventually not assigned to any category but did belong to the subcategory "lab" (for WUR data) or "inkoopgroep laboratorium" by the script were manually categorized if needed. The cycles of automatic matching followed by manual verification resulted in a stable and reliable output.suitable for hotspot analysis.

2.6 CO_2e estimation and data integration

CO_2e emission factors were assigned at the subcategory level using available NACRES metadata. Emission factors were used as published in De Paepe *et al.,* without applying inflation correction. For each matched procurement line, total emissions were calculated as:

CO_2e total = NACRES emission factor × euros spend on the product

The procurement datasets from UMCU and WUR were processed separately, and CO_2e values were calculated for all matched items within each dataset. This approach allowed us to analyse expenditure and emissions at the subcategory levels independently for each institution. By aggregating total spending and CO_2e emissions across items, we ranked the subcategories to identify the highest contributors in terms of climate impact, thereby highlighting the hotspot categories for potential interventions.

3. Results

3.1 Overall footprint of laboratory consumables and chemicals

The analysis of the 2023 procurement datasets shows that laboratory consumables and chemicals represent a substantial indirect (scope 3) carbon footprint at both institutions. After matching procurement data to the defined category list (**Supplementary Table 1**), the total estimated footprint for periodically ordered laboratory consumables amounted to approximately 2,073 tonnes CO_2e for WUR, which is 5.5% of the annual scope 3 emissions for WUR in 2023 (Wageningen Sustainability Report, 2023). For UMCU, the footprint of periodically ordered laboratory consumables equals 5,264 tonnes CO_2e, which is 4.6% of estimated scope 2+3 emissions for 2023 (Annual Report UMC Utrecht, 2023). In both institutes, climate impact was highly concentrated within a limited number of product subcategories. At WUR, the top 15 subcategories (from all 35 subcategories considered) accounted for approximately 86.5% of the total estimated footprint, while at UMCU this concentration was even more pronounced, with the top 15 subcategories contributing approximately 96.8% of total CO_2e emissions. This uneven distribution suggests that a relatively small number of laboratory consumables and chemicals dominate procurement-related climate impact and therefore represent priority targets for intervention.

3.2 Hotspot analysis at Wageningen University & Research

The footprint analysis for WUR indicates that laboratory kits are the dominant contributors to procurement-related CO_2e emissions (**Figure 2**, *Panels* **A-C**). Kits (purple-coded in **Figure 2**) represent the largest procurement-related CO_2e category at WUR. Within this group, detection kits have the highest footprint, estimated at 366 tonnes CO_2e (18%), followed by nucleotide editing and sequencing kits (255 tonnes CO_2e, 12%) and isolation and purification kits (137 tonnes CO_2e, 7%). Together with PCR kits and individual enzymes (125 tonnes CO_2e, 6%), these kit-based products constitute the core of WUR's laboratory procurement footprint. In addition to kits, several disposable plastic items (blue-coded in **Figure 2**) contribute substantially to WUR's overall footprint. Pipette tips and cell culture and PCR plates each account for approximately 118 tonnes (6%) CO_2e, while laboratory gloves contribute 113 tonnes CO_2e (5%) and Falcon tubes 108 tonnes CO_2e (5%). These four product types are the highest-impact disposable categories, reflecting their ubiquitous use across a broad range of laboratory activities. Other single-use plastic items, including Petri dishes & flasks and serological pipettes rank among the higher-impact categories, underscoring the cumulative environmental burden associated with routine disposable plasticware. Within the category of chemicals and reagents (orange-coded in **Figure 2**), primers and oligonucleotides are the largest contributors, with an estimated footprint of 97 tonnes CO_2e (5%). Acetonitrile (55 tonnes CO_2e, 3%) and cell culture medium (52 tonnes CO_2e, 3%) are the next highest contributors in this category. Other chemicals and reagents, including ethanol, antibodies, and methanol, contribute smaller yet still measurable shares of the remaining footprint.

Overall, the results for WUR reveal a mixed hotspot profile in which both specialised, high-impact laboratory kits and high-volume generic consumables are key drivers of procurement-related CO_2e emissions.

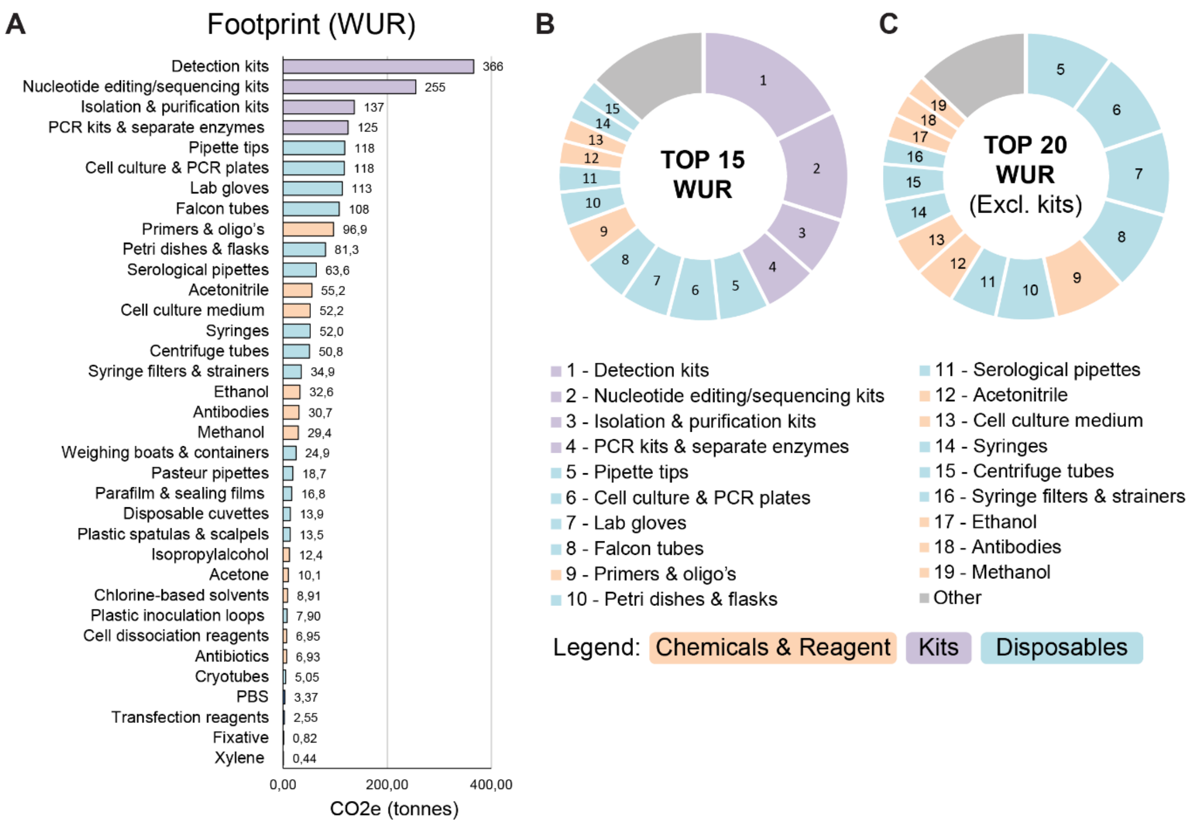

Figure 2. Procurement-related CO_2e emissions at WUR by product category. *Panel* **A** shows the full procurement footprint including kits. *Panel* **B** shows the top 15 hotspot categories including kits. *Panel* **C** shows the top 15 hotspot categories excluding kits.

3.3 Hotspot analysis at University Medical Center Utrecht

At UMCU, the footprint of laboratory consumables and chemicals is even more strongly dominated by a small number of high-impact product categories compared to WUR. As shown in **Figure 3**, *Panels* **A** and **B**, kit-based products (purple-coded in **Figure 3**) overwhelmingly shape the procurement-related emissions profile. Within this group, nucleotide editing and sequencing kits are the largest single contributor, with an estimated footprint of 2,128 tonnes CO_2e (40%). Detection kits follow closely at 1,890 tonnes CO_2e (36%). Together, these two categories account for the vast majority of UMCU's total laboratory footprint, reflecting the central role of high-throughput diagnostic and molecular workflows in the hospital setting. Other kit categories, such as PCR kits and separate enzymes (100 tonnes CO_2e, 2%) and isolation and purification kits (75.5 tonnes CO_2e, 1%), contribute less but remain substantial components of the overall footprint associated to kits. Because kits constitute such a large fraction of the footprint, we excluded kits from our analysis below when calculating the fraction of total footprint for each category (see Figure 3, Panel C).

In contrast to WUR, antibodies rank secondary to kits at UMCU with an estimated footprint of 190 tonnes CO_2e (18%), highlighting their intensive use in clinical diagnostics and biomedical research. Other chemicals, including cell culture medium (47.3 tonnes CO_2e, 4%) and primers and oligonucleotides (40.6 tonnes CO_2e, 4%), are among the top 15 contributors but have smaller impact than antibodies. Disposable laboratory items (blue-coded in **Figure 3**) also contribute notably, with lab gloves as the highest-ranking disposable at 154 tonnes CO_2e (14%), followed by Falcon tubes (129 tonnes CO_2e, 12%) and cell culture and PCR plates (86.7 tonnes CO_2e, 8%). Serological pipettes, pipette tips, cryotubes, Petri dishes & flasks, and centrifuge tubes are also among the top contributors (ranging within 3-6% of total footprint), reflecting their widespread use across departments and laboratory functions. Other hotspot categories listed within in the top 15 are ethanol, isopropyl alcohol, cell dissociation reagents and parafilm & sealing films.

Overall, the UMCU footprint is characterised by concentration of high-impact kit-based products, supplemented by consistently high contributions from commonly used disposable plastics and selected chemicals and reagents.

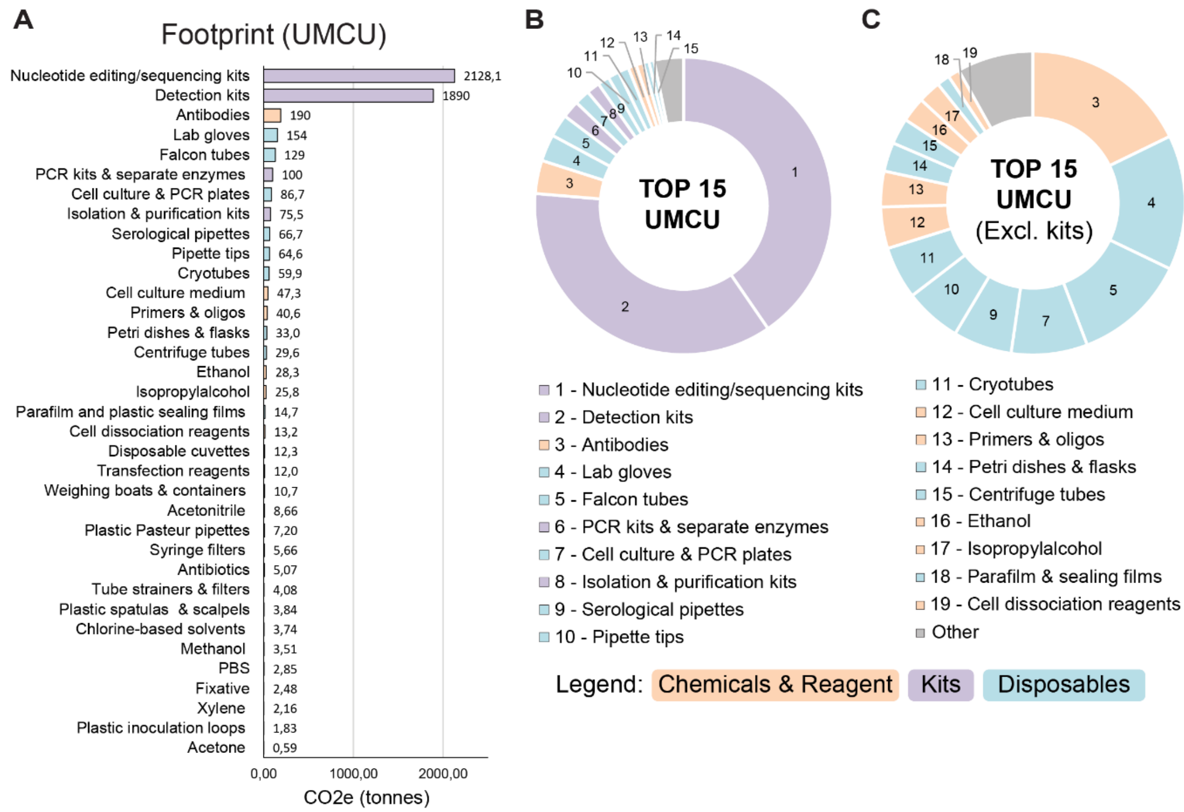

Figure 3. Procurement-related CO_2e emissions at UMCU by product category. *Panel* **A** shows the full procurement footprint including kits. *Panel* **B** shows the top 15 hotspot categories including kits. *Panel* **C** shows the top 15 hotspot categories excluding kits.

3.4 Comparison between UMCU and WUR

Comparison of UMCU and WUR highlights both shared patterns and institution-specific differences in laboratory procurement footprints. In both institutions, laboratory kits dominate the full procurement footprint (**Figure 2** and **3**, *Panels* **A** and **B**), confirming that kit-based products are a critical driver of procurement-related CO_2e emissions across research and clinical laboratories. Disposable plastics, including lab gloves, pipette tips, Falcon tubes, and cell culture and PCR plates, consistently appear among the top contributors, reflecting their widespread use and cumulative impact. When kits are excluded (*Panels* **C**), the hotspots shift: at WUR, pipette tips, plates, and lab gloves become the largest contributors, while at UMCU antibodies emerge as the leading non-kit contributor, followed by lab gloves and Falcon tubes. Other chemicals and reagents, such as acetonitrile, cell culture medium, ethanol, and isopropyl alcohol, also remain significant contributors in the kits-excluded view, though the exact composition differs between the research-focused WUR and the clinically oriented UMCU. Direct quantitative comparison of CO_2e across categories is complicated by differences in employee numbers, laboratory space, and the mix of research versus diagnostic activities at the two institutions. Nevertheless, overall trends are clear: kits dominate total procurement emissions, and high-volume disposable plastics and a limited set of chemicals remain key contributors in both contexts, providing actionable targets for circular procurement and environmental mitigation. **Figure 4** provides a visual comparison of the relative contributions of each subcategory to the total laboratory footprint at WUR and UMCU, with side-by-side bars representing the percentage contribution of each institution, enabling direct comparison of both individual and institution-specific impacts across key subcategories.

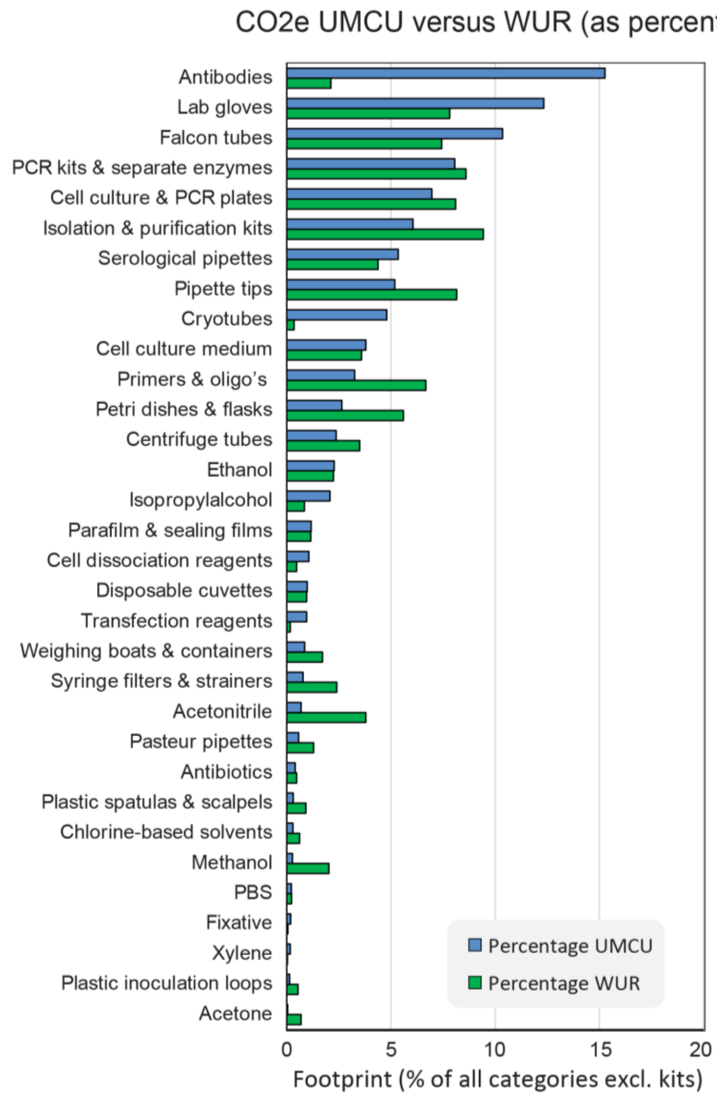

Figure 4. Side-by-side comparison of subcategory contributions (%) to laboratory CO_2e at UMCU (blue) and WUR (green), excluding kits, revealing both overlapping and institution-specific impact categories.

4. Discussion

This study demonstrates that laboratory consumables and chemicals constitute a substantial and highly concentrated share of procurement-related (scope 3) climate impact at both WUR and UMCU. Despite differences in institutional mission, scale, and laboratory function, the analysis shows a pronounced concentration of emissions, with a limited number of product subcategories accounting for the majority of estimated CO_2e. This pattern is consistent with previous procurement-based footprint analyses in healthcare and laboratory contexts (Noort *et al.,* 2024, Eckelman & Sherman, 2016; Rodríguez-Jiménez *et al*., 2023; De Paepe *et al*., 2024). At WUR, kits make up 37.5% of the emissions from all included categories, while 6 categories make up more than 50% of the total emission when only disposables, chemicals and reagents are considered. Similarly, at UMCU, kits make up almost 80% of total emissions and only 4 categories generate more than 50% of total disposable-, reagent- and chemical emissions. These findings highlight the potential effectiveness of targeted intervention strategies focussing on a relatively small number of frequently purchased laboratory products.

Several trends emerged when comparing the results of both institutes. First, across both institutions, detection kits and nucleotide editing & sequencing kits account for the majority of the procurement-related carbon footprint, particularly at UMCU. This likely reflects the central role of high-throughput diagnostic and molecular workflows in the hospital setting. Although kits also represent the largest emission source at WUR, their contribution is more evenly distributed across other high-impact categories, consistent with the broader diversity of research activities across laboratories.

Second, several single-use plastic disposables consistently rank among the highest-emitting product categories at both institutions, including products such as lab gloves, pipette tips, Falcon tubes, and cell culture & PCR plates. Interestingly, these product categories also account for the majority of laboratory waste (Weber *et al*., 2025). Weber and colleagues showed that 86% of laboratory waste consists of 10 standard laboratory products, nearly all of which appear among the top contributors in our procurement-based hotspot analysis.

Lastly, we observe that reagents and chemicals exhibit institution-specific patterns. At UMCU, antibodies are a major source of emissions, reflecting their intensive use in clinical diagnostics and biomedical research. At WUR, primers, oligonucleotides, and solvents such as acetonitrile are more prominent, consistent with the institution's stronger focus on analytical chemistry and molecular biology research. These differences illustrate how procurement-related laboratory emissions are shaped by institutional research profiles and laboratory purpose.

Collectively, although direct quantitative comparison of absolute CO_2e values between WUR and UMCU are complicated by differences in employee numbers, laboratory space, and the balance between research and diagnostic activities, the findings reveal a consistent pattern: a limited number of consumable categories account for the majority of procurement-related emissions at both institutions. These findings support a transition towards more sustainable alternatives for commonly used laboratory products, thereby contributing to efforts to reduce the environmental footprint of laboratory operations.

Despite the valuable insights generated by the spend-based hotspot analysis, several methodological limitations should be acknowledged. First, some NACRES-based emission factors were derived from a meso-analysis (see methods from De Paepe *et al.,* 2024), which is based on the carbon footprint of selected companies. While some of these companies indeed produce specific laboratory disposables or chemicals, others supply a broad range of products across multiple categories. Consequently, the resulting emission factors may not accurately reflect the environmental impacts of the specific laboratory products assigned to those categories. Second, uncertainties and variations in NACRES-based emission factors introduce additional variability into the results, particularly when comparing product groups with similar characteristics. Besides some uncertainty around NACRES codes, several limitations arose from the procurement data itself. Shipping and handling costs were occasionally registered separately from product prices, and combined orders complicated the attribution of emissions to individual product subcategories. In addition, product descriptions frequently contained insufficient information to assess the product category based on defined keywords. A clear example is the categorization of primers and oligonucleotides, for which the product description often consisted solely of customer defined names. Manual categorization was therefore inevitable for these products.

Furthermore, inconsistencies in procurement data between institutes make it challenging to conduct a spend-based footprint analysis for multiple institutes simultaneously and hinder the use of a standardized keyword table applicable across multiple institutions without manual refinement. Consequently, a material-based hotspot analysis of laboratory products would provide a more detailed and accurate assessment of the environmental impact per product category, while reducing uncertainties associated with expenditure-based allocation method.

Overall, this study identifies several environmental hotspots among frequently purchased laboratory products, providing procurement professionals with a practical basis for prioritising sustainability interventions in research and diagnostic laboratory settings. A relatively small number of product categories account for the majority of procurement-related emissions, highlighting opportunities for targeted action. Embedding environmental criteria into procurement decision-making, alongside cost and performance considerations, can support the transition towards more sustainable laboratory operations while aligning procurement practices with circular economy principles and broader healthcare sustainability objectives (Dutch Government, 2025). Besides identifying procurement-related emission hotspots, this work highlights the importance of improving procurement data quality. Greater consistency in procurement data structures across institutes, combined with more detailed product description, would improve the accuracy of environmental assessments and facilitate data-driven circular procurement strategies. Enhanced data quality and harmonisation across institutions would also increase the robustness, comparability and scalability of future procurement-based footprint analyses.

Despite the limitations associated with spend-based hotspot analyses discussed above, this study provides a detailed procurement-based assessment of the environmental impacts of commonly used laboratory consumables. Follow-up research using material-based approaches is needed to validate and refine the findings presented here and to improve the accuracy of product-level impact estimates. Nevertheless, the results provide procurement professionals with actionable insights into high-impact product categories and can support the integration of sustainability criteria into procurement processes for laboratory products. By incorporating environmental considerations alongside cost and performance criteria, institutions can better align procurement practices with broader sustainability objectives, including university sustainability strategies (e.g., Wageningen University & Research, 2025) and initiatives such as the Green Deal Sustainable Healthcare (Ministry of Health, Welfare and Sport).

Funding sources

This research was funded through a seed grant awarded under the *Circular Safe Hospitals* initiative by the "EWUU Alliance – Institute for a Circular Society" of the Netherlands, under project number EWUU-CS-Lab-24-05.

Acknowledgements

The authors gratefully acknowledge **Ryan Breinburg** from the Procurement Department at Wageningen University & Research for his cooperation and for providing valuable insights into procurement data and purchasing processes. We thank **Renate Kat**, **Bart Noort** and **Erik Schalken** for uniting multiple project groups working on similar projects to exchange ideas and methods. We thank **Jasper van den Herik, Anne Marie van den Berg** and **Renate Kat** for critically reviewing the report and advising on footprint analysis methodology.

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