Surgical pathology and sustainable development: international landscape and prospects

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ABSTRACT
The healthcare sector significantly contributes to global greenhouse gas emissions, with surgical pathology (SP) playing a notable role. This review explores the ecological transformation of SP, offering a global overview of existing challenges and sustainable initiatives worldwide. While some countries, such as the UK and France, have developed national strategies to reduce the carbon footprint of healthcare, including SP, many regions remain at an early stage of implementing green practices. Several studies have assessed the carbon footprint of SP, focusing on key aspects such as laboratory operations, pathology procedures and functional units, highlighting materials and transportation as major contributors to emissions. The integration of digital pathology and artificial intelligence (AI) presents opportunities to enhance efficiency and address medical deserts but also poses challenges due to the associated energy consumption.
Local initiatives such as the 'Transformation Ecologique en Anatomie et Cytologie Pathologiques' (Ecological transformation in SP) or TEAP collective in France, Belgium's 'Green Team' and sustainable practices in Tunisia and New Zealand demonstrate the global effort to reduce the environmental impact of SP. Key strategies discussed include ecodesign of care, circular economy practices, green AI and partnerships with industry. However, achieving meaningful reductions in SP's environmental impact requires international cooperation and support from national health policies. This review emphasises the importance of collaborative efforts to implement sustainable solutions without compromising the quality and safety of healthcare services.

INTRODUCTION
The escalating challenges of global warming, biodiversity loss and the encompassing concept of Planetary Health[1] call for an urgent evaluation of the interdependencies between human health and the Earth's well-being. Recent studies highlight the severe impacts of unprecedented warming on human health and advocate for radical actions to mitigate these effects.[2] Health systems globally play a significant role in this environmental crisis, not only as victims but also as contributors, given their ecological footprints. The carbon footprint of the healthcare sector in the world has been estimated at 4%–5% of global net greenhouse gas (GHG) emissions.[3] It varies across countries, influenced by factors such as energy mix, industrial activities and assessment methods. For example, in Mexico, healthcare contributes around 3% of GHG emissions, while in the UK, it accounts for about 4%.[4] In Canada, it corresponds to 5% GHG alongside significant pollutants such as ammonia and carbon monoxide.[5] In Australia and the Netherlands, healthcare accounts for 7%[6] and 8%[4] of GHG emissions, respectively. Despite France's relatively low CO_2 emissions due to its reliance on nuclear power, the healthcare system still emits around 8% of the national GHG emissions.[7] The USA has the highest contribution of GHG emissions from the healthcare sector, at 8.5%.[8]

Gradually, national plans for the decarbonisation of the health sector are being published particularly in Europe. The National Health Service (NHS) proposed an ambitious net zero programme[9] and more recently the French government published the roadmap for ecological healthcare planning.[10] Similarly, according to their commitment at Conference of the Parties (COP) 26, the Belgian government proposed its latest National Health Action Plan to make the healthcare system more sustainable and resilient and to initiate concrete policies against environmental pollution, soil degradation and biodiversity loss.[11]

However, these measures alone will fall short of fulfilling the commitments outlined in the Paris Agreement to reduce GHG emissions by 80% by 2050 compared with 2015 levels, aiming to keep global temperature rise below 2°C compared with the preindustrial era.[12]

A few medical specialties have been pioneers of ecological awareness and have made recommendations for greener practices. For instance, anaesthesia and intensive care have been recommending intravenous over gas anaesthesia where possible as well as the abandonment of certain inhaled anaesthetic agents.[13–15] Nephrologists have been advancing their efforts towards reducing the environmental impact of dialysis care; for example, with the position statement by the Italian Society of Nephrology[16] and the best practice guide from the French Society of Nephrology Dialysis and Transplantation.[17]

Ecological awareness in clinical laboratories began appearing in the literature as early as 2012, with the Asia-Pacific Federation for Clinical Biochemistry and Laboratory Medicine mitigation proposal for clinical laboratory impacts on the environment.[18] In 2018, the first study addressing the carbon footprint of a clinical laboratory in Europe was published[19] as well as the first waste audit of a histopathology laboratory in Greece.[20] In 2020, the carbon footprint of five common pathology laboratory tests in Australia was published.[21]

More recently, there has been a focus on environmental impacts specific to surgical pathology (SP) laboratories,[22–27] mainly in developed countries, but much work is still needed to effectively and sustainably mitigate the environmental impact of SP. The objective of this review was to (1) provide an international overview of the awareness of the need for action in SP, (2) describe the main environmental aspects in the field and (3) propose strategies for reducing carbon and environmental footprints while maintaining high-quality healthcare.

OVERVIEW OF SUSTAINABLE DEVELOPMENT INITIATIVES IN SP WORLDWIDE

Like other medical specialties, SP is becoming increasingly aware of its environmental footprint and the urgency to modify its practices. However, the level of awareness varies between countries and continents.

Europe

In the UK, it is recognised that sustainable development competencies and education play a significant role in achieving a greener NHS. Consequently, there is a drive to include sustainability education at all stages of clinical laboratory education.[28] The UK Royal College of Pathologists, in collaboration with the Centre for Sustainable Healthcare, Greener NHS and NHS England, works with partner bodies like the Institute of Biomedical Science and the Association of Clinical Biochemistry and Laboratory Medicine to promote sustainable practices in pathology. 'Green Champions' from these organisations regularly meet to ensure sustainability education is integrated into healthcare laboratories and sustainable practices are adopted. Efforts focus on reducing energy consumption through sustainability in quality improvement projects and adopting standards such as the Laboratory Efficiency Framework,[29] My Green Lab certification[30] and the European Federation of Clinical Chemistry and Laboratory Medicine Green Lab certification programme.[31] Other efforts include reducing unnecessary testing[32] and minimising sample rejection rates due to preanalytical errors,[33] aiming for a more sustainable and efficient collaboration between clinicians and laboratories in general.

In France, specific programmes for green healthcare and particularly for clinical laboratories have yet to be implemented. However, in the roadmap for ecological healthcare planning, a toolbox called The CAP (Understand, Act and Share) Sustainable Hospital has been promoted to inspire.[25] It offers three original, operational and complementary tools to (1) acculturate professionals in the sector with a collective game called Plan Health Faire, (2) build the establishment strategy in alignment with the 2030 Agenda strategy and (3) take action with healthcare professionals using The Sustainable Units programme which includes a specific certification. However, in response to the climate emergency, French pathologists founded the collective 'Transformation Ecologique en Anatomie et Cytologie Pathologiques' (Ecological transformation in SP) or TEAP. A survey of French pathologists (340 respondents out of 1651 French pathologists[34]) found that 91% regarded sustainable development as a major or intermediate issue in their personal lives, while only 42% felt the same about their medical institutions (unpublished data). Additionally, 75% of respondents expressed a willingness to take action through a sustainable development collective. Today, TEAP comprises over 100 members from public and private laboratories, including pathologists, residents, technicians and secretaries, from France and French-speaking countries such as Belgium and Tunisia. It aims to (1) coordinate the implementation of ecofriendly practices in francophone SP, (2) promote professional sensitisation and research and (3) collaborate with manufacturers to improve SP sustainability. Since 2022, it has been organising specific congress sessions at French SP congresses (two events per year) and more recently they were invited to collaborate at the International Academy of Pathology (IAP) Congress in Cancun in October 2024. On behalf of TEAP, several original studies have been published focusing on different aspects of sustainable development in SP, including carbon footprint,[35] ecodesign of care,[36] digital pathology,[24] circular economy[23] and education.[25 26] At the request of the French SP learnt society, the TEAP is now involved in a project to elaborate national recommendations for a greener SP.

In Germany, by the time of article submission, there is no coordinated national initiative or working group of professional societies addressing the ecological sustainability of SP practice. However, several individual centres are interested, including some with published scientific studies.[37]

In Belgium, the board of the Belgian Society of Pathology decided to create a working group in 2023 specially dedicated to the ecological transformation in Belgian laboratories. An educational session on this topic was organised the same year for the annual meeting of the society (Belgian Week of Pathology). A local initiative called Path Lab Green Team has been established with the goal of promoting systematic thinking of all laboratory activities, to develop sustainable alternatives to daily practice while ensuring the quality and security of care for patients and professionals.

USA

In the USA, sustainability efforts for clinical, hospital and other diagnostic laboratories have been in relation to the robust ongoing programmes available for research laboratories. For example, the International Institute for Sustainable Laboratories has cross-functional working groups including representation from clinical and research laboratories. At the building level, a federal plan for efficient laboratory design is available for diagnostic laboratories, but it is not mandatory. For example, the US Department of Energy National Renewable Energy Laboratory Smart Labs toolkit enables laboratory design with energy efficiency and safety at the forefront and typically delivers significant cost savings as well. The US Green Building Council Leadership in Energy and Environmental Design programme has certified hospital laboratory buildings, including at Emory Healthcare and at the Cleveland Clinic.

The National Academy of Medicine in the USA oversees The Action Collaborative on Decarbonizing the US Health Sector (Climate Collaborative), a public–private partnership focused on care delivery, supply chain, education and policy as the main areas for action.[38]

Sustainability in diagnostic laboratories has been a topic at the CleanMed Conference as early as 2014. In 2022, the American Public Health Laboratories hosted a Sustainable Laboratories webinar and the American Society for Clinical Pathology published an article on laboratory preparedness and resilience in the event of extreme weather.[39] A group at Vanderbilt has since published a series of papers on the effects of climate change and extreme weather events as they relate to laboratory preanalytics and specimen transport,[40 41] a topic which was also presented at the 2024 annual meeting of the Association for Diagnostics and

Laboratory Medicine. The Association for Molecular Pathology formed an interest group in 2023 for environmental sustainability in diagnostic molecular laboratories.

In 2022, the IAP introduced a Greening the Labs session during the US and Canadian Academy of Pathology (USCAP) annual meeting, as part of their Professional Development and Innovations in Pathology Education Symposium. This launched a 3-year Greening the Labs course at USCAP meetings, focusing on sustainability in SP and cytopathology laboratories, with expert panellists from Mayo Clinic, Cleveland Clinic and Texas Children's Hospital. Building on these programmes, we were invited to present a short course, 'Introduction to Laboratory Environmental Sustainability,' at the 2024 IAP Congress, featuring colleagues from the USA, the French TEAP group and New Zealand.

New Zealand

The Royal College of Pathologists of Australasia (RCPA) has made positive steps towards promoting more sustainable laboratory practice with their first Environmental Sustainability Guideline published in February 2024.[42] The guideline aims to integrate sustainability into all laboratory activities and commit pathology laboratories across Australia and New Zealand to sound environmental practices. Promisingly, both the RCPA and the New Zealand Institute of Medical Laboratory Science featured laboratory sustainability-themed presentations at their 2024 annual scientific meetings. Engagement with climate conscious SP practices is aligned with the sustainability priorities of the New Zealand primary national healthcare provider Te Whatu Ora.

African countries

In Africa, there are several isolated ecoresponsible initiatives within private pathology and cytology laboratories, focusing on the adoption of practices for sorting, treatment and secure disposal to minimise environmental impact. These actions are often driven by the need to reduce operational costs in SP and to address recurring supply chain deficiencies, particularly in countries with limited resources, fragile healthcare systems and unstable economies such as Tunisia. While awaiting the establishment of a national collaborative organisation comparable to the French TEAP group, to which some Tunisan pathologists are affiliated and contribute, a series of sustainable initiatives developed in one SP laboratory in Tunisia was published in 2023.[43]

KEY ENVIRONMENTAL CONSIDERATIONS IN SP

Carbon footprint assessment

Assessing the carbon footprint of pathology laboratories is essential for ecological transformation, helping to identify emissions and guide reduction efforts. CO_2 equivalent (CO_2eq) is the most widely used metric, comparing emissions of various GHGs based on their global warming potential. Emissions are categorised into three scopes: scope 1 (direct emissions), scope 2 (indirect emissions from purchased electricity) and scope 3 (all other indirect emissions). For healthcare systems worldwide, scope 3 has the largest contribution, representing between 50% and 75% of total healthcare system GHG emissions while scopes 1 and 2 range between 10% and 30% and 0.3% and 63.2%, respectively.[3]

In France, drugs and medical devices have been identified as the major GHG emission categories from healthcare, representing more than 50% of total health sector emissions.[3 7] Béchu *et al* published the first carbon footprint study of an SP laboratory in Lille, France, including evaluation of all three scopes over an entire year[44] (figure 1). The SP laboratory (without digitisation) processed around 17 242 pathology cases over the year (13 687 biopsies and 3555 surgical specimens) corresponding to 54 124 blocks (2021 annual activity). This activity emitted 117 tons of CO_2eq amounting to 0.4% of the hospital's total carbon footprint.[45] The major contributors to emissions were inputs such as reagents and materials (51%), input-associated freight (20%) and laboratory transport staff (12%). Energy (8%) and waste (9%) were less significant contributors.

These results were in accordance with those of Trecourt *et al*[35] analysing GHG emissions from four different pathology slides (excluding digitisation); production of an H&E-saffron-stained slide emitted 0.589 kgCO_2eq for biopsies and 0.618 kgCO_2eq for surgical specimens, whereas an immunohistochemistry slide produced 0.363 kgCO_2eq, and a frozen section slide produced 1.481 kgCO_2eq. The main contributors to GHG emissions in

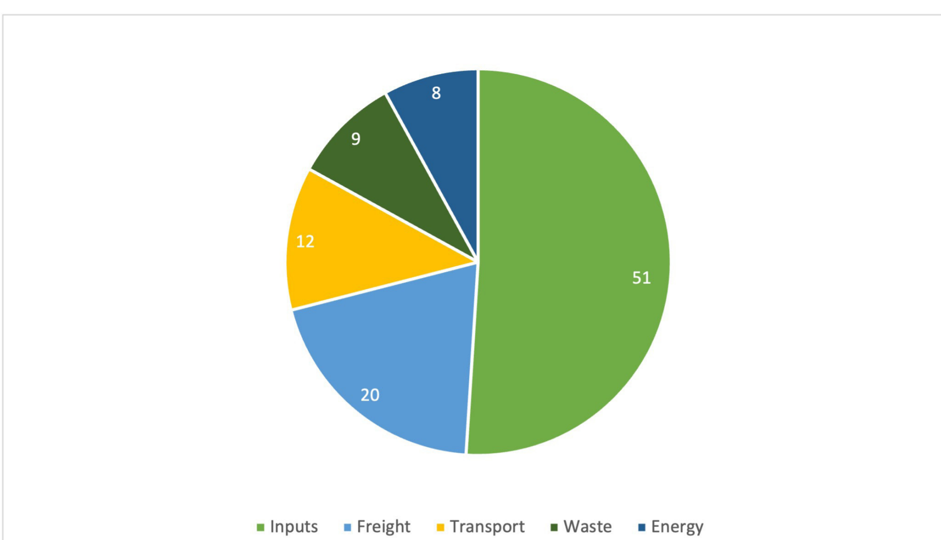

Figure 1 Contribution (%) of different sectors to the carbon footprint of the surgical pathology laboratory at Saint Vincent Hospital in Lille, France, in 2021.[44]

slide processes were materials and reagents, followed by staff travel. Notably, for immunohistochemistry slides, reagent packaging generated more emissions than the reagents themselves, underscoring the need for industry collaboration to find lower-impact solutions. Reagent and supply production were also the largest GHG contributors in biopsy processing.[46] Evaluation of Paris' hospitals (Assistance Publique-Hôpitaux de Paris) carbon footprint also showed that clinical laboratory consumables contributed 14% of the GHG emissions, placing it second after drugs and before medical devices.[47] A study of prostate cancer evaluation which included calculating the GHG emissions of the MRI procedure, the biopsy procedure and the biopsy processing in an SP laboratory in the USA, found that the GHG emissions of the entire process (80.3 $kgCO_2eq$) were dominated by the energy used by the MRI machine (42.3 $kgCO_2eq$), while the SP laboratory component was minimal (2.0 $kgCO_2eq$) representing between 3% and 8.1% of the whole process.[48]

These results show that the most effective approach in SP is moderation, also called ecodesign of care or climate-smart healthcare, to reduce consumables without compromising quality. Staff travel is another area for reducing GHG emissions, where professionals should seek sustainable options like biking, carpooling or flexible work schedules (such as working 4 days of 10 hours instead of 5 days of 8 hours), which can also offer physical and emotional benefits.

Digital pathology

The integration of digital pathology offers significant opportunities, including advancements in telepathology, artificial intelligence (AI) diagnostics and educational support, improving efficiency and accessibility in SP. While environmental concerns, such as the carbon footprint, are important, the potential benefits should not be overlooked.

An original study on behalf of the TEAP, presented at the 2023 Carrefour Pathologie conference in Paris and at the 2024 IAP Congress,[49] estimated that full digitisation of French SP laboratories could increase the carbon footprint by 5%–9%, with slide storage duration being the largest factor. This highlights areas where improvements can reduce environmental impact.

AI, particularly deep learning (DL), is a promising tool in surgical pathology, with the potential to profoundly transform daily diagnostic work.[50] Early AI diagnostic support programmes are already being used in routine practice, demonstrating the practical application of these technologies. One study examined the environmental sustainability of DL in SP, showing potential challenges related to global warming.[37] For example, using a large DL model for all cases at the Institute of Pathology in Aachen could result in 2795 tCO_2eq per year, with international extrapolation suggesting up to 600 $MtCO_2eq$.

Storage policy

Specimen storage, including paraffin blocks, slides and cold-stored tissue, has long been a sensitive issue in SP. Digital pathology introduces whole slide image (WSI) storage, but regulations still require long-term archiving, ranging from 10 to 30 years, or even lifelong for paediatric samples. In France, many hospitals outsource storage due to space limitations, which is both financially and environmentally costly (0.038 $KgCO_2eq$ per slide for 30 years).[35] While dearchiving is rare, long-term storage remains crucial, especially for rare diseases, despite its environmental impact.

Cold storage is another source of energy consumption and potential waste in the SP laboratory.[44] Ultra-low temperature freezers can hold outdated and otherwise forgotten specimens. Environmentally conscientious cold storage practices, including a regular freezer inventory, are needed. Increasing the temperature from −80°C to −70°C is another way to reduce energy consumption (by as much as 26%) and thereby SP CF without compromising specimen quality.[51] The International Freezer Challenge has spurred thousands of clinical and research laboratories in 195 countries to address energy demands from cold storage by implementing best practices.[52]

An international review of sample conservation laws, considering climate change and field practices, is essential. Digital storage should not replace physical storage due to the greater environmental impact of retaining WSI long term. Only samples of significant interest should be kept long term. Additionally, data duplication should be minimised since physical slides, which can be rescanned,[49] are preserved better over time compared with WSI.

STRATEGIES FOR REDUCING CARBON AND ENVIRONMENTAL FOOTPRINTS WHILE MAINTAINING HIGH-QUALITY HEALTHCARE

The last part of this article will address the solutions already implemented worldwide in SP to reduce our environment impact (figure 2).

Research and education

Developing a structured research and education initiative is essential to integrate environmental sustainability into SP. This initiative should encourage dissertations, theses and presentations at national and international conferences, alongside postgraduate courses and degrees that incorporate sustainability themes, enhancing professional awareness and competency. Despite their strong commitment and sense of responsibility, health professions students and staff face several obstacles, including time constraints, lack of support and insufficient training.[53–55] Education about environmental impacts of healthcare delivery is further supported by hospital committees. Such efforts, backed by guidelines from societies like the French Society of Anaesthesia and Intensive Care Medicine, help overcome obstacles, fostering a culture of ecoresponsibility among health professionals. Importantly, this education should be communicated from the SP teams to our clinical colleagues.

Ecodesign of care

Stewardship in SP[56 57] must emphasise minimising environmental impact while maintaining quality of care, safety and relevance, often referred to as 'ecodesign of care'[27] or climate-smart healthcare.[58] This includes various practices, such as formalin and alcohol recycling, and use of less harmful chemicals, offering both environmental and financial benefits.[59] For example, although formalin is the international gold-standard fixative used in SP, it is a toxic chemical without any validated substitute,[60] although some groups have experimented with the use of honey as a formalin alternative, with promising results[61]; the SP laboratory of Bordeaux's hospital developed a recycled formalin circuit based on the reuse of formalin following biopsy removal and filter paper filtration leading to a decrease in the total consumption of formalin by 26% in 2022 compared with 2021.[23] In addition to more than 2tCO_2eq reduction in GHG emissions, this programme has financial savings and substantial decreases in toxicity to humans and freshwater.[23] Alcohols and Xylen are also being recycled in SP laboratories.[62] As discussed previously, reduction of the SP laboratory carbon footprint

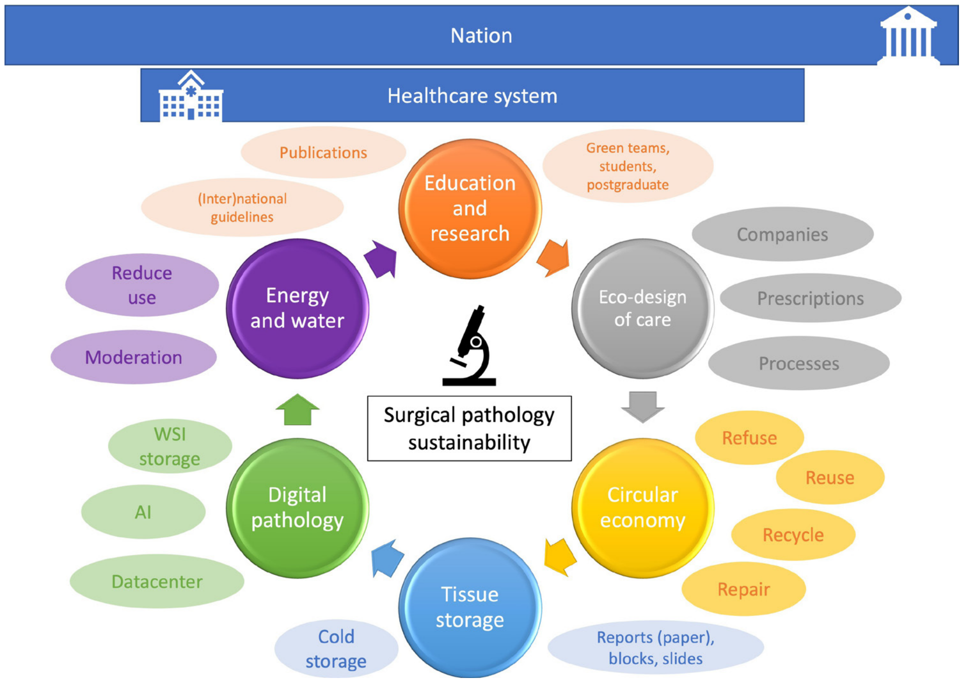

Figure 2 Diagram of the main challenges in the ecological transformation of surgical pathology. This diagram highlights the key areas necessary for the ecological transformation of surgical pathology: education and research, eco-design of care, circular economy, tissue storage, digital pathology and energy and water. To be effective, this transformation must be supported by both the healthcare system and national health policies. AI, artificial intelligence; WSI, whole slide imaging.

can be accomplished by reducing the inputs,[63] specifically the size and number of plastic specimen jars. For example, reduction of the use of containers for gastrointestinal biopsy samples reduced by approximately 67% of the GHG emissions of biopsy processing.[46] Similarly, a collaborative correct container size awareness programme between SP and theatre nursing staff included educational lectures, specimen container sizing posters and SP laboratory tours, to avoid unnecessary waste arising from the replacement and disposal of inadequately sized containers. Three months following these interventions, the percentage of containers disposed of for being too small to accommodate sufficient formalin decreased significantly from 36% to 13%.[64]

SP laboratories are set up to optimise economics and turnaround times and to satisfy clinicians and patients, however, less focus is given to material and human resources. In a French SP lab, omitting certain reflex first-line special histochemical stains (eg, PAS stain on all oesophagus biopsies) improved work satisfaction and cost-efficiency without compromising analysis quality or safety. The elimination of 7 out of 10 tests resulted in annual cost savings of €22 522 and reduced the workload by 5568 tests per year, maintaining an uncompromised workflow and diagnostic quality.[36] In the USA, according to the False Claim Act, it is illegal to bill unless medically necessary,[65] like upfront special stains without knowing the clinical context. In US SP laboratories, also for financial, storage and workforce reasons, submitting specimen sections has been optimised towards fewer tissue cassettes with the same diagnostic information, such as including representative lymph nodes in a cassette with representative bowel, rather than in their own cassette. Also, the use of glass slides for biopsies has dropped substantially in one US SP lab in Cleveland due to use of a tissue cutting algorithm designed to see the same volume of the specimen but on a single slide instead of two slides.[66]

Moderation should be applied during the entire SP laboratory process from macroscopy/gross specimen sampling, to initial H&E slides and through immunohistochemistry and molecular biology. This strategy should also extend to frozen sample libraries stored in ultra-low temperature freezers and biorepositories.[51]

Industry partnership

Reducing the environmental footprint of SP laboratories requires not only laboratory and procedural efforts but also collaboration with suppliers. Ecological design demands awareness of the environmental impact of all instruments and products, but such information is currently lacking in the health sector. Industry collaboration in green chemistry is also essential.[67 68] Efforts should focus on identifying alternatives to the toxic chemicals currently used in SP and decreasing the dependence of processes on petrochemical derivatives. A few forward-thinking laboratory supply companies are designing products with ecology in mind, for example, designing antibodies for shipping at room temperature rather than the more typical requirement for cold transport.[69] Industry partners can enhance their corporate sustainability by offering services that improve labs' carbon footprints, such as take-back programmes for plastics and glass, selling refurbished equipment with after-sales service and including right-to-repair language in service contracts. Recycling of laboratory chemicals should also be encouraged and supported through industry partnerships.[62] In the field of digital pathology, green AI is required to optimise digital workflows and data reduction strategies, DL model selection or model pruning.[37] Overall, the availability of life cycle assessment and clear and open lines of communication between product end-users and product suppliers will be necessary worldwide to accelerate collaboration between industry and laboratory consumers towards achieving GHG emissions reduction goals.

CONCLUSION

SP is actively transitioning towards sustainability, driven by global collaborative efforts which are currently heterogeneous between countries and continents. Key strategies include integrating sustainability into educational curricula, promoting resource stewardship and enhancing ecodesign through industry collaborations. Strategic partnerships with industry at an international level are essential for developing and adopting environmentally sustainable technologies and practices.

Alignment with ongoing activities, such as those in the UK, France and Belgium, would be of utmost interest. International alignment would be desirable, as collaboration could spare resources and provide a diversity of ideas and solutions tackling various aspects of sustainability in SP laboratories. International collaborative efforts will only be effective if they can be implemented locally, which will require support from governments, pathology specialty organisations and health systems. Advancing environmental sustainability interests of SP laboratories, the practice of pathology and healthcare, in general, will depend on alignment with existing areas of focus in the sector, such as financial considerations, high-quality and high-value care, and patient and worker safety and well-being.

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REFERENCES

1 Lerner H, Berg C. A Comparison of Three Holistic Approaches to Health: One Health. *EcoHealth Planetary Health Front Vet Sci* 2017;4:163.
2 van Daalen KR, Tonne C, Semenza JC, *et al*. The 2024 Europe report of the Lancet Countdown on health and climate change: unprecedented warming demands unprecedented action. *Lancet Public Health* 2024;9:e495–522.
3 Rodríguez-Jiménez L, Romero-Martín M, Spruell T, *et al*. The carbon footprint of healthcare settings: A systematic review. *J Adv Nurs* 2023;79:2830–44.
4 Pichler P-P, Jaccard IS, Weisz U, *et al*. International comparison of health care carbon footprints. *Environ Res Lett* 2019;14:064004.
5 Eckelman MJ, Sherman JD, MacNeill AJ. Life cycle environmental emissions and health damages from the Canadian healthcare system: An economic-environmental-epidemiological analysis. *PLoS Med* 2018;15:e1002623.
6 Malik A, Lenzen M, McAlister S, *et al*. The carbon footprint of Australian health care. *Lancet Planet Health* 2018;2:e27–35.
7 Lesimple H. Décarboner la santé pour soigner durablement: édition 2023 du rapport du shift project. Shift Proj; 2023. Available: https://theshiftproject.org/article/decarboner-sante-rapport-2023/ [Accessed 14 Jun 2023].
8 Eckelman MJ, Huang K, Lagasse R, *et al*. Health Care Pollution And Public Health Damage In The United States: An Update. *Health Aff (Millwood)* 2020;39:2071–9.
9 NHS England and NHS Improvement. Delivering a 'net zero' national health service. 2022. Available: https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2022/07/B1728-delivering-a-net-zero-nhs-july-2022.pdf [Accessed 5 Sep 2024].
10 Ministère délégué chargé de l'Organisation Territoriale et des Professions de Santé. Feuille de route - planification écologique du système de santé. 2023. Available: https://sante.gouv.fr/IMG/pdf/dp_pess.pdf [Accessed 5 Sep 2024].
11 Gouvernement fédéral belge. NEHAP 3 - plan national d'Action environnement-santé. 2023. Available: https://www.environnement-sante.be/sites/default/files/public/NEHAP3_FR.pdf [Accessed 5 Sep 2024].
12 United nations framework convention on climate change. Paris Climate Change Conference - Report of the Conference of the Parties on Its Twenty-First Session. Available: https://unfccc.int/sites/default/files/english_paris_agreement.pdf
13 Allen C, Baxter I. Comparing the environmental impact of inhalational anaesthesia and propofol-based intravenous anaesthesia. *Anaesthesia* 2021;76:862–3.
14 American Society of Anesthesiologists. The environmental impact of inhaled anesthetics. 2024. Available: https://www.asahq.org/about-asa/governance-and-committees/asa-committees/environmental-sustainability/greening-the-operating-room/inhaled-anesthetics
15 Sherman J, Le C, Lamers V, *et al*. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesth Analg* 2012;114:1086–90.
16 Piccoli GB, Cupisti A, Aucella F, *et al*. Green nephrology and eco-dialysis: a position statement by the Italian Society of Nephrology. *J Nephrol* 2020;33:681–98.
17 Société Francophone de Néphrologie Dialyse Transplantation. Guide des bonnes pratiques de la dialyse verte. 2023. Available: https://www.sfndt.org/sites/www.sfndt.org/files/medias/documents/SFNDT_guide%20complet-VF-HD.pdf [Accessed 23 Sep 2024].
18 Lopez JB, Badrick T, *et al*, ad hoc IFCC Panel on the Environmental Responsibility of Clinical Laboratories. Proposals for the mitigation of the environmental impact of clinical laboratories. *Clin Chem Lab Med* 2012;50:1559–64.
19 Ni K, Hu Y, Ye X, *et al*. Carbon Footprint Modeling of a Clinical Lab. *Energ* 2018;11:3105.
20 Kalogiannidou K, Nikolakopoulou E, Komilis D. Generation and composition of waste from medical histopathology laboratories. *Waste Manag* 2018;79:435–42.
21 McAlister S, Barratt AL, Bell KJ, *et al*. The carbon footprint of pathology testing. *Med J Aust* 2020;212:377–82.
22 Chicaud M, Montero-Macias R, Taconet S. Ecology: The blind spot in pathology research. *Ann Pathol* 2024;44:47–56.
23 Chicaud M, Vergara R, Théate I, *et al*. Recycled formalin: A new environmental mitigation tool in pathology? *Ann Pathol* 2024;44:346–52.
24 Guillory T, Tilmant C, Trécourt A, *et al*. The environmental impact of digital technology and artificial intelligence, in the era of digital pathology. *Ann Pathol* 2024;44:353–60.
25 Rullier A, Guihenneuc J, Ayraud-Thevenot S, *et al*. CAP, understand, act and share: A toolbox made in Nouvelle Aquitaine to support healthcare establishments in their ecological transformation. *Ann Pathol* 2024;44:331–7.
26 Sarfati M, Trecourt A, Sous l'égide du collectif de Transformation Écologique en Anatomie et Cytologie Pathologique (TEAP). Medical education in ecology and environmental health: A sustainable tool for action. *Ann Pathol* 2024;44:S0242-6498(24)00120-2:323–30:.
27 Vergara R, Del Castillo M, Ginestet F, *et al*. In the face of climate change, is a relevant and sustainable eco-pathology in France possible? *Ann Pathol* 2024;44:338–45.
28 Scott S. Embedding education into clinical laboratory professional training to foster sustainable development and greener practice. *Clin Chem Lab Med* 2023;61:638–41.
29 UCL. LEAF - laboratory efficiency assessment framework. sustain. UCL; 2022. Available: https://www.ucl.ac.uk/sustainable/take-action/staff-action/leaf-laboratory-efficiency-assessment-framework
30 My Green Lab Certification. My green lab. Available: https://www.mygreenlab.org/green-lab-certification.html [Accessed 5 Nov 2024].
31 Gammie AJ, Lopez JB, Scott S. Imperative: reducing the environmental impact of clinical laboratories. *Clin Chem Lab Med* 2023;61:634–7.
32 Mughal Z, Narayanan A, Gupta V, *et al*. Clinical need-directed blood tests: a step in saving the NHS? *Ann Clin Biochem* 2016;53:568–74.
33 Plebani M. The detection and prevention of errors in laboratory medicine. *Ann Clin Biochem* 2010;47:101–10.
34 Commission Medtech & Diagnostic de France Biotech. Task force anatomopathologie numérique. 2024. Available: https://france-biotech.fr/wp-content/uploads/2024/07/20240704_Synthese-TF-ACP-5Juin-FINAL.pdf
35 Trecourt A, Cottinet P-J, Donzel M, *et al*. Carbon footprint evaluation of routine anatomic pathology practices using eco-audit: Current status and mitigation strategies. *Ann Diagn Pathol* 2023;67:152210.
36 Vergara R, Chouvel R, Vergier B, *et al*. Reducing reflex first-line prescriptions in a surgical pathology laboratory: toward sustainable practice with positive economic and clinical effects. *Virchows Arch* 2024;10.
37 Vafaei Sadr A, Bülow R, von Stillfried S, *et al*. Operational greenhouse-gas emissions of deep learning in digital pathology: a modelling study. *Lancet Digit Health* 2024;6:e58–69.

38 Action Collaborative on Decarbonizing the U.S. Health Sector. Natl. acad. med. Available: https://nam.edu/programs/climate-change-and-human-health/action-collaborative-on-decarbonizing-the-u-s-health-sector/ [Accessed 23 Sep 2024].

39 Swails K. Is your laboratory ready for hurricane season? crit. Crit. Values; 2024. Available: https://criticalvalues.org/news/all/2022/11/16/is-your-laboratory-ready-for-hurricane-season

40 Wiencek JR, Pierre CC, Füzéry AK. Environmental factors in the preanalytical phase of laboratory testing. *Clin Biochem* 2023;115:1–2.

41 Pierre CC, Wiencek JR. The impact of environmental factors on external and internal specimen transport. *Clin Biochem* 2023;115:13–21.

42 Board of Professional Practice and Quality TRC of P of A. Environmental sustainability in pathology laboratories. 2024. Available: https://www.rcpa.edu.au/getattachment/42654e17-82ba-4d55-9b76-c6d7811fbd93/Environmental-Sustainability-in-Pathology-Laborato.aspx

43 Abdelmoula S, Gharbi S, Ben Alaya N, *et al*. Atelier Médico-Technique 3 - Comment faire de l'ACP de qualité en conditions contraintes. *Rev Div Fr L'AIP* 2023.

44 Béchu C, Rullier A, Lesoin P-E, *et al*. The carbon footprint of a surgical pathology laboratory in France. *Am J Clin Pathol* 2024;162:103–9.

45 Lesoin P-E. Bilan des émissions de gaz à effet de serre du groupement des hopitaux de l'Institut catholique de lille. 2021. Available: https://bilans-ges.ademe.fr/bilans/consultation/93bdcd7a-b1cd-11ed-8fce-005056b7acd1/fiche-identite

46 Gordon IO, Sherman JD, Leapman M, *et al*. Life Cycle Greenhouse Gas Emissions of Gastrointestinal Biopsies in a Surgical Pathology Laboratory. *Am J Clin Pathol* 2021;156:540–9.

47 AP-HP. Bilan carbone de l'Assistance publique des hôpitaux de paris (ap-hp). 2024. Available: https://s3-eu-west-1.amazonaws.com/static.hospimedia.fr/documents/231446/10179/synthese_bilan_carbone_a4_v9s_web_interactif.pdf?1713858816 [Accessed 16 Sep 2024].

48 Leapman MS, Thiel CL, Gordon IO, *et al*. Environmental Impact of Prostate Magnetic Resonance Imaging and Transrectal Ultrasound Guided Prostate Biopsy. *Eur Urol* 2023;83:463–71.

49 Béchu C, Gaillot-Durand L, Trécourt A, *et al*. Carbon footprint of digitization of surgical pathology in france: 100% digitization scenario - poster presentation. IAP 2024 Annual Meeting, Cancún, México; 2024.

50 Boor P. Deep learning applications in digital pathology. *Nat Rev Nephrol* 2024;20:702–3.

51 Madhusoodanan J. What can you do to make your lab greener? *Nature New Biol* 2020;581:228–9.

52 Best Practices Overview. Int. lab. freez. chall. Available: https://www.freezerchallenge.org/best-practices-overview.html [Accessed 16 Sep 2024].

53 Ryan EC, Dubrow R, Sherman JD. Medical, nursing, and physician assistant student knowledge and attitudes toward climate change, pollution, and resource conservation in health care. *BMC Med Educ* 2020;20:200.

54 Kotcher J, Maibach E, Miller J, *et al*. Views of health professionals on climate change and health: a multinational survey study. *Lancet Planet Health* 2021;5:e316–23.

55 Guihenneuc J, Cambien G, Blanc-Petitjean P, *et al*. Knowledge, behaviours, practices, and expectations regarding climate change and environmental sustainability among health workers in France: a multicentre, cross-sectional study. *Lancet Planet Health* 2024;8:e353–64.

56 White TE, Wong WB, Janowiak D, *et al*. Strategies for laboratory professionals to drive laboratory stewardship. *Pract Lab Med* 2021;26:e00249.

57 Kroft SH. A Different Kind of Laboratory Stewardship. *Am J Clin Pathol* 2021;156:493–4.

58 World Bank Group. Climate-smart healthcare - low-carbon and resilience strategies for the health sector. 2017. Available: https://documents1.worldbank.org/curated/en/322251495434571418/pdf/113572-WP-PUBLIC-FINAL-WBG-Climate-smart-Healthcare-002.pdf?_gl=1*1hcp9sl*_gcl_au*MTM2NDIwOTQyMy4xNzI3MDkwOTM4 [Accessed 23 Sep 2024].

59 Cho J-H, Jin S-Y, Park S. Carbon footprint and cost reduction by endoscopic grading of gastric intestinal metaplasia using narrow-band imaging. *J Gastroenterol Hepatol* 2024;39:942–8.

60 Agence nationale de sécurité sanitaire alimentation, environnement, travail. Alternatives potentielles au formaldéhyde en anatomie et cytologie pathologiques humaines. 2019. Available: https://www.anses.fr/fr/system/files/VSR2014SA0236Ra-1.pdf [Accessed 12 Sep 2024].

61 Yee AWM, Oo PS, Aye SN, *et al*. Natural fixatives alternative to formalin in histopathology: A systematic review. *Med J Malaysia* 2023;78:98–108.

62 Chisholm C, Hayford K, Stewart M. Dermatopathology Laboratory Green Initiatives. *Am J Clin Pathol* 2022;158:372–7.

63 Badrick T. The Role of Laboratories in Reducing the Carbon Footprint: Waste: Reduce It Before It Reduces You. *Am J Clin Pathol* 2022;158:322–4.

64 West J, Wright P, Lambie N. Minimising plastic waste through correct specimen container size selection at specimen retrieval. *Pathology (Phila)* 2024;56:S43.

65 Western district of north carolina | hickory pathology lab agrees to pay the united states $601,000 to settle false claims act allegation | united states department of justice. 2017. Available: https://www.justice.gov/usao-wdnc/pr/hickory-pathology-lab-agrees-pay-united-states-601000-settle-false-claims-act [Accessed 24 Sep 2024].

66 Toscano M, Castano PT, Khaitan N, *et al*. How many slides are needed for colon polyp diagnosis? - poster presentation (abstract #876) at USCAP 2024 annual meeting, Baltimore, MD, March 27, 2024. 2024.

67 12 principles of green chemistry. am. chem. soc. Available: https://www.acs.org/greenchemistry/principles/12-principles-of-green-chemistry.html [Accessed 5 Sep 2024].

68 O'Neil NJ, Scott S, Relph R, *et al*. Approaches to Incorporating Green Chemistry and Safety into Laboratory Culture. *J Chem Educ* 2021;98:84–91.

69 Frequently asked questions - why do most cst products ship at room temperature. Cell Signal. Technol. Available: https://www.cellsignal.com/learn-and-support/frequently-asked-questions [Accessed 23 Sep 2024].