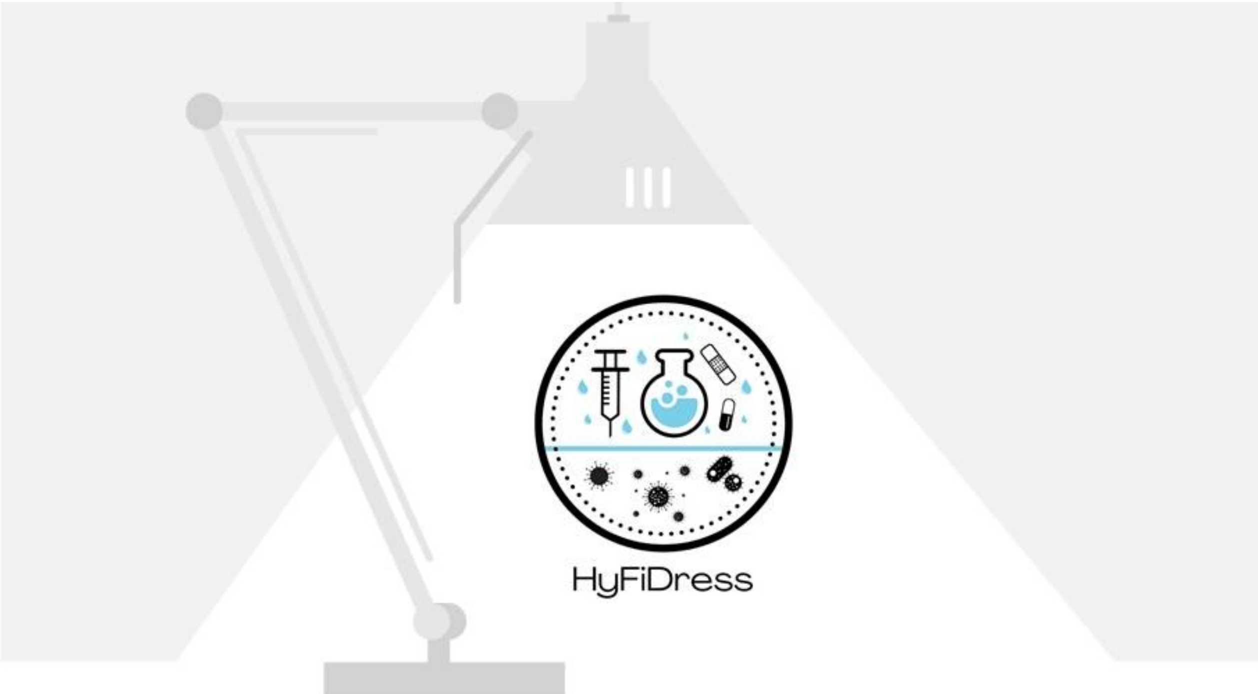

Green Lab Guide

This Green Lab Guide is a practical, values-driven manual to support researchers, technicians, and administrators in creating more sustainable laboratories.

1. Introduction

Laboratories are at the heart of scientific discovery. They enable the experiments, analyses, and breakthroughs that shape our world. Yet, behind every discovery lies a significant environmental footprint: laboratories consume 5–10 times more energy than a comparable office space and generate large amounts of waste. This impact is not inevitable. Many of the resources consumed and wastes produced can be avoided, reduced, or recycled. By embedding sustainability into everyday laboratory practice, researchers can reduce their environmental footprint while improving the efficiency, quality, and reproducibility of their work.

This Green Lab Guide is dedicated to supporting sustainable research practices within the HyFiDress consortium and beyond. The guide is not a rigid manual but a practical, adaptable resource. It highlights best practices, offers checklists, and provides frameworks that can be tailored to local contexts. The goal is clear: to reduce the environmental impact of laboratory work, while supporting safe, high-quality, and reproducible science.

2. UN Sustainable Development Goals (SDGs)

In 2015, the United Nations adopted the **2030 Agenda for Sustainable Development**[1], a shared blueprint for peace, prosperity, and environmental stewardship. At its heart are the **17 Sustainable Development Goals (SDGs)**, which call for urgent, collective action to end poverty, protect the planet, and ensure wellbeing for all.[2,3] These goals are deeply interconnected, recognizing that progress in one area, such as sustainable energy, can accelerate advances in others, like climate action or responsible consumption.

Figure 1: Alignment of Green Lab practices with the UN Sustainable Development Goals (SDGs), illustrating how laboratory actions in energy, water, waste, travel, and culture contribute to global sustainability targets.

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1 https://www.un.org/sustainabledevelopment/development-goals/
2 https://sdgs.un.org/goals
3 https://www.undp.org/sustainable-development-goals

The Green Lab Program directly contributes to several of these goals by embedding sustainability into research practices and laboratory operations. Laboratories are among the most resource-intensive spaces in universities and research institutions, yet they also offer some of the clearest opportunities for measurable impact. By linking laboratory sustainability with the SDGs, we situate our work within a global framework of responsibility and innovation.

The following SDGs are most relevant to the Green Lab Program:

SDG 6: Clean water and sanitation

Goal 6 emphasizes the importance of sustainable water use and improved efficiency. Laboratories consume large volumes of water for cooling systems, sterilization, and cleaning. Green lab practices—such as replacing single-pass cooling with recirculating systems, maintaining water baths to avoid unnecessary refills, and ensuring autoclaves or dishwashers operate only at full loads—support this global goal. These actions reduce water stress and contribute to responsible water stewardship.

SDG 7: Affordable and clean energy

Goal 7 calls for universal access to affordable, reliable, and sustainable energy, alongside significant improvements in energy efficiency. Research laboratories typically use 5–10 times more energy than office spaces of the same size. By consolidating samples in freezers, raising ultra-low temperature freezer settings from –80 °C to –70 °C where safe, switching off equipment when not in use, and choosing energy-efficient infrastructure, laboratories can drastically cut energy consumption. These efforts directly support SDG 7 and demonstrate the feasibility of clean energy transitions in science.

SDG 9: Industry, innovation, and infrastructure

Goal 9 highlights the need for sustainable, resilient, and innovative infrastructure. The Green Lab Program reflects this principle by encouraging the retrofitting of laboratories with energy- and water-efficient technologies, sharing equipment across research groups to reduce redundancy, and fostering collaborations that optimize resources. By embedding sustainability into the very infrastructure of research, laboratories enhance both innovation and responsibility.

SDG 12: Responsible consumption and production

Goal 12 lies at the heart of green laboratory practice. This goal calls for the reduction of waste, the promotion of resource efficiency, and the adoption of circular economy principles. Laboratories generate significant volumes of plastic and chemical waste, much of which can be reduced or replaced. The use of reusable glassware instead of single-use plastics, recycling where safe and possible, and establishing sharing schemes for surplus reagents or consumables all contribute to more responsible patterns of consumption.

SDG 13: Climate action

Goal 13 is supported across all these efforts. Every kilowatt-hour of energy saved, every liter of water conserved, and every kilogram of waste diverted from landfill contributes to mitigating climate change. Though laboratories are just one part of the global emissions picture, their symbolic and practical contributions to climate action are powerful. Researchers can demonstrate that excellence in science and responsibility for the planet are not opposing forces but mutually reinforcing goals.

Table 1: Green Lab practices mapped to UN SDGs

SDG	Relevant targets[4]	Examples of Green Lab practices
SDG 6: Clean water & sanitation	**6.3:** Improve water quality; **6.4:** Increase water-use efficiency	Use recirculating cooling systems; maintain water baths; run autoclaves/dishwashers only when full
SDG 7: Affordable & clean energy	**7.2:** Increase renewable energy share; **7.3:** Double energy efficiency improvement rate	Participate in Freezer Challenge; raise ULT freezer temps to –70°C; switch off idle equipment; purchase energy-efficient models
SDG 9: Industry, innovation & infrastructure	**9.4:** Upgrade infrastructure for sustainability; **9.5:** Enhance research and innovation capacity	Share core equipment; retrofit labs with efficient systems; encourage sustainable procurement and infrastructure upgrades
SDG 12: Responsible Consumption & Production	**12.2:** Sustainable resource management; **12.5:** Substantially reduce waste generation	Replace single-use plastics with glassware; recycle packaging and materials; establish sharing shelves for reagents
SDG 13: Climate Action	**13.2:** Integrate climate change measures into policies and planning	Reduce lab energy and waste footprint; log savings in institutional reporting; encourage sustainable travel and events

By aligning with the SDGs, the Green Lab Program strengthens its role not only as an institutional initiative but as part of a broader global movement. Each freezer defrosted, every piece of equipment switched off, and every plastic tube avoided contributes to a more sustainable and equitable future. In this way, the Green Lab Guide is not just about laboratories: it is about positioning research at the forefront of sustainability, in solidarity with the international community's pursuit of the 2030 Agenda.

3. Principles of Good Green Lab Practices

At the heart of a sustainable laboratory are guiding principles that shape everyday decisions. These principles ensure that environmental responsibility is not a side activity but a fundamental part of scientific practice.

3.1. Responsibility

Every researcher is accountable for the environmental impact of their work. Laboratories are estimated to consume up to ten times more energy than office spaces of the same size and

[4] https://sdgs.un.org/sites/default/files/2020-09/SDG%20Resource%20Document_Targets%20Overview.pdf

produce significant volumes of plastic and chemical waste[5,6]. Embedding sustainability into daily practice acknowledges that reducing this footprint is not optional, but part of the researcher's duty of care. Responsibility means recognizing the link between local laboratory decisions and global challenges such as climate change and resource scarcity.

3.2. Efficiency

Efficient use of energy, water, and consumables is a cornerstone of laboratory sustainability. Simple measures, such as raising ultra-low temperature (ULT) freezer settings from –80 °C to –70 °C, switching off unused equipment, or running autoclaves only when full, can reduce consumption dramatically. For example, the international "Freezer Challenge" demonstrated that optimizing freezer management can save tens of thousands of kilowatt-hours annually per institution[7]. Efficiency supports both environmental and financial sustainability, as reducing resource use also lowers operational costs.

3.3. Circularity

Circularity involves designing laboratory systems according to the principles of **reduce, replace, reuse, and recycle**. This includes minimizing single-use plastics, replacing them with glassware when possible, and ensuring materials are recycled properly. A recent study estimated that academic research laboratories worldwide generated nearly 5.5 million tonnes of plastic waste in a single year,[5] underlining the urgency of circular practices. By adopting a circular economy mindset, laboratories transform waste into resources, creating closed-loop systems that benefit both science and the environment.

3.4. Safety & quality

Sustainability must never compromise safety or the integrity of research. Practices such as waste segregation, safe chemical disposal, and responsible substitution of hazardous materials ensure that "green" does not mean "unsafe." Similarly, efficiency measures like lowering freezer temperatures or switching equipment off must be balanced with protocols that protect samples and data integrity. Good research support integrates sustainability with compliance to international safety standards, ensuring that laboratory quality and reproducibility remain uncompromised.[8]

3.5. Collaboration

Laboratory sustainability is not achieved in isolation. It requires coordinated action across research groups, institutions, and international networks. Initiatives such as GO4GREENLAB (Max Planck, Germany)[9] and GreenLab Initiative (i3s, Portugal)[10] and collaborations within consortia like HyFiDress show how pooling knowledge and resources accelerates sustainable change. At an institutional level, collaboration between researchers, facilities staff, procurement

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[5] Urbina, M. A., Watts, A. J., & Reardon, E. E. (2015). Labs should cut plastic waste too. *Nature*, 528(7583), 479. DOI: 10.1038/528479c.
[6] U.S. Department of Energy, 2015: https://docs.nrel.gov/docs/fy03osti/33410.pdf
[7] https://mygreenlab.org/de/programs/freezer-challenge/
[8] OECD: https://www.oecd.org/en/topics/sub-issues/testing-of-chemicals/good-laboratory-practice-and-compliance-monitoring.html
[9] https://www.nachhaltigkeitsnetzwerk.mpg.de/about-us
[10] https://www.i3s.up.pt/news?v=252

officers, and leadership ensures that sustainability principles are embedded into procurement policies, training, and infrastructure planning. International frameworks such as the UN Sustainable Development Goals[1] provide a shared global language for aligning laboratory sustainability with broader societal objectives.

4. Key focus areas

The Green Lab Program focuses on a set of priority areas where sustainable practices can make the greatest difference. These areas address the main environmental impacts of laboratories, *i.e.*, energy, water, waste, travel, and culture, and provide clear, actionable pathways for change.

4.1. Energy reduction

Energy use is the single largest contributor to the environmental footprint of laboratories. Ultra-low temperature (ULT) freezers, fume hoods, incubators, and other high-demand equipment consume vast amounts of electricity, often running continuously.

- **Freezer challenge:** By consolidating samples, defrosting freezers regularly, and raising ULT freezer settings from –80 °C to –70 °C where scientifically safe, laboratories can cut electricity use dramatically. For example, raising a freezer's temperature by 10 °C can reduce energy consumption by up to 40%.[7] Since 2017, the Freezer Challenge, coordinated by My Green Lab and the International Institute for Sustainable Labotories, has helped labs worldwide save more than 20.7 million kWh of energy (equivalent to removing 15,000 metric tons of CO_2 emissions). Winning labs report improved sample management, reduced costs, and greater collaboration.
- **Equipment management:** Switching off equipment when not in use, or using timers and smart plugs, prevents unnecessary "standby" consumption. Even small devices left on overnight add up to significant waste across large research facilities.
- **Shared resources:** Promoting shared use of high-energy equipment through core facilities reduces redundancy and maximizes utilization. Instead of many half-used freezers, one well-organized shared freezer can serve multiple groups.
- **Ventilation systems:** Fume hoods are among the most energy-intensive devices in labs. Closing sashes when not in use can cut energy waste by 50% or more.[11] For example, Harvard University's Fume Hood Sash Campaign (USA) reduced energy use by 30% in participating labs and saved over $240,000 annually simply by reminding researchers to close fume hood sashes when not in use.
- **Procurement decisions:** When purchasing new equipment, energy-efficient models and those with sustainability certifications should be prioritized. Life-cycle assessments (LCA) can help compare not only upfront costs but also long-term energy and maintenance impacts.

Together, these measures support SDG 7 (*Affordable and clean energy*) by improving efficiency and reducing greenhouse gas emissions.

[11] Harvard Green Labs Symposium 2016 (YouTube).

4.2. Water stewardship

Water is another critical resource in laboratories, often consumed in large quantities for cooling, sterilization, and cleaning. Yet many systems operate far below efficiency standards.

- **Cooling systems:** Traditional single-pass cooling wastes vast amounts of potable water. Replacing these with recirculating chillers drastically reduces demand. For example, the University of California (UCSF: San Francisco, USA) replaced single-pass cooling with closed-loop recirculating systems across several labs, reducing water consumption by an estimated 20 million litres per year.
- **Water bath maintenance:** Regular cleaning and preventive care reduce the need for frequent water replacement, extending water lifespan and ensuring consistent performance. Adding antimicrobial agents (*e.g.*, benzoic acid, proprietary antimicrobial solutions) can prevent microbial growth, minimizing contamination risks and reducing the frequency of water changes. Using lids on water baths also helps to limit evaporation and maintain stable conditions. Alternatively, metal bead baths can replace water baths in many applications. Bead baths eliminate water consumption entirely, are less prone to microbial contamination, and are generally more energy efficient than water baths because the beads retain heat better and reduce standby energy use, while still providing uniform temperature control.
- **Low-flow fixtures:** Installing aerators on faucets or using foot-pedal systems allows researchers to access water efficiently, reducing unnecessary flow.
- **Sterilization systems:** Running autoclaves and glassware washers only with full loads prevents waste of both water and energy. In many institutions, autoclaves are responsible for the majority of laboratory water consumption.

Implementing these practices advances SDG 6 (*Clean water and sanitation*) by improving water-use efficiency and reducing waste.

4.3. Waste reduction & circular economy

Laboratories are major producers of plastic and chemical waste. Research has estimated that laboratories worldwide generate millions of tonnes of plastic waste annually, much of which could be reduced or recycled.[5] A circular economy mindset, where materials are **reduced, reused, and recycled**, helps address this challenge.

- **Replace and reuse:** Where feasible, replace disposable plastics with reusable glassware, stainless steel tools, or biodegradable alternatives. Autoclavable glass pipettes and reusable conical tubes are increasingly viable options.
- **Segregation and recycling:** Providing clearly labelled recycling bins for cardboard, plastics, glass, and metals ensures that non-hazardous waste does not enter incineration streams. Hazardous waste should be segregated carefully to avoid contaminating recyclable materials. For example, the University of York's "Lab Plastics Recycling" pilot program (UK) recycled over 10 tonnes of uncontaminated lab plastics in its first year and has since expanded across departments, demonstrating scalability in academic settings.
- **Packaging:** Procurement policies can favour suppliers who minimize packaging or use recyclable materials. Bulk purchasing also reduces the volume of waste generated.
- **Sharing shelves:** Establishing a culture of sharing surplus reagents, kits, or consumables prevents unused items from expiring and going to waste.

These steps support SDG 12 (*Responsible consumption and production*), shifting laboratory systems toward circularity and resource efficiency.

4.4. Sustainable travel & events

While laboratories are resource-intensive, the broader research culture also contributes to environmental impact through travel and events. Conferences, project meetings, and daily commuting all add to carbon emissions.

- **Low-carbon commuting:** Encouraging public transport, cycling, or car-sharing helps reduce emissions from staff travel. Institutions can support this through incentives such as bike facilities or subsidized transit passes. Within HyFiDress, we encourage all participants to choose train travel for journeys within Europe that are under eight hours one way, and to prioritize virtual meetings whenever possible.
- **Virtual collaboration:** Advances in digital platforms mean that many meetings and workshops can be held virtually, saving both time and travel-related emissions. The pandemic forced scientific communities to adopt virtual meetings, reducing emissions dramatically. For example, one analysis of the 2020 American Geophysical Union virtual conference found a 99.9% reduction in travel-related CO_2 emissions compared to previous years.[12]
- **Sustainable events:** When in-person meetings are necessary, organizers should select venues with environmental certifications, offer catering that emphasizes vegetarian and seasonal food options, and minimize single-use items. Avoiding bottled water and plastic cutlery are simple but effective steps.

These practices contribute to SDG 13 (*Climate action*), aligning research activities with the broader effort to reduce global emissions.

4.5. Culture & training

Sustainability is not only about infrastructure but also about culture. Embedding environmental responsibility into the daily routines of researchers requires awareness, training, and leadership.

- **Green Lab Ambassadors:** Each research unit can nominate sustainability champions to motivate colleagues, share best practices, and monitor progress. The HyFiDress partners are also part of this program, or in the process of considering it, and we actively share experiences across institutions to accelerate learning and improvement. For instance, over 1,500 labs worldwide have completed the My Green Lab Certification[13], which uses a third-party assessment to guide labs in implementing best practices for energy, water, and waste reduction. Certified labs report increased staff engagement and measurable sustainability gains, showing that embedding sustainability into research culture benefits both people and the planet.
- **Training and workshops:** Regular sessions on sustainable lab practices, procurement policies, and waste management help build a knowledgeable community.

[12] Burtscher, L., Barret, D., Borkar, A.P. *et al.* The carbon footprint of large astronomy meetings. *Nat Astron* 4, 823–825 (2020). DOI: 10.1038/s41550-020-1207-z
[13] https://mygreenlab.org/programs/mgl-certification/

- **Onboarding and inductions:** Including sustainability in lab inductions ensures that new staff and students adopt good practices from the start.
- **Celebrating progress:** Recognizing and rewarding achievements—such as reductions in freezer energy use or high recycling rates—encourages continuous improvement and reinforces a positive culture.

A culture of sustainability supports collaboration (SDG 9; *Industry, innovation & infrastructure*) and ensures long-term commitment, embedding responsible practice into the fabric of research.

5. Roles in the Green Lab Program

The success of the Green Lab Program relies on the active involvement of all stakeholders in the research ecosystem. Sustainability in laboratories cannot be achieved by individuals acting alone; it requires clear roles, shared responsibility, and collective action across multiple levels. Each actor plays a distinct but complementary role in creating a culture of sustainability.

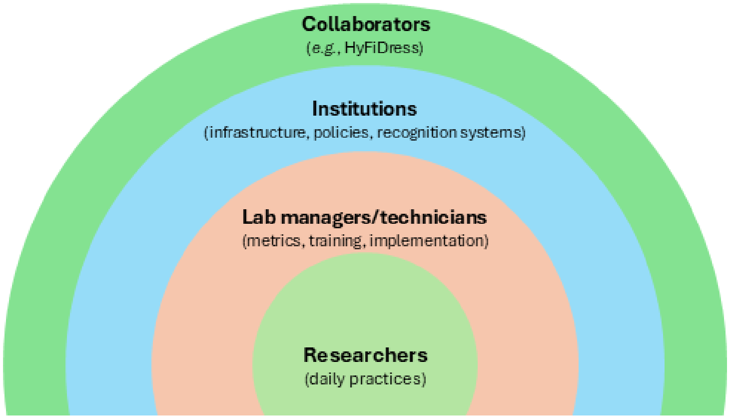

Figure 2: Roles in the Green Lab Program: researchers at the core, supported by lab managers/technicians, embedded within institutional policies and infrastructure, and connected through external collaborators (*e.g.*, HyFiDress consortium) for knowledge exchange and benchmarking.

5.1. Researchers

Researchers are at the frontline of laboratory sustainability. By integrating sustainable practices into daily routines, such as switching off unused equipment, choosing reusable alternatives, and segregating waste properly, they directly influence the environmental footprint of the lab. Researchers can also play a key role in experiment design, planning procedures that minimize energy, water, and reagent use without compromising scientific outcomes. Embedding sustainability into everyday habits not only reduces impact but also fosters a sense of personal responsibility and leadership.

5.2. Lab managers/technicians

Lab managers and technicians oversee the operational side of the laboratory and are central to ensuring sustainability is implemented consistently. Their responsibilities include tracking metrics such as energy consumption, waste generation, and freezer management; coordinating initiatives like the Freezer Challenge; and ensuring equipment is properly maintained for maximum efficiency. As key points of contact, they often provide training, monitor compliance with sustainability guidelines, and serve as the link between researchers and institutional sustainability offices.

5.3. Institutions

At the institutional level, support structures are essential for embedding sustainability into laboratory practice. Institutions can enable progress by providing sustainable infrastructure (*e.g.*, energy-efficient buildings, water recirculation systems), developing procurement policies that prioritize low-waste and low-carbon products, and recognizing achievements through certification programs or internal awards. Institutional leadership also has the power to align laboratory sustainability efforts with broader strategies, such as carbon reduction plans or commitments to the UN Sustainable Development Goals.[2] By establishing clear policies and providing resources, institutions create the enabling environment in which sustainable labs can thrive.

5.4. Collaborators

Collaboration extends the reach and impact of green lab initiatives. Networks, such as GO4GREENLAB (Max Planck, Germany)[9] and GreenLab Initiative (i3s, Portugal)[10], provide platforms for sharing expertise, benchmarking progress, and exchanging tools and training materials. Through such partnerships, best practices can spread beyond individual institutions and be adapted across diverse scientific contexts. Within the HyFiDress consortium, collaboration ensures that sustainability knowledge and experiences flow across partners, fostering innovation and accelerating change.

6. Conclusion

This Green Lab Guide is a living document. Its success depends on continuous feedback, adaptation, and shared responsibility across all members of the research community. By embedding sustainability into daily laboratory practice, the HyFiDress consortium fosters a culture of responsible, ethical, and reproducible research while actively reducing its environmental footprint.

Through collective effort, laboratories can remain centres of scientific innovation while also serving as leaders in sustainability, setting an example for how cutting-edge research and environmental stewardship can go hand in hand.

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[14] https://cezamat.pw.edu.pl/projects/in-progress/hyfidress/

Recommended checklist for sustainable laboratory practice

This checklist summarizes key points of good practice for researchers, technicians, and lab managers across various stages of the experimental lifecycle. Laboratory staff should review this checklist regularly and refer to institutional sustainability policies and safety guidelines when necessary.

PART 1: Before experiments

Before starting laboratory work, researchers must ensure that sustainable preparations are in place. This includes planning experiments to minimize resource use, confirming access to efficient equipment, and proactively addressing potential environmental risks.

- Have you considered whether reusable alternatives (*e.g.*, glassware instead of single-use plastics) are available and safe to use?
- Have you checked that equipment (*e.g.*, freezers, fume hoods, incubators) is operating efficiently and not consuming unnecessary energy?
- Are you consolidating samples and runs to reduce duplicate equipment use and maximize efficiency?
- Have you verified that water-intensive equipment (*e.g.*, cooling systems, water baths) is maintained and not wasting water?
- Have you reviewed institutional or project-specific sustainability policies and guidelines?
- Have you considered sharing unused reagents, consumables, or equipment with colleagues instead of purchasing duplicates?

PART 2: During experiments

Throughout experiments, continuous attention to energy, water, and waste management is essential. Researchers should monitor equipment usage, practice proper waste segregation, and use resources responsibly.

- Are you switching off equipment, lights, and water taps when not in active use?
- Are you closing fume hood sashes and biosafety cabinet windows when not required?
- Are you segregating hazardous and non-hazardous waste correctly to avoid unnecessary incineration?
- Are you reusing or recycling materials wherever possible without compromising safety or quality?
- Have you ensured that autoclaves, dishwashers, or other shared equipment are run with full loads?
- Are you minimizing unnecessary travel by using virtual meetings for collaboration where possible?

PART 3: After experiments

Once experiments are completed, attention should turn to sustainable shutdown, reuse, and documentation of lab practices. This includes ensuring that energy and materials are not wasted and that sustainability metrics are tracked.

- Are all instruments switched off or placed in low-energy standby mode?
- Have you defrosted and organized freezers and refrigerators regularly to maintain efficiency?
- Have leftover reagents, consumables, or materials been reused, recycled, or shared where possible?
- Is waste properly disposed of according to type (hazardous, recyclable, compostable, general)?
- Have you logged sustainability actions (*e.g.*, freezer temperature adjustments, energy savings, recycling volumes) for tracking and reporting?
- Have you provided feedback on sustainability challenges or improvements to the Green Lab Ambassador or institutional sustainability team?

This checklist aims to foster an environment of proactive, informed, and responsible laboratory practice, enabling researchers to conduct excellent science while reducing environmental impact. By embedding sustainability into every stage of laboratory work, the HyFiDress consortium contributes to a culture of efficient, ethical, and sustainable research.