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How Can I Improve Sustainability in My Lab?

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Executive Summary

The topic of sustainability receives more and more attention in the scientific community. In contrast to private life, habits, working processes, and equipment in labs are still far away from being really sustainable. How can we optimize the workflows, reduce the power consumption, produce less plastic waste? The sustainability footprint of the laboratory is a multi-factor story. This White Paper proposes the first steps to improve the situation in your lab.

Introduction

Sustainability, the holistic approach of integrating social, economic, and ecologic aspects in our actions, is becoming a more and more important issue. Wherever we interact in our personal area, we face a growing list of sustainability aspects. For sure, this is definitely no longer a "nice-to-have" but a central issue in politics, society, and business. Companies are measuring their carbon footprint and initiating measures to become carbon-neutral, politics are setting up programs such as the Green Deal to meet the 1.5 °C target and to fulfill the Paris European Agreement, and movements out of the society are calling for more actions while giving advice what everyone can do to be more sustainable.

We shop plastic-free, we go to work by bike, we switch off the lights to save energy, and we feel responsible for our environmental impacts. And then we enter the lab…

A Typical Day in the Lab

As you enter your lab on an ordinary Tuesday morning, these might be some typical routines and experiments.

- You will need the water bath later this morning. Fortunately, the water bath is switched on 24/7 at 37 °C, so you already save time. You adjust the temperature to +50 °C, as you need it today and want to be sure that it has the right temperature.

- You turn off the PCR that ran overnight – what a relief without that loud fan.

- You prepare your agarose gel to identify your two PCR fragments. There is only the chamber with 48 slots left – but anyway, it is just agarose. After the run, you cut out the ethidium bromide-stained fragments, and isolate your DNA from the little piece of agarose. Then it's time to incubate your sample in the water bath at +50 °C.

- Now you can proceed with the isolation of your PCR fragment by spinning several times – the lid of the instrument was not closed, but the temperature display still shows +4 °C. The two little microtubes look kind of lost in the big benchtop machine but the acceleration speed of that rotor is really impressing.

- After you have isolated and purified your PCR fragment, you perform a ligation to transform your plasmid into *E. coli* – wait, the waste bin for contaminated plastic is already full and the other 3 big bags from yesterday are still not autoclaved.

- You are looking for your competent cells in the -86 °C freezer to perform your transformation. It takes some time because the cells are not in the place you put them last time. The freezer is beeping – what an annoying sound! Plus, it is so warm in the room due to the 3 other units in this little chamber.

- You notice that the freezer is quite icy – it's really time to defrost the freezer. Someone should take care about it, sometime in the future…

- Since you have some time in between, you check flights to your next conference – finally an on-site event. You could also go there by train but that would take an hour longer, so you decide to take the plane (and it's also cheaper).

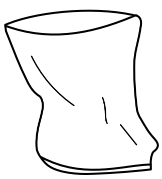
- In the afternoon, you autoclave your bacterial media, as you will need them tomorrow to culture your cells. It is just one bottle, but it's really necessary as you need it tomorrow morning.

- For your tomorrow's experiment, you also need a specific restriction enzyme. When searching for this particular restriction enzyme in the -20 °C freezer, you discover that it has already been used up. So, you have to order a replacement quickly. Similar to private life, the supplier offers dropshipment within 24 h from the UK. Great!

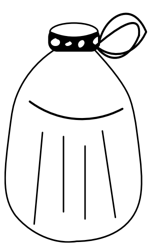
Great? Really? How many of these aspects did you already face in the lab? With how many of them you did have a bad conscience?

The Environmental Impact of your Lab Work

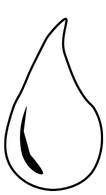
Lab work is resource-intensive. Everyday routines, typical lab processes and experiments in the lab require a huge amount of resources such as energy, water, or plastic.



If you take a look at a typical lab, the large amount of plastic is striking. A microbiology lab, with a total of seven persons working there, produced 97 kg of plastic waste in one month [1]. On average, a scientist produces 300-400 g of plastic waste per day [2a] and 5.5 million tons of plastic waste have been generated in life sciences labs worldwide in 2014 [3]. This accounts for 1.8% of all plastic waste generated globally in 2015 [2b].



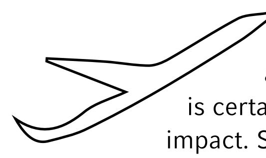
Also, the amount of chemicals and reagents waste is enormous. Around 35 tons of chemical waste were generated at the technical university of Dresden (Germany) in 2020, including solvents, inorganic and organic chemicals as well as washing liquids and mother liquor. A further 13 tons were generated by packaging which was contaminated with hazardous substances or containing residues of hazardous substances. [4] The university of Graz (Austria) stated in its environmental report 2020 that a total of about 10 tons of chemical residues, laboratory waste, and solvent mixtures had been generated.



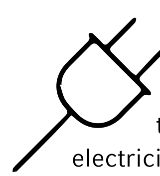
These are resource consumptions which many of us working in the lab do see on a daily or weekly basis. But there are other impacts that you do not notice right away. Lab buildings require 3-5 times more energy and water than office buildings [5]. On average, a 700 L ULT freezer needs as much energy (4,000 KWh/ anno) as a 4 person single-family house in Germany [6], older models even more [7] and fume hoods consume a similar amount of energy. [7] But it's not just about energy. Water is used in many places, for example to prepare buffers or HPLC-solvents, for heating or cooling. Did you know that it takes 3-5 liters of tap water to prepare 1 liter of lab water? [8] And if you think about autoclaving: these devices need a high amount of energy, but also a lot of water respectively steam. Large autoclaves, designed for use by members of an entire building, can consume up to 2,453 liters per day. [9]

CO_2

Finally, the increased use of IT and growing digitalization are responsible for high CO_{2e} consumption, which we do not see either. A typical metagenome analysis of 100 soil samples releases between 14 kg CO_{2e} and 186 kg CO_{2e} [10]. A 100 ns simulation of the molecular dynamics of the Tobacco mosaic virus releases between 17.8 kg and 95 kg CO_{2e}. Due to strongly increasing digitalization and the use of connected devices in the laboratory, these CO_2-load based on digitalization will further grow.



In addition to the daily work in the lab, there are other activities with a major environmental impact. Flying is certainly one with the most significant impact. Scientists are used to fly to conferences to present their work, exchange ideas with colleagues, and network. While these aspects are important, the related CO_{2e} emissions are important as well. A recent study compared an on-site conference in 2019 with its digital counterpart in 2020. The total travel emissions for the on-site conference were estimated to be 1,855 t CO_{2e}. By switching to a virtual event, the carbon footprint decreased by a factor of 3,000 down to 582 kg. At the same time, even more scientists were attending the digital event. [11] In view of these figures, we should not return completely to our old conferencing habits.



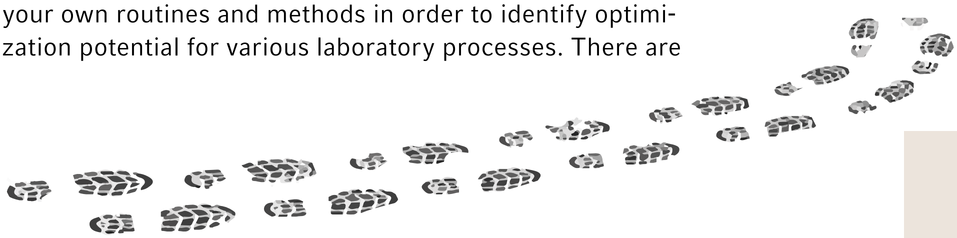
Looking more closely at the various sources, a distinction shall be made between direct CO_{2e} emissions generated by an organization through the consumption of resources for electricity, heating, and cooling on the one side and indirect emissions. The latter are related to all of an organization's indirect actions, such as the aforementioned employee travels, but also to the manufacturing and transportation of products that an organization purchases, as well as their disposal and recycling at the end of their life. [12] An analysis by the University of Copenhagen (Denmark) found that more than 85% of the university's emissions were due to such indirect emissions. Consumables for laboratory use, chemicals used in education and research, and chemicals used in laboratories account for an estimated 15% or even 20% of these emissions. [12]

Considering all these figures, it is clear that change of habits and processes in the lab is mandatory.

As scientists, we are trained to understand the processes in the nature. At university times, we all listened to the guidance on limited resources, diversity, waste, and recycling. And now we spend our time in the lab, producing many bags full of plastic waste, using big machines in the lab which run 24/7 and consume many kWh per day, handling toxic substances and so on. We cannot stop this 100% as science needs to continue. Safety regulations require single-use consumables and usage of resource-intensive disinfection methods. Many experiments require complex instruments to perform the analysis.
But there shall be ways to improve the sustainability situation in the lab – also in your lab.

How to Reduce your"Lab Footprint"

If you aim to start sustainable actions in your lab, you are probably wondering where the best starting can be. At this point, it makes sense to take a closer look at first your own routines and methods in order to identify optimization potential for various laboratory processes. There are also a number of simple actions that – despite their simplicity – have a big impact. Here are some best practical tips to help you get started:



1) Energy – exploit large saving opportunities
Focus on big energy consumers like fume hoods or biosafety cabinets (BSC). Especially older models have ineffective blower systems and classic lights. The university of Nottingham (UK) was able to save between 5% to 25% of energy by implementing a "shut the sash" program. Such an action should include a brief introduction to employees and a reminder sticker on the sash front to recall people to close the fume hood when not in use.
Such an action is free-of-cost, but can have a huge impact. Ask the supplier of the hood or BSC if broken classic lights can be replaced by LED bulbs.
Check whether your samples really need -86 °C or if you can set your freezer to -80 °C or even -70 °C. A study of the university of Copenhagen found that setting the freezer temperature to -70 °C can save up to 22% of energy [13].
The Table 1 shows the average energy savings of Eppendorf ULT freezers when changing the set-point from -80 °C down to -70 °C.
On average, the decrease results in a saving of ca. 30% power consumption. The data are based on Eppendorf-external tests with 3 empty units (230 V) in parallel and 20 °C room temperature. The greenhouse gas emission calculation is based on 275 g CO_2/ KWh (2019).
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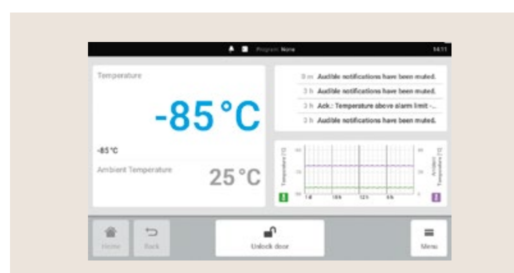


Freezer Range CryoCube®						
Energy savings	F740hi	F740h	F570h	F570n	F440h	F440n
-70 °C in (KWh/day)	7.5	8.1	4.9	5.7	4.8	5.7
-80 °C (KWh/day)	10.5	11.8	7.4	8.3	6.8	8.3
-80 °C -> -70 °C Savings in KWh	3.0	3.7	2.5	2.6	2.0	2.6
-80 °C -> -70 °C Savings in %	-28%	-31%	-34%	-31%	-29%	-31%
Power savings/ anno (KWh)	1,095 KWh	1,350 KWh	913 KWh	949 KWh	730 KWh	949 KWh
CO_2 savings/ anno (kg)	301 kg	371 kg	251 kg	261 kg	201 kg	261 kg

Table 1: The table shows the effect of changing the set-point from -80 °C down to -70 °C in respect to the average energy savings of Eppendorf ULT freezers. The data are based on Eppendorf-external tests with 3 empty units (230 V) in parallel and 20 °C room temperature.

Organization of your Samples

Concentrate on a proper freezer management – this not only saves energy but also increases safety.
A case study at the University of Edinburgh (UK) showed, i.e., [14]:

Freezer Maintenance
Poor defrosting practices result in higher energy consumption, but can also compromise the integrity of your samples by damaging the seals through ice crystals, allowing cold air to escape or warm air to enter the interior of the freezer.

Sample Storage
Ineffective sample storage by using bags or non-standardized containers e.g., limits the available space and hinders efficient and fast searching for samples period. Use standardized freezer boxes with lids and benefit from full space usage.

Sample identification & tracking
Inventory management helps to reduce door opening time – even one minute of an open freezer door requires about 30 minutes (or more) for the freezer to reach its set temperature of -80 °C again

Sample management
Inventory management saves space, for example, by avoiding redundant samples

Exchange and communicate with other lab groups and gain further knowledge. With the International Freezer Challenge, there is a global competition in which every lab can participate and where you can learn a lot about best practice. [15]

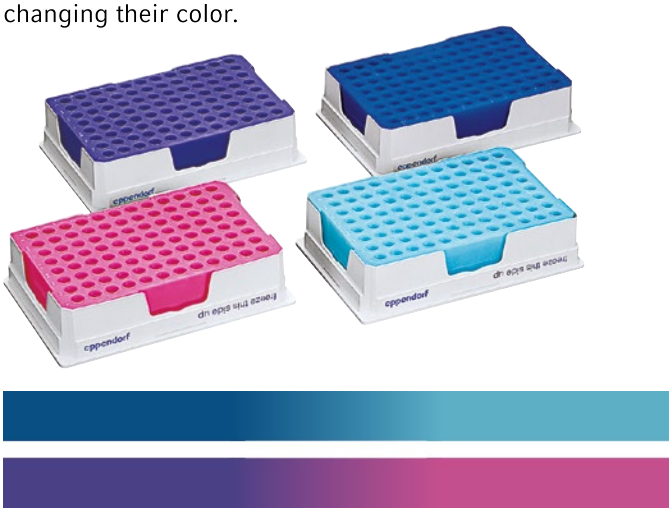
Energy consumption is not limited to the big consumers in the lab, but there are all the "little helpers" like heating blocks, PCR machines, shake tables, vortex mixers….

Simple power meters can provide you information which equipment requires the highest amount of energy and where "shut-off" policies may make sense

Even though they are smaller, these devices have an impact on your overall energy consumption. By taking a closer look at your workflows, you can easily save energy. Be sure to avoid standby functions and turn off your devices when you do not need them. By adjusting the running times of its devices, one lab was able to save 30% on energy. [16] This can be done by simple tricks like timers (please check with your local safety officer to see what is allowed in your facility) and better training of colleagues.
Where possible, choose the appropriate centrifuge which fits to your needs if several units are available. The multipurpose centrifuge for up to 4 L is oversized when spinning only 2 microtubes for 60 sec. Select programmable centrifuges for cooldown right before use rather than running a centrifuge for hours on pre-cooling.
Finally, do you know what kind of electricity is being used in your lab? Quite often this is out of our sphere of influence, but ask your facility management or procurement department nonetheless. Express your request for green power. Price is no longer a real argument in favour of conventional energy, as green power is nowadays in the same price range as electricity generated from coal, oil, or gas.

2) Water – lower your consumption

Autoclaves are big energy and water consumers. Do not let them run half-empty as they always use a very similar amount of energy and water. Big autoclaves can consume up to 2,450 liters of water per day and 84 kWh per day. [17] Water is mainly used for heating and cooling, but there are also alternatives. Did you know that metal beads can replace the water in your water bath? Quite often, ice is used to cool enzymes and samples. But an ice machine is running 24/7 and needs quite a lot of water and energy. Cooling blocks are a feasible alternative as they can hold deep temperatures for up to one hour. If they get too warm, they inform you by changing their color.



Cooling blocks with color change indicating a change of temperature from below +7 °C towards above +7 °C

And in general, rethink which water quality you need and choose the lowest water grade acceptable for your specific task. Why is that? The higher your water quality is, the more purification steps have been needed to reach this specific quality. And in nearly every step, water is lost and further resources (energy, consumables) have been used.
Last but not least: avoid single pass-cooling, where water is sent directly to the drain, and switch to recirculation systems.

3) Digitalization – be aware of the unseen impact

Include digitalization in your energy footprint. Data storage in the cloud, the analysis of data, or the simulation of experiments use a lot of energy and release a large amount of greenhouse gas. Check your cloud supplier or choose your next cloud supplier in respect to green energy usage for their servers. A metagenome assembly on 100 forest soil samples emits between 14 kg CO_{2e} to 186 kg CO_{2e}, depending on which software version you're using.
By switching to the newest software version, you can diminish your CO_{2e} emissions. [10] Used wisely, the effects of employing software products can also be positive. Sample management software helps you keep track of everything. It keeps your inventory up to date and prevents old and no longer needed samples from accumulating in your freezers and taking up unnecessary space. It also makes it easier to find your samples – saving you time (and energy, as mentioned above). By switching to a digital lab notebook, you can also save a lot of paper and also time.

4) Waste – keep the 4R's in mind

Reflect on the use of consumables, chemicals, and reagents to reduce the overall waste.
Storage and organization of your items are crucial. By setting up an inventory system, you choose the best way to keep track of your samples and other supplies, and you can save money. Here's an impressive example from the UCL (UK). They could realize a savings of around £ 90,000 a year by implementing an inventory scheme for their chemicals. [18]

Single-use consumables generate bags of contaminated waste

Reducing waste also implies a rethinking of your experiments and methods. Based on the "Reduce, Reuse, Replace, Rethink" approach, you can identify opportunities in your lab environment. [19] Here are some examples for each of the 4 "Rs":

(a) Reduce: Single plate-serial dilution spotting (SD-SDS) is a simple, miniaturized method for determining bacterial and yeast plate counts. Instead of using a total of six agar plates for a dilution series, apply 10-15 microdroplets from each dilution series to an agar plate divided into six sectors. [20, 21]

(b) Reuse: A lab implemented a procedure to reuse 50 mL conical tubes and saved 1,670 plastic tubes in one month. This is equivalent to 20,000 plastic tubes in one year [1]. By re-using 50 mL tubes, a study shows that the carbon footprint can be reduced by a factor of 11 compared to single-use tubes [22]. For sure, this is limited to applications where sterility and purity are not the key factor for reliable results.

(c) Replace: β-mercaptoethanol is often used in biochemistry as a reducing agent, but it is also toxic and hazardous. One can replace it with dithiothreitol (DTT), e.g., in RNA extractions [23]. Foetal calf serum (FCS) is a common component of cell culture media, and there are many efforts to replace it. This website provides a comprehensive overview of FCS-free culture media [24]

(d) Rethink: Routines are fixed in laboratories. Do DNA and RNA always have to be stored at -80 °C? It depends. Experiments have shown that you can store DNA at 4 °C for up to 12 months [25] and RNA at -20 °C for up to 1 month [26]. Check it out for your samples. Rethink your pipetting habits – instead of pipetting the same solvent into different tubes and using a new pipette or pipette tip each time, consider using a dispenser. With an adapted attachment, you can even go down to the µL range. Apply a "first in – first out"-policy for reagents, chemicals, and kits to avoid overlooking reagents and exceeding expiration dates.

Finally, consider sharing experiences about experiments that did not work. By reporting about failed experiments, you prevent others from wasting time and resources. Share best practices.

Lab Environment – Stay Organized

The overall organization of a lab can also contribute to its sustainability performance.
There are a lot of special instruments in a lab – but how many hours per day are they really being used? What about colleagues from other labs who bought the same instrument for their group because they need them too? Is that always necessary? Why not transfer the car sharing system to your lab equipment? There are already databases in place like the free online platform openiris. [27]
Booking systems, integrated in PCR cyclers or combined in a central, cloud-based instrument management systems are available.
When we buy products in our private lives, we are used to environmental and organic labels. And in the lab?

Nowadays, with labels like ACT® for chemicals, consumables and instruments, or the ENERGY STAR® label for freezers and refrigerators, it is becoming much easier to establish a sustainable procurement. Look for these independent labels before making your next purchasing decision.

ACT. The Environmental Impact Factor Label

energy ENERGY STAR PARTNER

Independent product certifications in respect to sustainable aspects of lab products

Streamline your purchase process in a sustainable way. As mentioned above, transportation contributes to your indirect CO_{2e} emissions. Keep your inventory up to date, check and ask regularly what is needed, and combine orders. This not only saves costs but also reduces both transport distances and emissions. A good inventory management can reduce drop shipment within 24 h to a minimum.

And the next time you are invited to an onsite-conference – rethink your travel habits, take the train instead of flying and use the extra time in the train to work – or to relax.

Establishing a Sustainable Lab Starts with Simple Steps

Working in the lab has a big impact in terms of energy, water, and other resources. Nevertheless, there is a whole range of measures that each of us can take. Use the check lists to guide your actions. They can help you start taking some actions right away – and when you walk into your lab tomorrow, you're sure to have some ideas about what you can do better.

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