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Original article

The unintended contribution of clinical microbiology laboratories to climate change and mitigation strategies: a combination of descriptive study, short survey, literature review and opinion

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ABSTRACT

Objective: Climate change poses a significant threat to humanity and human activity is largely responsible for it. Clinical microbiology laboratories have their unintended shares in carbon dioxide (CO_2) emissions. The aim of this study is to estimate CO_2 emission of a clinical microbiology laboratory and to propose initiatives to reduce the emissions.
Methods: CO_2 emission of instruments was estimated based on their electricity consumption. CO_2 emitted in producing consumables was estimated by weighing the consumables needed to perform major tests in a large academic hospital. A systematic literature review was performed to identify studies on the impact of clinical microbiology laboratories on the environment. A short survey was sent to four major manufacturers of agar plates on initiatives to reduce the environmental impact of their products. Opinion was given on activities that can reduce CO_2 emission in laboratories.
Results: The study shows that the largest amount of CO_2 emission in the microbiological laboratories comes from consumables and personnel commuting. For example, the production and transportation of agar plates needed to culture samples for a year in a hospital with 1320 beds result in 16 590 kg CO_2 is emitted. All survey participants mentioned that they were committed to reduce environmental impact of their products. The initiatives to reduce CO_2 emission can be performed at the laboratory and at policy level, such as reducing the number of tests to only the necessary amount to reduce consumables.
Discussion: The calculations contribute to map CO_2-related emissions in clinical microbiology laboratory activities, and the proposed initiatives to reduce the CO_2 may serve as starting point for further discussions. **Erlangga Yusuf, Clin Microbiol Infect 2022;■:1**

Introduction

On September 6, 2021, 233 health and clinical medicine journals published an editorial calling on governments to take emergency action to tackle the catastrophic harm to health from climate change [1]. This call was published a decade after the Lancet Commission naming climate change the biggest global health threat of the 21st century [2], and it follows a recent Intergovernmental Panel on Climate Change (IPCC) report that stated that ‘it is unequivocal that human influence has warmed the atmosphere, ocean, and land’ [3]. According to the IPCC report, emissions of greenhouse gases, such as carbon dioxide (CO_2) from human activities, are responsible for approximately all of the observed 1.1°C of warming since the preindustrial time (1850 to 1900) [3]. As of 2021, 194 countries have signed the Paris agreement that aims to keep the rise of global temperature well below 2°C and to pursue efforts to keep it below 1.5°C [4]. Unfortunately, using multiple modelling scenarios, it is projected that a 1.5°C increase in temperature will already have been reached by 2035 despite action taken so far [3].

Global climate change and hotter temperatures will have an impact on human health, and the impact can be direct, such as heat-related mortality for older people, but also indirect. Indirect impact on health involves many infectious diseases, such as vector-

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borne and water-borne diseases. The number of vector-borne diseases will increase because climate change will likely lengthen the transmission season and alter the geographic range of the vectors such as Ixodid ticks. For example, in 2017, two autochthonous cases of Crimean Congo hemorrhagic fever were reported in Spain, while prior to this report, the disease had only been reported in the southeastern part of Europe (outside of Africa) [5]. Another example is water scarcity, which is related to global warming and was associated with increased hospital admissions due to diarrhea in 18 Pacific islands [6]; a global cross-sectional study showed a significant correlation between low-rainfall areas and the prevalence of diarrheal disease in children [7].

Other than being impacted by climate change, health care services also contribute to climate change itself. It is estimated that healthcare services contribute 4.4% of the 54.4 gigatons of total global emitted CO_2 in 2015 [8]. In the Netherlands, healthcare sector is responsible for 7% of total CO_2 emissions. The energy use of buildings and the transport of healthcare workers, patients, and medicines are the most important factors [9]. As part of healthcare services, clinical microbiology laboratories also have their share to this emission. Yet, to the best of our knowledge, no studies have been published on this topic. Among the signees of the climate emergency editorial mentioned above are the American Society of Microbiology and four clinical microbiology and infectious diseases journals [1]. The aim of this study is to describe and quantify the impact of clinical microbiology laboratory on CO_2 emissions and to propose initiatives that can be done to reduce its impact.

Materials and methods

Literature search

To find information about the environmental effects of clinical microbiology, a literature review was performed together with a medical librarian in Embase, Medline, Cochrane, and Google (Scholar), articles and data up to March 2021 were considered (supplementary file). The results of this search (8811 hits) were screened and no formal inclusion criteria was applied to select studies.

CO_2 emission of medical microbiology laboratory

The activities in the medical microbiology laboratory were categorized in instruments, laboratory consumables, and supporting utensils such as computers and papers for reporting results.

We estimated the CO_2 emission of the clinical microbiology diagnostic instruments based on the information on electricity consumption as provided by the manufacturers. To calculate the CO_2 emissions based on the electricity consumption of the instruments, we used the emission factor of 0.435 kg/kWh for the Netherlands [10]. CO_2 emission of consumables was estimated by calculating CO_2 emission associated with production of plastic (for petri dishes and other consumables). To produce 1 kg plastic, about 2.5 kg CO_2 is emitted [11]. For petri dishes, we also added the CO_2 emitted to produce cardboard for their packing. To produce 1 kg cardboard, 5 kg of CO_2 equivalent is emitted [12,13]. To give a magnitude and dimension, we described CO_2 emissions due to the production of consumables needed to perform high volume bacteriology culture, serology, and molecular tests in a large academic hospital with 1320 beds (all single rooms). In a year, approximately 26 800 blood, 15 700 urine, and 10 000 respiratory samples were cultured in the Erasmus University Medical Center. Syphilis screening (9500 tests a year), latent tuberculosis infection screening (2700 tests), aspergillus antigen (2100 tests), and toxoplasma screening (1700 tests) were the most common serologic tests performed at this center. The most common commercial molecular tests performed were *Chlamydia trachomatis*/*Neisseria gonorrhea* polymerase chain reaction (PCR); 20 900 tests), and gastrointestinal multiplex enteric panel (1900 tests). For infection purposes, around 17 000 in-house PCR tests were performed in a year to screen for methicillin-resistant *Staphylococcus aureus* and other carbapenemase producing genes.

Short survey on major agar manufacturers

We sent e-mails to major manufacturers of agar plates (BD, Oxoid, Sigma-Aldrich, and Thermofisher) asking three questions: 1. Whether their agar plates are recyclable, 2. If not, whether there is any plan to produce recyclable agar plates, and 3. Whether there is any initiative (with examples) from the manufacturers to reduce the environmental impact of their products.

Initiatives to reduce CO_2 emission

We described initiatives that can be done or has been done in our experience in reducing the CO_2 emission.

Results

Technical aspect of calculating CO_2 emissions of a clinical microbiology laboratories

Calculating the amount of CO_2 emissions can be difficult. An instrument has variable energy use when it is in operation or when it is on stand-by mode. Emission factors differ from country to country, limiting direct comparison, and we noted that CO_2 emission data are available from various sources with various results. The variation may be due to different emission factors and whether the calculation included the life-cycle assessment for a material. Paper can be recycled, and the recycled part should not be included, but energy for recycling used should be taken into the CO_2 emission calculation. Furthermore, processing clinical microbiology laboratory waste (waste water, plastic, and cardboard for packing and shipping) also needs energy and contributes to CO_2 emissions.

An approach in calculating CO_2 emissions in a laboratory is by calculating emission per performed test. This can be done by simply measuring the total energy use in the laboratory, plus the energy needed to produce, transport, and perform waste management of the materials, dividing by the number of tests performed in the laboratory during a certain period. A study in a clinical chemistry laboratory calculated the CO_2 emission per test of major clinical chemistry test by weighing all consumables. This study also included into its calculation waste for venipuncture and laboratory analyses and electricity and water use for laboratory analyses [14]. It showed that the CO_2 emission for arterial blood gas determination was 49 g/test (95% CI, 45 to 53) and 0.5 g/test (0.4 to 0.6 g) for C-reactive protein determination.

CO_2 emission in an academic medical microbiology laboratory

Table 1 shows estimates of CO_2 emission of common instruments in an academic medical microbiology laboratory.

To perform bacterial cultures, 385 000 agar plates were used in a year. Each plate without agar weighs 14 g, which is 5390 kg plastic in total. The production of this amount of plastic was associated with 13 475 kg of CO_2. The agar plates were packaged in 963 boxes

Table 1
Estimation of carbon dioxide emission from instruments of a clinical microbiology laboratory of an academic hospital with 1320 beds

Source	Unit	Power consumption (watt/hour)[a]	CO_2 emission for 8 hours in use and 16 hours in standby mode (kilograms)	Maximum CO_2 emission[b] (kilograms)
Instruments				
Automated blood culture system (BD BACTEC FX Blood Culture System)	24 hours	650	Na	6.8
Automated mycobacterial detection system (BD BACTEC MGIT automated mycobacterial detection system)	24 hours	1000	Na	10.4
Mass spectrometry for identification of bacteria, including data system and monitor (Bruker Biotyper MALDITOF MS)	24 hours[c]	780–1138	9.4	11.9
Instrument		250–400	3.2	4.2
Data system		500–700	5.9	7.3
Monitor		30–38	0.3	0.4
Automated antimicrobial susceptibility system, only instrument (VITEK 2	24 hours[c]	300–600	2.1	6.2
Broth microdilution antimicrobial susceptibility system (Sensititre Vizion)	24 hours[c]	8	nd	0.09
Tissue homogenizer (gentleMACS Dissociator)	24 hours[c]	320	nd	3.3
Point of care nucleic acid amplification test (Cepheid GeneXpert 16-module)	24 hours[c]	170–270	2.1	2.8
Chemiluminiscent assay for serology tests (DiaSorin LIAISON XL)	24 hours[c]	400–550	4.7	5.7
Thermocycler (Veriti Thermal Cycler)	24 hours[c]	10–800	2.8	8.4
Fully automated real time PCR (Roche cobas 6800 System)	24 hours[c]	3500	nd	36.5
Real time PCR amplification and detection	24 hours[c]	1500	nd	15.7
Whole genome sequencing (Illumina iSeq 100)	24 hours[c]	80	nd	0.8

Na, not applicable; nd, no data (on stand-by power consumption); PCR, polymerase chain reaction.
[a] When a range is mentioned, the lower limit indicates power consumption when the instrument is in stand-by mode and the upper limit indicates power consumption when the instrument is in use.
[b] Calculated per 24 hours, assuming that the instrument is in use for 24 hours.
[c] Power consumption of these instruments varies depends on whether they are in use or in stand-by mode.

Table 2
Estimation of carbon dioxide emission from consumables and other activities of a clinical microbiology laboratory of an academic hospital with 1320 beds

Consumables	Unit	CO_2 emission (kg)	References for CO_2 calculation
Bacteriology procedures			
Production of plastic (polystyrene) petri dishes	1 kg	2.5	[11]
Cardboard for packing petri dishes	1 kg	3.3 to 5.4	[12,13]
Total consumables (plastic and cardboard packing) for 385 000 agar plates	1 year	16 590	[a]
Serology tests (total consumables plastic)			
Latent tuberculosis screening (including collection tubes; QuantiFERON-TB)	1 year	902	[11]
Aspergillus antigen (PLATELIA ASPERGILLUS)	1 year	142	[11]
Treponema screening (LIAISON Treponema Screen)	1 year	120	[11]
Toxoplasma serology (LIAISON Toxoplasma assay)	1 year	13	[11]
Molecular tests (total consumables plastic)			
Tips, processing cartridge, and output plates for in house PCR tests (Roche)	1 year	2280	[11]
Commercial Chlamydia trachomatis/Neisseria gonorrhoea PCR kits, pipettes, and PCR plates (using Roche cobas 6800 system)	1 year	877	[11]
Commercial multiplex PCR Enteric panel (BD MAX Enteric Bacterial Panel)	1 year	95	[12]
Waste			
Plastic barrels for microbiology waste of 385 000 agar plates, especially plastic (9600 waste bins)	1 year	31 680	[12]
Reporting results			
Energy used to assess laboratory information system for 8 hours a day for 10 desktops	1 year	880	[18]
Production of papers and printing documents	20 pages	1 to 1.9	[19]
Personnel			
Assessing standard operating protocol on laptop	1 hour	0.3	[19]
Driving to work	10 km	1.2	
Attending a conference by plane	Amsterdam–Barcelona (Return)	217	[20]

[a] 385 000 petri dishes packed per 400 in cardboard boxes, each weight 650 g.

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of each 0.65 kg, totaling 623 kg card boxes a year. To produce 623 kg of cardboard boxes, 3115 kg of CO_2 is emitted. CO_2 emitted to produce consumables of major serological and molecular diagnostic tests are presented in Table 2.

Survey results

All manufacturers answered no on the question whether their agar plates are recyclable. They mentioned that they have commitment to minimize the environmental impact of their products. Several manufacturers reported that their policy always complies with government regulation or ISO 14001 standard regarding waste and carbon footprint. They also highlighted initiatives in their own factories to reduce the environmental impact, such as the use of reusable pallets, recycling of plastic foils and cardboard waste, and replacement of polystyrene as packaging material. One of the manufacturers sent us their yearly sustainability report.

Initiatives to mitigate the problem

By knowing the sources of CO_2 emissions, plans can be made to reduce them. Several examples are presented in Table 3. These initiatives can be performed at a laboratory or policy level. A link can be made for example with the diagnostic stewardship. Diagnostic stewardship means efforts to use diagnostic tests responsibly and to eliminate unnecessary and ineffectual tests [15]. Reducing the number of the tests to only the necessary amount will reduce consumables, which is one of the most important sources of CO_2 emission. Small steps in laboratories, such as performing tests in batches whenever possible, should always be considered. When choosing manufacturers, the CO_2 footprint of instruments and consumables and information regarding waste management should be considered, and this information should be made available by the manufacturers. The transport distance of continuously needed consumables is a factor that influences the CO_2 footprint. A possible out-of-the-box solution that has been tested is the delivery of consumables without carboard boxes; the agar plates would be delivered in carts from the distributors to the laboratories and then the carts would be returned for the next delivery.

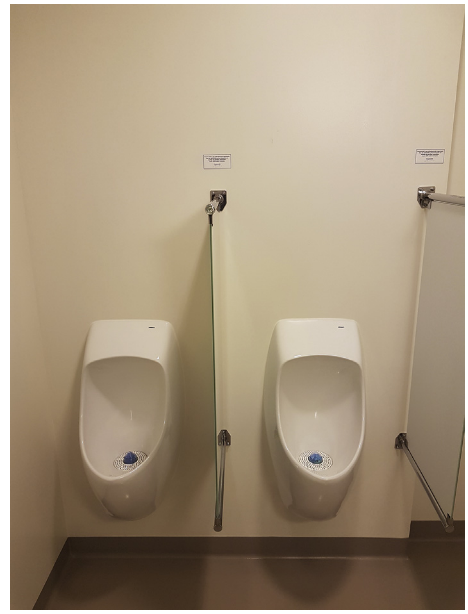

Fig. 1. Waterless urinals. A waterless urinal can reduce the use of water significantly and indirectly reduce CO_2 emissions.

Discussion

This paper coincides with a recent call from over 200 health journals urging world leaders to tackle the catastrophic harm of climate change to health. To the best of our knowledge, this is the first paper that discusses the CO_2 emissions of a clinical microbiology laboratory. The calculations and initiatives to reduce the CO_2 impact of the microbiology laboratory mentioned in this paper are certainly not complete. For example, we did not calculate the CO_2 emission for producing, transporting, and processing the (plastic)

Table 3
List of possible strategies in reducing CO_2 emissions in the laboratory

Points of Interest	Strategies
Instruments	Use instruments with small footprints (that take up less space)
	Use instruments with low or almost no water waste
Consumables	Batch test
	Contracting a nearby manufacturer for consumables
	Deliver disposables without cardboard boxes (in leased trolleys)
	Use reusable petri dishes and other consumables
	Use biplates
	Use wooden toothpicks for MALDI-TOF spotting
Personnel	Attend conferences virtually
	Assess papers and standard operating protocols digitally
	Bike or use public transport to commute
	Work from home whenever possible
Laboratory space and building in general	Supply energy via solar panels
	Recycle warmth from instruments in the winter
	Use LED lighting
	Build more efficient ventilation systems
	Use waterless urinals (Fig. 1)
Recycle	Recycle soft plastic (plastic bags, plastic wrapping foils, bubble wrap; Fig. 2)
Organization and policy	Consider manufacturers with responsible environment plans
	Manage waste
	Consider energy use and waste management in choosing instruments and consumables
	Write curriculums in medical education on climate change to increase the recognition of the climate change problem
	Diagnostic stewardship (appropriate use of microbiological diagnostic testing to guide therapeutic decisions)
	Digitally report of laboratory results instead of printing on paper
	Strict plan in ordering consumables

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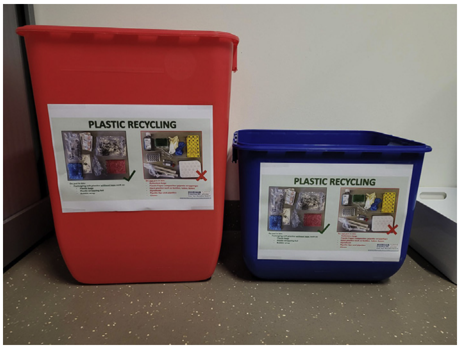

Fig. 2. Recycling bins separating soft plastic (plastic bags, plastic wrap, bubble wrap) from other recyclable waste.

waste of used agar, and this is certainly a limitation of the present study. Moreover, we did not assess the impact of plastic waste itself, which is also an important environmental problem. However, with this study, we can map which activities in our laboratories make the most impact so that we can make changes where there is the most to gain. The presented information may serve as starting point to be discussed further by the medical microbiologists, laboratory managers, clinicians, and other policy makers.

Clinical microbiology laboratories do contribute to a certain extent to climate change. Screening the data presented in Table 1, the largest amount of CO_2 emission comes from consumables, waste processing, and personnel commuting and travelling (for a conference, for example). Recycling of consumables is difficult because used plates have to be discarded as infectious waste and incinerated. Blank plates can be recycled, but not all of them are 100% recyclable. Moreover, the quality of recycled plastic may not be the same; for example, the plates may be less transparent, which may influence reading of plates. Among the materials in the plastic for agar plates, polystyrene and Pyrex 'glass' are difficult to recycle. The latter's difficulty to recycle is due to a high melting temperature. Recycling may be even more costly than incineration. Studies are needed to compare recycling with the incineration of plastic waste regarding CO_2 emission. According to a manufacturer, glass Petri dishes may be also reused, but they need sterilization, which in turn is accompanied by energy-related CO_2 emissions. Regarding travelling, next to daily commuting, a comment should be made on long distance travel of personnel, which has a large CO_2 footprint. A person flying from Amsterdam to Barcelona and back emits as much CO_2 as the CO_2 emitted by 38 days of an automated blood culture system. COVID-19 has unintentionally brought some positive, though temporary, changes on this matter. Although it seemed impossible before the pandemic, a 100% online European Congress of Clinical Microbiology and Infectious diseases recently took place. Surely, the online conference experience is not the same as an onsite conference because of the lack of personal interactions, but the online options could always be considered because air travel has a large effect on CO_2 emissions. A recent study on radiologists attending a Radiology congress in the United States showed that the 39 506 038 kg of CO_2 they emitted cost the global population 51.4 to 79.0 disability-adjusted life years [16].

Many of the initiatives to reduce CO_2 may appear to state the obvious. However, several issues need to be repeated so they appear at the top of the policies. The present review takes several examples from the Netherlands. Other settings or other countries may also come with other problems and solutions. In the Netherlands, for example, up to 20% of commuting is done by bike due to the flat terrain and small country size. This solution is perhaps not possible for larger countries. Another example is, while laboratories in countries with four seasons need energy to warm up their space during the winter months, those in tropical countries need to reduce heat using air conditioning [17]. This narrative review calls for more discussion and innovation in facing this problem, though the actions required will differ from laboratory to laboratory and country to country. All actors, including manufacturers and distributors, are needed to reduce the size of this problem.

Several adjustments to mitigate the CO_2 problem need some investment, for example, because the energy use of buildings is one of the main contributors to CO_2 emissions in health care, laboratories can be built to be more energy efficient [9]. The architect was certified by LEED (Leadership in Energy and Environmental Design), who incorporated the three basic tenets of good environmental practices, that is, to reduce, reuse, and recycle materials [17]. In the field of research laboratories, there are already some initiatives regarding laboratory sustainability practices. An example is the Laboratory Efficiency Assessment Framework (LEAF) certification, which was piloted in 23 research institutions in the United Kingdom and Ireland between 2018 and 2020. LEAF is regarding actions relating to waste, travel, energy, water, procurement, and research quality. LEAF provides an estimation of the current sustainability performance of the laboratory and tracks improvements. It gives technical and procedural guides and it provides a tailored workshop for user engagement and training. This pilot study has led to a CO_2 reduction of 648 tons and a savings of £641 000 with presentation by Green labs NL at Erasmus Medical Center on September 9th, 2021, entitled: Pilot project: Increasing research lab sustainability with the Laboratory Efficiency Assessment Framework (LEAF).

Further research is needed to show which activities reduce CO_2 emissions. In the case of alternative practices, it should be investigated whether these alternatives reduce CO_2 emissions when they are compared with present practice, for example, incinerating waste versus recycling agar plates and paper reporting versus digital reporting of laboratory results. The studies should take into account the life cycle of the product, from production to waste management.

It is clear that something needs to be done. We should have regrets in the future because we have not done enough today. Since the burden of the problem will be shared by everybody, including those who are working in our field, everyone should also participate in thinking about and mitigating the problem.

Transparency declaration

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cmi.2022.03.034.

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