‘Cooling for All’: Needs-based assessment

Country-scale Cooling Action Plan Methodology

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Project Partners

Building on our joint work launching the original concept and framework for a Cooling for All Needs Assessment in Autumn 2019, this is a more detailed first-of-a-kind methodology and comprehensive data collection instrument to enable countries to better understand access to cooling and how to meet it sustainably, underpinning the development of robust needs-driven Cooling Action Plans. To discuss the method and for a copy of the data collection instrument, please contact Professor Toby Peters, Centre for Sustainable Cooling, t.peters@sustainablecooling.org

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The Centre for Sustainable Cooling

The Centre for Sustainable Cooling (CSC) is a global collaborative coalition, bringing together a consortium of international academic institutions from the fundamental sciences and engineering through to business, economics and social sciences to work with governments, industry, development agencies and NGOs to deliver sustainable and equitable cooling for all. The CSC will develop new systems approaches integrating technological, policy, social, economic, energy, finance and business pathways to better manage cooling demand and deliver sustainable solutions, including to help the most vulnerable in our society. By sharing experiences and expertise, the CSC will lead the way in radically reshaping cooling provision – translating research into practical, affordable solutions applications whilst helping to develop innovative policy and business process that result in a cooler world. A focus for the CSC will be to develop the right mix of novel energy solutions, thermal storage, cooling technologies, business models and policy interventions to give people who need to use sustainable cooling an opportunity to maximise their business whilst helping to limit global warming.

www.sustainablecooling.org

Centre for Sustainable Cooling

Sustainable Energy for All

Sustainable Energy for All (SEforALL) is an international organization working with leaders in government, the private sector and civil society to drive further, faster action toward achievement of Sustainable Development Goal 7 (SDG7), which calls for universal access to sustainable energy by 2030. SEforALL's Cooling for All programme aims to identify and overcome the challenges to, and seize the opportunities of, providing access to affordable, sustainable cooling solutions for all. To do this, SEforALL engages leaders, benchmarks progress and supports access to cooling initiatives to protect the world's most vulnerable populations from intensifying global heat.

www.seforall.org

SUSTAINABLE ENERGY FOR ALL

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Preparing fruits for sale in a makeshift grocery stall near the Rift Valley town of Mai Mahiu

Sustainable cooling for a warming world

More than 1bn people do not have access to cooling and suffer the consequences. In a warming world, the need for cooling for health, food and safe environments is only going to increase. We have developed this 'Cooling for All: Needs-based Assessment' and 'Country-scale Cooling Action Plan: Methodology' aligned to the United Nations' (UN) Sustainable Development Goals (SDGs) to provide Governments and Development Agencies with the contextual cooling demand and market data to underpin the development of comprehensive National Cooling Plans and to assess, among other things, the policy, technology, capacity building and finance measures to address those needs sustainably.

"Cooling" refers to any natural phenomenon, human activity, design or technology that extracts heat and/or reduces temperatures, typically including refrigeration and air conditioning. Cooling contributes, in both the built and transport environments, to achieving: (i) safe/adequate thermal comfort for people (or indeed increasingly livestock), or (ii) preservation of products (food, medicines, vaccines, etc.), or (iii) effective and efficient processes (for example, data centres, industrial or agricultural production, and mining).

It is now accepted that we cannot meet our Sustainable Development Goals without deploying considerable volumes of new cooling, potentially a five-fold increase in energy demand from today[1]. We therefore need to provide resilient cooling for all who need it while avoiding or minimising its environmental damage and climate impact.

However recognising that we are living in a warming world, we also need to consider the future impact that global temperature rises will have on society and cooling demand. Without transitioning to energy efficient, clean cooling, managing the increased uplift in cooling demand from climate change, will itself accelerate climate change through fast growth in CO_2 emissions.

As one example of the need for more cooling to support delivery of the SDGs, according to the ILO[2] by 2030 the equivalent of more than 2% of total working hours worldwide is projected to be lost every year, either because it is too hot to work or because workers have to work at a slower pace. In parts of Africa, productivity loss may

Fixing air conditioning units in rural China

[1] Global quadrupling of cooling appliances to 14 billion by 2050, University of Birmingham, July 2018 https://www.birmingham.ac.uk/news/latest/2018/07/Global-quadrupling-cooling-appliances-14-billion-increase-energy-consumption.aspx

[2] Working on a warmer planet: The effect of heat stress on productivity and decent work, International Labour Organization (ILO), July 2019 https://www.ilo.org/global/publications/books/WCMS_711919/lang--en/index.htm

even reach 5%. Even if it does prove possible to limit global warming by the end of the century to 1.5°C above pre-industrial levels, ILO projects the accumulated financial loss due to heat stress is expected to reach US$2,400 billion by 2030.

While our urgent goal is to ensure basic needs are met for all people in a warming world, we have to simultaneously put in place the strategies for climate adaptation to future-proof society. Rising ambient temperatures and the increasing frequency and severity of heat waves will demand more cooling for health, food, productivity, data and, increasingly, safe living.

In short, cooling must sit at the intersection of the Paris Climate Agreement, the Kigali Amendment, the Montreal Protocol and the SDGs - environmentally, socially and economically sustainable cooling that helps the global community adapt to and thrive in – but also mitigate the impacts and risks of – a warming world.

To fulfil the ‘cooling needs’ of a nation/region sustainably, the Government and community must understand the cooling demand and supply strategies available. Our framework is a generic approach which can be adopted by countries to quantify cooling needs as the basis on which to develop mitigation, adaptation and solution delivery strategies aligned to the SDGs and Nationally Determined Contributions (NDCs) simultaneously. It is specifically designed to enable countries to understand and manage both the societal cooling gaps today and the needs tomorrow in a fast warming world.

This is a draft framework and after it has been further tested in-country, our ambition is to convert it into a user-friendly online toolkit that allows decision-makers to input data and design/simulate a range of solutions based on a country's needs, demand and objectives. We appreciate your valuable comments and feedbacks to help strengthen a needs driven approach to better understand access to cooling and how to deliver it sustainably going forward.

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Supported by Dr Salman Ahmad who led the work on the cooling for all questionnaire.

Section 1: Background

Understanding cooling needs

Significant parts of the world — especially in the Global South with the most substantial number of vulnerable people — are subjected to increasingly frequent and extreme heat exposure as a combined effect of climate and population change. Without significant intervention to mitigate CO_2 emissions, in just 50 years, 2 billion to 3.5 billion people could be living in a climate that historically has been too hot to handle[3]. Cooling is an essential service for accessing fresh, nutritious food, safe medicines, economic productivity and protection from the adverse effects of extreme heat for populations in a warming world, as a mechanism of adaptation and mitigation due to climate change. Despite the projected 300% increase in cooling provision over the next 30 years, access to cooling for all who need it will still be significantly challenging.[4]

For a Government to ensure that the cooling needs of their population are met equitably and sustainably, including for the most vulnerable - they first need to understand what these needs are - health, food productivity and safety. For example, how much cold-chain would be required to enable farmers' incomes to double by 2025, or to end hunger and malnutrition? How much cold-chain is needed to provide access to vaccines? And not just for new-born children, or at-risk groups, such as the elderly, but broader populations demand in the event of pandemics and epidemics. Or how many degrees of cool comfort is required to avoid heat stress at home or in the workplace? In short, what needs must be met in a country to meet the SDGs with no-one left behind?

If the cooling demand is not analysed correctly, it will pose significant challenges to - (a) Quantify the potential environmental impact of access to cooling for the benefit of all who need it; (b) Properly mitigate demand; (c) Design optimised solutions and comprehensive Cooling Action Plans which meet the needs of all the people; (d) Quantify the capacity building required, as well as (e) Track one country's progress in tackling the problem. An underestimation of the scale of the cooling demand and its impact on energy demand risks contributing to a lack of ambition in policy, infrastructure and technology development, and could ultimately have far-reaching social, economic and environmental consequences. Universal access to clean cooling is a multi-faceted challenge: In short - how do we meet the urgent global need for cooling for the benefit of all without further overheating the planet?

A needs-based assessment

To date, much analyses and projections of cooling demand have been based on models of Gross Domestic Product (GDP) and population growth and associated variables projections (e.g. IEA[5] – The Future of Cooling, Economist Intelligence Unit – The Cooling Imperative[6]). These do not deliver access to cooling for the benefit of all who need it nor drive strategies to harness the portfolio of solutions available to mitigate and meet demand sustainably.

To deliver clean cooling for all in alignment with the SDGs, the Paris Agreement on Climate Change, and the Kigali Amendment to the Montreal

[3] Future of the human climate niche Chi Xu, Timothy A. Kohle, Timothy M. Lenton, Jens-Christian Svenning, and Marten Scheffer PNAS first published May 4, 2020 https://doi.org/10.1073/pnas.1910114117

[4] A Cool World - Defining the energy conundrum of cooling for all, University of Birmingham, July 2018 https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf

[5] The Future of Cooling: Opportunities for energy-efficient air conditioning, IEA, May 2018. https://www.iea.org/reports/the-future-of-cooling

[6] The Cooling Imperative, The Economist Intelligence Unit, December 2019 https://www.eiu.com/n/the-cooling-imperative/

Protocol, we propose a needs-based assessment of cooling which begins by going back to first principals and understanding how do people use cooling today; and how do they seek to maintain or enhance this level of cooling to meet their nutritional, health, economic and comfort needs, and how much cooling do they need today and will they need in the future?

The Needs Assessment is not though a stand-alone tool but designed to quantify the cooling needs requirements at a national (or community) level for an integrated toolkit, the output of which is sustainable and equitable "fit for market" cooling solutions.

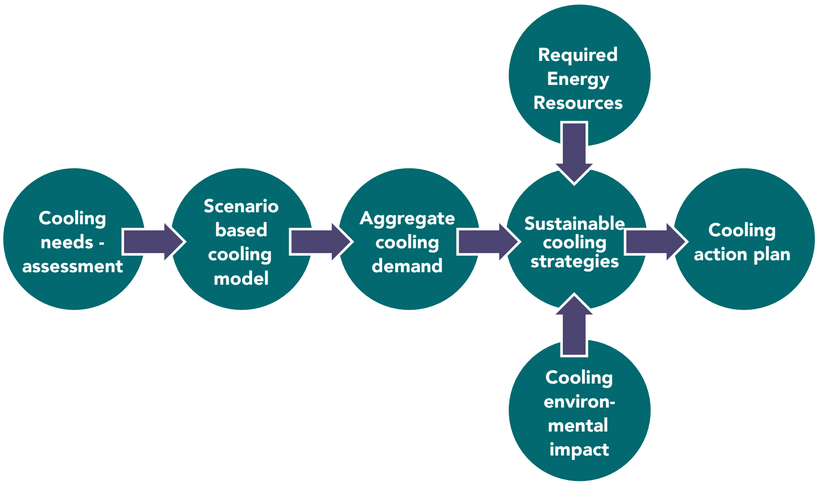


Figure 1: Cooling Needs-assessment to Cooling Action Plan

The 'Cooling for All: Needs-based Assessment' and 'Cooling Action Plan: Methodology' looks to provide a structured process and set of comprehensive data-gathering templates to understand better the context, size and economic, societal and environmental implications of cooling needs and gaps. From the gathered data, one can estimate the financial costs and environmental consequences of meeting all cooling needs on a business as usual (BAU) approach and understand the implications of the Intended Nationally Determined Contributions (INDCs).

By combining needs with other resources and infrastructures such as energy, electricity and transport, this can then enable optimum and "fit for the market" choices from demand mitigation to harnessing untapped thermal resources and traditional cooling provision technologies and renewable electricity with respect to local conditions and context (environmental, social, economic etc). Furthermore, we can understand the skills and capacity required to meet demand which would vary greatly across countries and communities. As such, the data from cooling needs assessment would lead towards the development of country-specific cooling action plans delivering access to cooling for the benefit of all who need it.

Key objectives

- **Model Cooling Service Needs, to include impact of temperature increases;**
- **Assess the extent to which Cooling Service Demand will be met on current trajectories (or not, with corresponding gaps) and evolve in response to changing climatic conditions;**
- **Calculate the economic, social, energy and emissions implications of the current trajectory and cooling services gap;**
- **Explore a portfolio of behaviour, aggregation, design, operational and technology options to meet the need while minimising costs, energy and emissions from the sector;**
- **Provide a range of actionable outputs that can be the basis of policy interventions, capacity building and financing instruments; and**
- **Establish a framework for tracking progress towards meeting unmet needs.**

Discarded fridges and freezers after contractor went bankrupt

Our toolkit is designed as a generic approach which can be adopted by countries to quantify cooling needs as the basis to develop mitigation, adaptation and solution delivery strategies aligned to the SDGs and INDCs simultaneously.

Cooling and the Sustainable Development Goals

The Sustainable Development Goals are a collection of 17 global goals adopted by all Nations Member States in 2015 to be achieved by 2030[7]. Cooling is now recognised as a crucial factor to ensure health, well-being, productivity, economic growth and welfare for rural communities and is linked with achieving many SDGs.[8]

It is necessary to enable access to cooling for hundreds of millions of people - identified as more than 1 billion[9] - to meet societal and economic goals, as well as, to deploy significantly more cooling to adapt to societies for a warming world. However, how much cooling is needed is unknown.[10]

Our needs assessment aims to quantify the volume of cooling and cold-chain required to meet social, health, economic and political targets as defined with the communities; no-one left behind. In two of our background documents: 'Cooling for All: Needs Assessment' and 'Cooling Action Plan: Methodology', we present a first-of-a-kind granular framework understanding of the links between Cooling and SDGs and their indicators.

We have categorised the following three significant purposes, and each has a series of guiding questions that informs next steps for demand measurement and falls to different needs:

Food security, connectivity and rural incomes [Agriculture, post-harvest and transport sectors]	• How many people have access to the food they need to achieve a healthy (and socially acceptable) diet? • How much food is lost between farm, beach and market? • Are agricultural and fisheries incomes sufficient to keep workers out of absolute and relative poverty? • Is there a missed opportunity for new or more distant market connectivity? • Does the supply chain meet commercial customers' product management demands (domestic and international)? *For agriculture and fisheries, cold-chain to enable market connectivity and maintain quality is essential to allow increased income.*
Thermal comfort for living, learning, working and connectivity [Building and transport sectors]	• What do people regard as the minimum acceptable level of thermal comfort for living, learning and working? • How do people seek to maintain or enhance current levels of cooling? • To what extent does the population have access to space and mobility cooling that is adequate to maintain safety and productivity, at home, in education and the work environment and while moving between each? *Here, thermal comfort includes not just temperature but also humidity and percentage of fresh air versus recycled.*
Health services including safe storage and transportation of vaccines and medicines [Health sector]	• Are national vaccine programmes reaching their target population? Can they support vaccine demand in the event of a pandemic? • Is there sufficient unbroken cold-chain to ensure the provision of medicines and healthcare products? • Are the health infrastructure buildings equipped with the cooling they need to deliver existing health services?

[7] About the Sustainable Development Goals, United Nations, 2020 https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[8] Clean Cold and the Global Goals, Peters.T, January 2016, https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/Clean-Cold-and-the-Global-Goals.pdf

[9] Chilling Prospects: Tracking Sustainable Cooling for All 2019, Sustainable Energy for All, November 2019 https://www.seforall.org/publications/chilling-prospects-2019

[10] A Cool World - Defining the energy conundrum of cooling for all, University of Birmingham, July 2018 https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018- clean-cold-report.pdf

Cooling needs assessment must fully account for people’s perceptions of need at the same time; they must be service or practice-based, and they must take national, regional or community circumstances into account. Equally, needs are not constant but dynamic and change with other factors, which requires to shift away from ‘passive’ towards ‘active’ models of cooling assessment.

They also need to consider projected future demand, the implications of increasingly hotter climates, and the climate implications of cooling demand occurring at peak times and meeting those capacity requirements with sustainable energy. These sectoral needs assessments can then be integrated into a comprehensive picture of demand at a community, national and international level. In this study, we divide the cooling demand into five main sectors: 1) Agriculture; 2) Food industry; 3) Building; 4) Health; and 5) Transport.

The scale of the climate challenge

Cooling sectors already contribute approx. 10% to global warming[11]; approx. 80% of the Total Equivalent Warming Impact (TEWI) of refrigeration is from the indirect emissions[12] – the electricity and the generation mix, primarily fossil-fuels. The total global energy consumption associated with cooling equipment today is estimated to accounts for ~20% of all electricity produced.[13]

While there are projections of the uplift in air-conditioning demand based on population and GDP growth[14], there is not

Nurse checks donated breast milk temperature at the Guangzhou women and children’s medical centre

[11] Role of Refrigeration in the Global Economy, IIR, November 2015, https://iifiir.org/en/fridoc/138763

[12] Technology and Economic Assessment Panel Volume III: TEAP Decision XXVIII/3 Working Grouped Report on Energy Efficiency, UNEP, October 2017 https://ozone.unep.org/sites/default/files/2019-05/TEAP-EEWG-Report-october2017.pdf

[13] Role of Refrigeration in the Global Economy, IIR, November 2015, https://iifiir.org/en/fridoc/138763

[14] The Cooling Imperative Forecasting the size and source of future cooling demand, The Economist Intelligence Unit, 2019 http://www.eiu.com/graphics/marketing/pdf/TheCoolingImperative2019.pdf

a comprehensive understanding of the size of current nor future cooling demand across all sectors at local, national or international scales required to deliver universal access to cooling and meet global social, nutrition, health and economic needs - the UN's SDGs - with no-one left behind.[15]

The implications this demand has for the energy systems, new-build generation requirements and the environment (climate change and pollution) are therefore poorly understood. This also acts as a barrier to achieving a cohesive and integrated system strategy to mitigate or meet cooling needs in the most economically and environmentally sustainable and resilient way, while managing natural capital and greenhouse gases, sustaining economic growth and minimising negative social impacts. It also means there is no robust societal nor environmental dataset to track progress.

Although specific estimates vary, all studies investigating global demand for cooling have projected a substantial uplift over the coming decades.[16] The energy demand, and consequently environmental (climate change and air pollution) implications of these growth projections, are gravely concerning.

In a study, 'A Cool World, Defining the Energy Conundrum of Cooling for All' published by the University of Birmingham in 2018, the implications of achieving universal access to cooling were explored via convergence modelling in equipment penetrations globally to provide an evidence-based first-ever analysis of the size of the challenge. Various scenarios were developed and then compared to an implied energy budget calculated from the IEA's 2DS scenario.[17]

The 'Cooling for All' scenario, without step change energy efficiency or technology intervention (i.e. BAU incremental improvements), reviewed in the report resulted in an energy requirement of 19,600 TWh - three times the implied IEA budget for cooling of 6,300 TWh and double the current projections for cooling demand by 2050.[18] The energy demand volumes projected by the study could exceed the IEA's forecast total solar photovoltaic and wind generation in 2050.[19]

To come within the budget and still provide the cooling required under the SDGs through this convergence pathway, energy consumed per unit of cooling would have to be reduced to about a 1/3 of the levels envisaged. The challenge that this will represent will, to some extent, vary across sectors. However, there is no sector currently proposing a tripling of device efficiency by 2050 from today. Although ultimately the exact detail of the numbers in the 'Cooling for All' scenario — such as penetration levels, energy consumption, solution choices—might have some statistical dispersion, given the quantum of the gap between current demand projections and those including Cooling for All, the conclusions are, however, highly likely to be correct.

Cooling demand and impact on energy systems

Cooling the the Arab States of the Persian Gulf region already consumes over 70% of energy supply in some cases while 30%[20] of the total energy at peak times. The additional stress that growth in universal access to cooling services will place on energy systems (time of use, peak demands as well as overall volume) also needs to be placed in the context of the broader fundamental structural changes to these systems driven by targets to cut emissions and the associated transition to renewables from fossil fuels. Within this, thermal, transport and electrical energy systems are becoming interconnected as electrification is seen as the cornerstone of transport and thermal decarbonisation.

Cooling accounts for ~6%[21] of passenger transport energy consumption but modelling suggests this could grow triple by 2050, as drive technologies

[15] What does it mean to leave no one behind?, UNDP, July 2018. http://www.undp.org/content/dam/undp/library/Sustainable%20Development/2030%20Agenda/Discussion_Paper_LNOB_EN_lres.pdf

[16] The Future of Cooling: Opportunities for energy-efficient air conditioning, IEA, May 2018 https://www.iea.org/reports/the-future-of-cooling
The Cooling Imperative Forecasting the size and source of future cooling demand, The Economist Intelligence Unit, 2019
http://www.eiu.com/graphics/marketing/pdf/TheCoolingImperative2019.pdf
Solving the Global Cooling Challenge How to Counter the Climate Threat from Room Air Conditioners, Iain Campbell, Ankit Kalanki, and Sneha Sachar, Rocky Mountain Institute, November 2018
https://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf

[17] A set of policy, technology and economic measures where the amount of carbon dioxide released to the atmosphere is consistent with a significant probability of limiting global temperature increases to two degrees Celsius.

[18] Clean Cooling Landscape Assessment, T.Peters, December 2018.
https://www.clean-cooling.ac.uk/resources/CleanCoolingLandscapeAssessment%2012-18.pdf

[19] Annual Energy Outlook 2019 with projections to 2050, IEA, January 2019
https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf

[20] Buildings sector: Energy Productivity in the GCC, Kankana Dubey and KAPSARC, 7th International Forum on energy for Sustainable Development in Baku, October 2016 https://www.unece.org/fileadmin/DAM/energy/se/pp/eneff/7th_IFESD_Baku_Oct.2016/3GEEE_ee_build/KankanaDubey.pdf

[21] Cooling on the Move, IEA, September 2019, https://www.iea.org/reports/cooling-on-the-move

improve, temperatures rise, and warmer regions motorize. This complicates other innovations, for instance, for electric vehicles, mobile air-conditioning can reduce driving range by up to 50% on hot and humid days[22]), as well as cooling of batteries. In hotter climates the battery pack must be temperature controlled to maintain a safe performance (<35°C).[23]

By understanding the detail of customers' operational, market and regulatory needs and pressures, within specific social and cultural contexts, we can leverage mitigation, adaptation and technology bundles to offer new combinations of products and services that provide efficiency, flexibility, resilience, and cost-effective decarbonisation.

Climate Change Adaptation Impacts

In considering and therefore planning for the extent to which cooling services will evolve and increase in the future, it is essential to understand and quantify the impacts that global temperature rise would have on the volume of refrigeration and cooling (RAC) equipment required and its energy consumption and climate impacts in different scenarios.

Global temperature rises will impact RAC demand in two main ways:

- **Changes to ambient temperatures** – expected to manifest in the form of higher average temperatures, increased cooling degree days (CDD) and consecutive days of extremely high temperatures which will need to be mitigated through the deployment of RAC equipment.
- **Reductions in food production capability** – will be caused by temperature, ice melt and flooding and reduce the amount of food available to feed a growing population, making farm to fork cold-chain losses even less acceptable which will need to be mitigated through the deployment of RAC equipment.

At a sector level, changes to ambient temperature are likely to impact in the following ways:

- **Stationary space cooling:** Impacted through increased air conditioning fitment (UAC and chiller) and increased number of operating hours (if CDD increases) and higher cooling powers (if temperatures get materially higher).
- **Industrial and Commercial Refrigeration:** Impacted through increased equipment deployment (as cold-chain coverage needs would increase) and cooling powers may need to be higher to offset increased ambient or peak temperatures.
- **Portable Cooling:** Impacted through increased transport refrigeration units (TRU) deployment because cold-chain coverage would need to grow as well as higher loads for both Mobile Air Conditioning (MAC) equipment and TRUs because of increased ambient temperatures. Insulation may improve, but this may negatively impact energy and emissions if it substantially reduces payload.
- **Domestic refrigeration:** impacted through a need for increased coverage to reduce post-purchase food losses. The minor potential impact from increased ambient temperatures.

The Needs Assessment should be able to be flexed for different increases in temperature to show the impact on cooling demand and associated energy demand.

The rest of the report is organised as follows. Section 2 describes our methodology. Section 3 presents potential outputs from our proposed methodology. Section 4 provides the conclusion.

Refrigerated containers at the dockside

[22] Cooling on the Move, IEA, September 2019, https://www.iea.org/reports/cooling-on-themove
[23] Battery Thermal Management Systems Development and Vehicle Integration for Conventional and Ultra-Fast Charging, Ricardo, AESIN Conference, October 2019 https://aesin.org.uk/wp-content/uploads/sites/9/2019/11/James-Baxter-Ricardo-UK.pdf

Section 2: Country-scale Cooling Action Plan Methodology

Why is our approach different from current Cooling Action Plans?

In order to tackle the future cooling challenge and encounter the adverse effects of climate change, UN Secretary-General urged countries to develop National Cooling Action Plans (NCAP) to identify pathways to reduce the Global Warming Impact of growth in cooling and an opportunity for a country to consider how to improve access to cooling and address SDGs.[24] Kigali Cooling Efficiency Programme (K-CEP), working with international development partners, developed a first-of-a-kind top-down approach for developing NCAP in 2018[25, 26], and countries ranging from India and China to Trinidad and Tobago, and Rwanda have implemented NCAPs. These are an important step in understanding and managing the climate impacts of rapid growth in cooling demand.[27]

However, NCAPs currently are based on historical equipment trend analysis and projections. They are not need-oriented nor designed to address the need for cooling across all sectors, instead they are equipment-based projections driven by the socio-economic variables such as GDP and population growth. Therefore, the subsequent action plan fails to capture unmet needs and deliver access to cooling for the benefit of all who needs it— especially in the global south— where 'cooling security' may emerge as important as energy security soon. Studies have already suggested that top-down socio-economic variable driven modelling frameworks are inefficient to address the complex issues found in the global south.[28, 29]

Equally, while equipment based projections of cooling demand are an essential element of producing meaningful emissions and energy consumption data and so have been used in all cooling demand projections that were found in the literature. However, this approach suffers from three significant weaknesses:

- Poor quality data: data about unit stocks in each of the cooling categories are fragmentary as verified sales and disposal figures and second-hand transfers of equipment, are not systematically collected or universally available. Unit stock data rarely includes expected product lifetimes. As a result, the equipment parc is genuinely challenging to estimate and projections are uncertain.
- Failure to capture needs: equipment- based projections do not start by seeking to understand household, business or community needs, or address how demand for cooling solutions will be shaped by these needs. There is a lack of high-fidelity data on cooling demand at the household, neighbourhood/ community or business level.
- Pre-supposing a solution: a focus on per capita equipment penetration rates pre-supposes a top-down technical solution to cooling needs and risks. This approach ignores the possibility of electricity demand mitigation through the redesign of systems, the aggregation of demand, modal shifts, the use of waste or currently untapped resources, as well as support for existing cooling practices and behaviours.

[24] UN Secretary-General Wants National Cooling Action Plans, Stausholm.T, September 2019. http://www.r744.com/articles/9159/un_secretary_general_wants_national_cooling_action_plans_for_all_countries19
[25] K-CEP Annual Report, K-CEP, 2018 https://www.k-cep.org/wp-content/uploads/2018/05/180412-K-CEP-Report-Final-Review.pdf
[26] Principles for National Cooling Plans, K-CEP, April 2019 https://www.k-cep.org/wp-content/uploads/2019/04/Principles-for-National-Cooling-Plans.pdf
[27] Principles for National Cooling Plans, K-CEP, April 2019 https://www.k-cep.org/wp-content/uploads/2019/04/Principles-for-National-Cooling-Plans.pdf
[28] L. T. Biardeau, L. W. Davis, P. Gertler and C. Wolfram, "Heat exposure and global air conditioning," Nature Sustainability, vol. 3, no. 1, pp. 25-28, 2020.
[29] J. Wang, Y. Chen, S. F. Tett, Z. Yan, P. Zhai, J. Feng and J. Xia, "Anthropogenically-driven increases in the risks of summertime compound hot extremes," Nature communications, vol. 11, no. 221, pp. 1-11, 2020.

Solving the problem

Country-level needs assessments, measurement and planning, are essential to overcome these data limitations as mentioned earlier, understand the dimensions of risk, the quantum of energy required, and develop sustainable solutions that can be targeted at specifically vulnerable groups.

NCAP should be based on a bottom-up country–scale cooling needs assessment and aligned to the UN’s SDGs and INDCs (Fig 1) to provide Governments and Development Agencies with a rigours framework to assess the policy, technology and finance measures to address those needs sustainably. A country-specific cooling needs assessment would pinpoint the supply chain, which requires cooling intervention in the future and also the associated energy requirement and emissions such as greenhouse gases (GHGs) and Ozone-depleting gases.

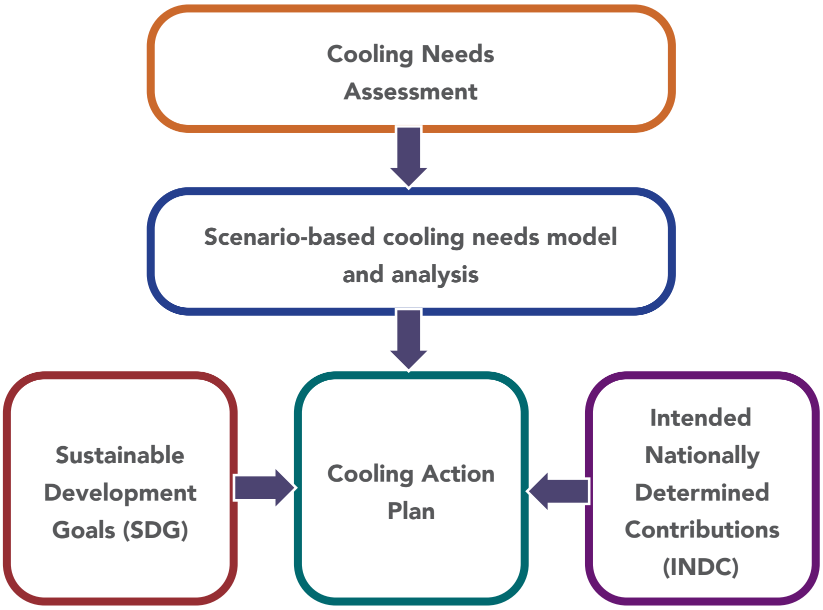


Fig 1: National Cooling Action Plan of a country should be a result of a bottom-up cooling needs-based assessment and scenario-based cooling needs model and analysis. Furthermore, it should align with the SDGs and INDCs of the country, which allows the incorporation of the NCAP into the decision-making process effectively.

Although NCAP should be based on country-scale cooling need-based research and modelling, these are still at their infancy, as there are massive data inadequacy and lack of standardised methodology on quantifying cooling needs. Countries should start collecting specific needs related data — rather than unit sales — for bottom-up cooling needs modelling, and projection as the variables are not always similar to the country’s socio-economic and energy development indicators.

Why is this important?

Most current approaches to the challenge of sustainable global cooling tend to begin with the question: how many Room Air Conditioners or fans are people going to buy (for thermal comfort), and how can this level of cooling be provided in the most efficient, clean and sustainable way? These global frameworks fail to address broader social dimensions of complex cooling needs and climate adaptations, their implication on energy systems, as well as inability to address people’s thermal practices, cultures and knowledge complexities.

As mentioned previously, for a country or a community to ensure that the cooling needs of their population are met they first need to understand the cooling requirements. Through such an assessment, across human comfort and safety needs, health service needs, and food security and agricultural needs, demand can be measured more comprehensively, and a roadmap to delivering access to sustainable cooling for all can be developed. Such an assessment is crucial to planning and investment required to minimise demand, aggregate services, maximise the potential to harness all available waste and free energy resources, and harness new and renewable technologies, whether through a national cooling action plan or equivalent set of measures. Conversely, without such an assessment, any thermal planning seems likely to be inadequate.

It is also possible to derive the consequences of meeting these needs with current technologies, energy resources, infrastructure tools, and the associated environmental impacts. With such a baseline established it could help ensure the business models used to enhance access to cooling are both financially sustainable and purpose-driven, we can track progress and quantify the impacts of more sustainable routes.

Developing a needs-driven national cooling action plan

One of the major hurdles for developing a NCAP is the lack of contextual detail and granular data in the top-down models of country-scale action plan formulation, especially for the global south. We proposed a bottom-up methodology to develop an NCAP which works with a country's underlying constraints and priorities (e.g., data, resources). The initial analysis of the global south demonstrated a considerable gap in available data to estimate the demand and supply for cooling.

Figure 2 on the next page outlines our proposed methodology of analysing needs-based cooling assessment and developing a cooling action plan for a country has four levels. Note that a full methodology and set of questions are developed and available from Heriot-Watt University. (Please contact Professor Toby Peters or Dr Bing Xu). This includes the following data capture frameworks:

- Contextual Data
- Current technologies deployed
- Cooling Requirements
- Specific sectors aligned to SDGs and INDCs

While the methodology follows a structured process, it is designed to be customised based on a country's specific context and circumstances, including focus on priority sectors.

Level 1: Contextual analysis

The first step of our methodology involves a Contextual Analysis which aims to provide an overview of the context related to cooling of the selected country based on gathering and analysing high level and general secondary data predominantly with literature and data review. It includes analysis of climatic, demographic, socio-economic statistics, infrastructure, current industry mapping as well as the first understanding of sectoral needs and an overview of existing technologies, policies, targets, commitments and initiatives.

A narrow street in Singapore cluttered with AC units

'Cooling for All': Needs-based assessment Country-scale Cooling Action Plan Methodology

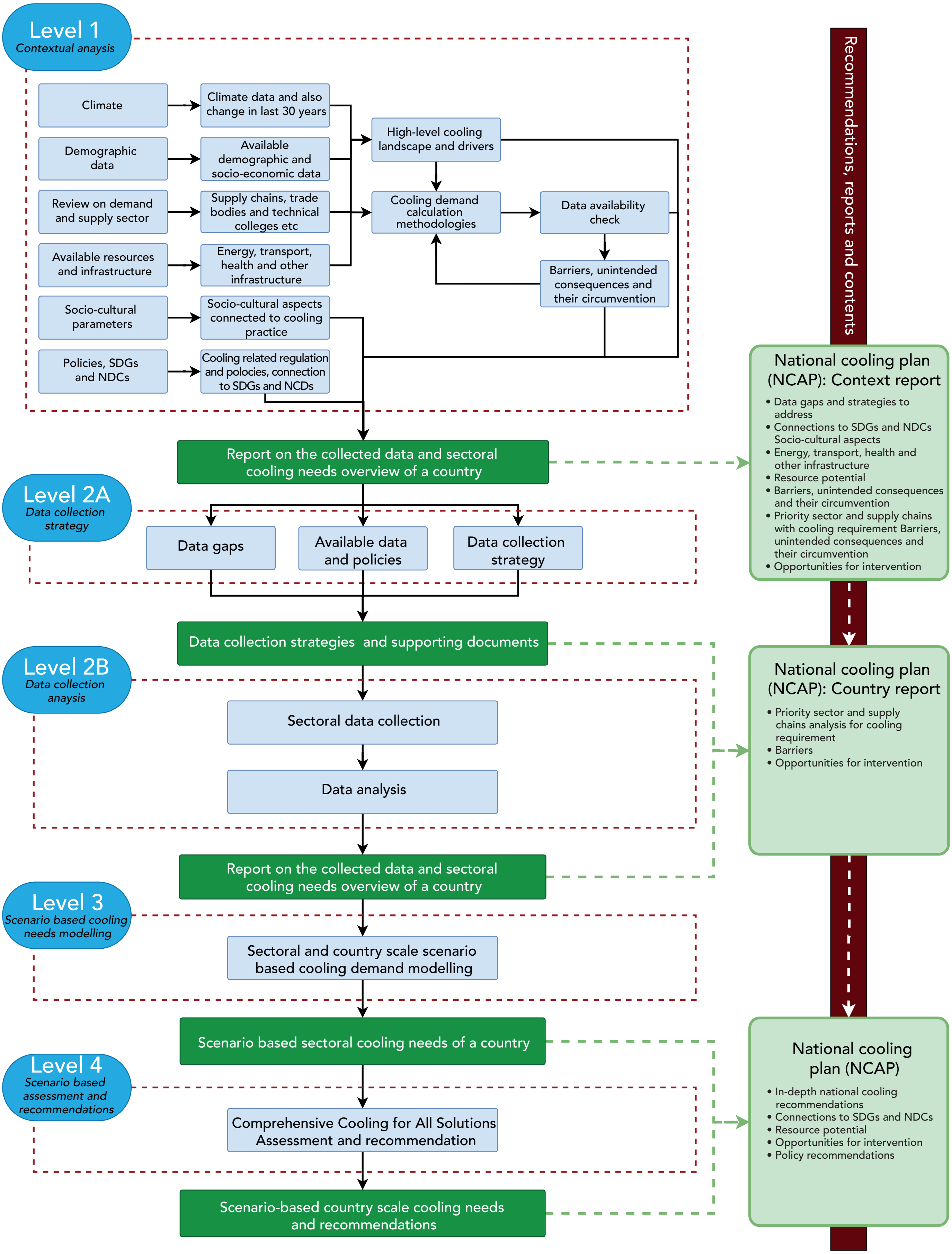


Figure 2 : Cooling Action Plan methodology

Contextual Data

A detailed contextual study of the country would be divided into the following main aspects:

- **Climate** – analysis of climate data of the country is essential for understanding and estimating the cooling demand. Climate variables such as temperature, relative humidity, solar radiation and wind speed, and their progression over time may have a direct or indirect relationship with the demand for cooling.[30] Also, the variables would be used to calculate the Cooling Degree Days (CDD) and Environmental Stress Index (ESI), which may be used to model the sectoral demand and future scenarios.
- **Demographic data** - demographic and socio-economic data and historical progression of their variables are essential for estimating the cooling demand and developing future scenarios. It is essential to collect variables such as population, income-wise population, age-wise population, Gross Domestic Product (GDP), Gross National Income (GNI) and others can be used for cooling demand estimation. Some of the demographic and socio-economic data can be extracted from databases such as World Bank, International Energy Agency (IEA), Central Intelligence Agency (CIA), Asian Development Bank (ADB).
- **Demand and supply sectors** - the insight into the demand and supply sectors of the country is essential to point out the areas where cooling is required and used.[31, 32] In the demand and supply sector, the supply chain of different sectors needs to be analysed along with trade bodies and technical colleges, associated with the systems. The analysis of the supply chain would offer the details of cooling demand in different stages from harvest to consumer.
- **Available resources and infrastructures** - analysis of the available resources and infrastructure such as energy resources, electricity, transmission & distribution, transport (Passenger, freight, air and shipping), import & export, and others, would be essential to examine the cooling requirement and demand-supply gaps in the country.
- **Socio-cultural parameters** - socio-cultural parameters are essential to understand the nuances of a particular country and its people.[33] Often the cultural parameter influences the policy development in specific directions. Different countries based on their economic condition or religion or government types put pre-existing boundaries on policy development.
- **Policies, SDGs and INDCs** - analysing the policies for different sectors such as energy, electricity, transport, demography, health, import & export, agriculture, industry and others, are essential to formulate the future cooling needs scenarios as well as the present condition of the policy landscape. Also, the countries' commitment towards NDCs and SDGs, with the level of accomplishment also needs to be examined to develop future scenarios.

The analysis of the contextual data would offer the understanding of the high-level cooling landscape of the country and the variables linked to the cooling needs from demand and supply sides. The cooling landscape and their drivers, as well as the variable data, would be used to finalize the cooling demand calculation methodology. In addition to the contextual analysis, the data required but not available for further modelling would be identified.

[30] L. Hernández, C. Baladrón, J. M. Aguiar, L. Calavia, B Carro, A Sánchez-Esguevillas, D. J. Cook, D. Chinarro, and J. Gómez "A Study of the Relationship between Weather Variables and Electric Power Demand inside a Smart Grid/Smart World Framework," Sensors (Basel), Vol. 12, no.9, pp. 2012. doi: 10.3390/s120911571

[31] D. Vu, K. M. Muttaqi and A. P. Agalgaonkar, "Assessing the influence of climatic variables on electricity demand," in IEEE Power and Energy Society General Meeting, pp. 1-5, 2014.

[32] Heat and cooling demand and market perspective, JRC scientific and Policy Report, European Union, 2012. https://core.ac.uk/download/pdf/38627585.pdfpdf

[33] S.Sloan, and T. Arrison, Cultural Differences and Nuances. In S. Sloan & T. Arrison, Examining Core Element of International Research Collaboration (1st ed.). Washington DC: The National Academies Press , 2011.

Data Gathering

Contents of a full comprehensive data collection for cooling needs assessment. A full set of questions is available from Heriot-Watt University (contact Professor Toby Peters or Dr Bing Xu for further information).

Level 1 - Contextual Data	
National Data	Climate Data
	Demographics
	Cooling Dependent Sectors
	Resources and Infrastructure
	Social & Cultural
National Policies	International Commitments
	National Level Masterplans, Legislations or policies
	Regulations/Policy Targets
	Market Mechanisms
	Financial Incentives
Active Cooling Technology	
Passive Comfort Cooling	Behavioural practices
	Passive cooling technology

Level 2 - Sectoral Needs	
Cooling Need	Thermal comfort for Living and sleeping
	Household Safe Living
	Workplace Productivity
	Mobility Thermal Comfort
	Agriculture: Income
	Agriculture: Space cooling
	Agriculture: Refrigeration
	Agriculture: Production/loss
	Agricultre: Connectivity
	Access to affordable, nutrious and safe diet
	Vaccine Outreach
	Vaccine Safe living and Waste avoidance
Food and Nutrition	Cultivation and processing: Passive
	Cultivation and processing: Active
	Fishery
	Fish Market
	Livestock
	Post harvest management
	Dairy and dairy products
	Dairy and dairy products transportation
	Large scale cold storage
	Supermarkets and covenience stores
Health	Medical centres
	Vaccine
	Medicine
	Blood

Key Outputs in Level 1

One of the significant outputs in Level 1 would be the barriers, unintended consequences and their circumvention for the data availability. If the data is not available and somewhat not possible to be collected the methodology of calculating cooling demand would have to be adapted or changed. In sum, after conducting Level 1, Contextual Analysis will allow us to generate a ***National cooling plan (NCAP): Context report*** that provides critical answers to the following aspects:

1) Data gaps and strategies to address;
2) High-level understanding of cooling needs, current technology and gaps
3) Connections to SDGs and NDCs;
4) Socio-cultural aspects;
5) Energy, transport, health and other infrastructure;
6) Resource potential;
7) Priority sector and supply chains with the cooling requirement;
8) Barriers, unintended consequences and their circumvention; and
9) Opportunities for interventions.

Level 2: Data collection and analysis

The contextual analysis of Level 1 would reveal the data availability of different variables of estimating cooling needs in a country. The unavailable data would be gathered in Level 2.

Building on the context analysis and understanding data gaps from Level 1, gaps in secondary data should be collected and analysed comprehensively to develop the insights, future direction of cooling needs in the supply chains, and also the barriers and opportunities of intervention at the present condition.

Data collection strategies

Depending on the context of the country, different nations may have different priority sectors for cooling. For example, our initial study suggests that agriculture and thermal comfort has the most significant need for cooling. Although other sectors such as health or food industry are not the primary focus, they also have a substantial need for cooling.

The data gaps or unavailable/incomplete data would need to be collected from the studied country. The data collection on a nation-wide scale would be a daunting task. The alternative procedure for collecting data can be a small scale pilot study to infer the results. For example, most but not all countries especially from the global south have limited data on how much is the cooling need for the different vaccines, ice pack and blood storage facilities, as well as the space cooling need. The data constrain is more prevalent in the sub-urban and rural areas than that of cities. There can be a random selection of hospitals from all over the country to conduct pilot studies on the cooling needs for comfort and storage of blood, vaccine and ice pack. Depending on the data required, the method may vary. For example, the data collection strategies can range from pilot study, literature review to semi-structured interviews with field experts and questionnaires.

Data collection and analysis

After finalizing the strategies of data collection, the data should be collected and analysed comprehensively to develop the insights, future direction of cooling needs in the supply chains, and the barriers and opportunities of intervention at the present condition.

Key Outputs from Level 2

The outputs of Level 1 and Level 2 is a Country-level report which is an analytical report and includes recommendations (technical, energy and policy). However, it is not an in-depth analysis of all sectors but still robust to drive policy recommendations and solutions and be published. The outputs of Level 2 would be reported in the 'National cooling plan (NCAP): Country report' which would have the following addition to the contextual analysis from Level 1:

1) Priority sector and supply chains analysis for cooling requirement;

2) Barriers; and

3) Opportunities for intervention.

Level 3: Scenario-based sectoral cooling needs modelling

Once we have gained an in-depth understanding of the country under consideration, the next objective is to develop the scenario-based cooling needs model. Depending on the data frequency and availability, we will identify suitable econometrics models to estimate and predict cooling needs as well as the energy required, associated emissions and economic impact. The historical estimating would work as a process of validation to check the accuracy of the model for future predictions. The cooling needs model

A doctor in west Africa treats a mother and child in a makeshift clinic

should be developed into sectoral and country scale. The model developed, can be divided into demand and supply sectors. The outputs of the demand-side model would be cooling demand, the energy required, emission (e.g. GHGs, Ozone gases and pollutants) and economics factors (e.g., capital investment; operational costs).

A sector-based Modular Approach to Cooling Assessment allows focusing different levels of efforts and resources to different cooling sectors, potentially starting with more in-depth analysis of selected priority sectors. Such an approach provides essential flexibility to countries with limited resources to apply and test the methodology in all sectors. However, this must be with the understanding that it is essential to cover all the cooling sectors to get an optimised, comprehensive NCAP and deliver maximise socially, economically, and environmentally sustainable and inclusive cooling strategies.

Key Outputs from Level 3

The output of Level 3 would be reported in the 'National Cooling Plan (NCAP)' - produced as the output of Level 4 - which would have the following:

1) Cooling needs modelling;

2) Connections to SDGs and NDCs;

3) Resource potential;

4) Opportunities for intervention; and

5) Policy recommendations.

Level 4: Scenario-based assessment and recommendations

After quantifying the cooling needs at sectoral and country scale, we can then model what the impacts and costs could be for meeting these cooling demands if we are going to deliver them using conventional BAU strategies, for example, fossil fuels and high global warming potential (GWP) refrigerants. Country-specific Clean Cooling scenarios can be tested against the BAU scenario results for evaluation and policy development. Various criteria should be considered, including but not limited to emissions, biodiversity, water consumption, land use etc.

We will review existing and future mitigation strategies and technologies and use the scenario-based model to evaluate their performances against the cooling needs and gaps, outline available energy resources to identify clean and sustainable (without environmental damage and climate impact) solutions for cooling that are the most appropriate for in-country conditions, including economic model, and thereby propose realistic development pathways for cooling scale up based on clear needs-driven and sustainability goals.

A robust Needs Assessment will help to identify the parameters for clean, sustainable cooling technologies (with improved energy efficiency, reduced costs, increased renewable energy sourcing and reduced environmental impact) appropriate to in-country conditions, both in terms of affordability and current and potential future technical capacity to deploy and support.

With an understanding of demand, we can also explore realistic, real-world opportunities for local capacity building to ensure successful outcomes to deployment interventions in terms of sustainable cold-chain infrastructure operation and maintenance, both of which are crucial to the ability to deliver a NCAP effectively. The methodology of developing NCAP can point out priority sectors for countries based on localised priority areas, and the scenario-based model can also model priority sector-based scenarios.

Key Output from Level 4

In addition to the outputs for Level 3, the output of 4 would be reported in the comprehensive NCAP which would have the following:

1) In-depth national cooling recommendations;

2) Connections to SDGs and NDCs;

3) Resource potential;

4) Opportunities for intervention; and

5) Policy recommendations.

Section 3: Output

As explained earlier, analysis of cooling demand scenarios indicate that current equipment deployment and operations trajectories will result in:

- A massive growth in electricity demand, challenging supply infrastructure arrangements;
- Energy budgets for cooling provision implied by Greenhouse Gas (GHG) emissions reduction targets of the Paris Agreement being exceeded significantly; *but still*
- A lack of access to cooling for many people around the world, particularly the poor and those in developing and emerging economies.

There is, therefore, a need to deliver clean cooling interventions not just cooling per se.

Clean Cooling[34]

Clean Cooling starts with what we can do today to reduce demand for cooling and deliver incremental efficiency improvements in cooling systems while providing access to cooling for all. This includes, among other things, behavioural change; more effective use of passive design elements such as shade and natural ventilation in building design; cool roofs; doors on chilled display cases in supermarkets; best-in-class, very low global warming potential (GWP), high-efficiency refrigeration and air-conditioning equipment; district cooling systems where possible; and the use of waste heat in parallel thermal processes. Clean Cooling also requires regular preventive and predictive maintenance to ensure optimal operating performance.

These interventions are essential, but, given the growth in cooling demand, they will not deliver the required reductions in energy usage, emissions and pollution, nor will they adequately increase resource productivity, or deliver access to cooling for all who need it.

Delivering Clean Cooling is, therefore, also about investing in a radical reshaping of cooling provision to design more ambitious routes to mitigation and management of energy use and cooling demand. This will include:

- Starting with understanding the first principles of "what we are trying to do" to meet the cooling needs for all;
- Prioritising how to mitigate cooling demand and meet it through behaviour change and design;
- Recognising the portfolio of free, natural and energy-waste resources to help meet demand;
- Defining the right mix of energy sources, natural refrigerants, thermal energy storage, cooling technologies, business models, manufacturing, maintenance regimes, end-of-life management and policy interventions – and then to optimally, and safely, integrate all available energy resources through complete system approaches;
- In short, thinking thermally, which means, among other things, defining a new set of incentives and behaviour changes that impact individual and organisational decisions - how we mitigate cooling demand; de-electrify cooling where possible; store energy for use on-demand; balance heating and cooling; and transition fully from fluorinated to natural refrigerants;
- Also ensuring that we have an adequate skilled workforce to design, install and maintain **Clean Cooling** systems;
- Finally, in delivering the above, driving inclusive and sustainable industrialisation in a holistic approach to creating resilient and future-proof communities.

By pooling demands and fully understanding the portfolio of resources available, Clean Cooling can facilitate a re-mapping and integration of processes, thermal energy storage and technology to achieve efficiencies and harness all resources; and it will enable new business models to make cooling affordable and accessible to all. This would not be possible with a siloed or sub-system approach.

[34] Defining 'Clean Cooling', Centre for Sustainable Cooling and Shecco, April 2020, https://issuu.com/shecco/docs/cleancooling

This needs-driven approach and robust cooling action plan methodology will enable governments and development agencies to quantify how much cooling provision is required to meet societal, health, economic, environmental and natural resource goals, with no-one left behind … in a warming world. Furthermore, understanding local resources, it will enable countries to develop National Cooling Action plans which best mitigate demand and harness all available sources of waste, free and renewable energy to meet the multiple cooling service needs of a community, rather than approaching the problem with pre-ordained assumptions.

The output would be reflected in a 'National Cooling plan (NCAP)' which would have in-depth national cooling recommendations, financial implications, impacts to SDGs and NDCs and be aligned to resource potential:

1. Current and future cooling needs of the country are identified and analysed, based on the current situation in the society and economy and policy priorities to improve the situation in future:

- *What cooling is currently used for and what cooling is needed for in order to ensure people's well-being, development of agriculture as well as essential industries, the achievement of policy targets, NDC and SDGs, i.e. sustainable cooling for all?*
- *How meeting these needs in the future will impact energy use for cooling?*
- *Social-economic-environmental impact of the priority cooling sectors for countries will be quantified and various scenarios modelled.*

2. The current cooling technological mix is mapped and analysed across cooling sectors:

- *What cooling technologies and equipment are currently used in the country?*
- *How much energy and refrigerants they currently use?*
- *How much emissions are currently resulting from cooling?*

3. Solutions linked and tailored to current and future cooling needs, as well as aligned with critical national policies and international commitments, are identified and explained in terms of their design, implementation and impact:

- *What solutions can be adopted in order to satisfy identified cooling needs and achieve policy targets in the most efficient and climate-friendly way, while meeting requirements of Kigali Amendment, Paris Agreement, SDGs, NDC and national policies?*
- *How much energy and refrigerants will be used after these solutions are implemented?*
- *How much emissions will be resulting from cooling?*

How could the Needs Assessment and Methodology be used?

Clean Cooling for All is not only urgent, but it is also complex. Developing sustainable and equitable solutions requires a holistic approach and a complete understanding of the need across multiple sectors. Deploying such integrated solutions will require smart coordination among many actors and industry sectors in planning, implementation, business models and systems management.

The purpose of this Needs Assessment and Cooling Action Plan Methodology is to provides governments with the tools to understand - through the data - cooling in terms of societal cooling needed and the energy equivalent to meet that need under different scenarios compared to business as usual. It will enable governments and developing agencies to understand better the real size of cooling demand in adapting to the paradigm shifts we face and better define a country's Cooling Action Plan and fit-for-market solutions which:

- Contributes to achieving: (i) safe thermal comfort for people, (ii) preservation of products and produce (medicines, food and others), and (iii) effective and efficient processes (data centres, industrial or agricultural production) for the benefit of all who need it and
- Delivers this in-line with the objectives of the Paris Agreement on Climate Change and the Kigali Amendment to the Montreal Protocol.

Key deliverables will include

- **Missing data:** One of the critical contributions and outcomes of the needs assessment framework is to provide the framework (includes the data capture templates) for all the contextual data that one needs to collect to quantify the cooling needs at both sector/industry and national level for health, comfort, agriculture/fisheries and nutritional food. This framework will help to pinpoint the missing, incomplete and non-exist data that requires urgent action to start collecting.
- **Contextual analysis:** In the first instance, it will be designed to provide Governments and development agencies with a high-level context analysis and knowledgebase understanding of the high-level cooling landscape of the country and the variables linked to the cooling needs from demand and supply sides to consider their societal, economic and development cooling needs properly and how far current technology and future deployment projections go towards meeting these needs and therefore identify the critical cooling access gaps.
- **Environmental impacts:** Once Governments have quantified the full cooling needs, they can use the data to identify what are the emissions and costs for meeting these demands if delivering them using a conventional "business as usual" approach (e.g. current technology strategies, domestic energy mixes and high GWP refrigerants).
- **Clean cooling strategies:** They can review existing and future strategies and technologies against the cooling needs and gaps, available energy resources to identify clean and sustainable solutions for cooling that are most appropriate for in-country conditions, including economic models, and thereby design realistic development pathways for cooling scale up based on clear needs-driven and sustainability goals. This will be captured through the Solutions Assessment which will also allow the analysis of the cooling needs for a country under different scenarios as compared to BAU and against climate targets and National Determined Contributions (NDCs). This is the basis for a robust National Cooling Action Plan.
- **Capacity building:** With an understanding of demand, one can also explore realistically, local capacity building needs to ensure successful outcomes to deployment interventions in terms of sustainable cooling infrastructure installation, operation and maintenance, all of which are crucial for our objectives to be delivered effectively.
- **Track progress:** The needs assessment will also establish a critical baseline for access to sustainable cooling (access gap and climate impact) against which to track progress.

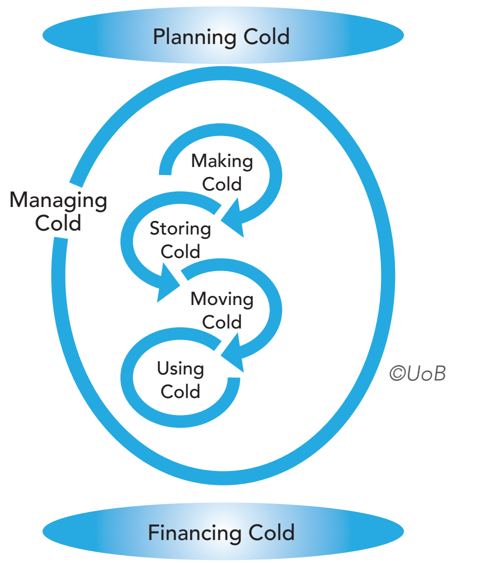
How do we deliver clean cooling?

There are significant routes to mitigate cooling demand as well as vast resources of waste heat, free cold and other under-exploited energy resources that could be used to make cooling globally accessible, sustainable and cheaper – but only if we re-think how we use, produce, store and transport cold to meet our cooling demands, and develop the necessary policies, technologies and pathways to support new approaches.

A systematic approach to cooling should be developed along a value chain with the following elements:

- **Planning cold:** Understand cooling (demand and supply) as an essential factor in infrastructure planning; where to locate a data centre or food aggregation hub, an LNG terminal; how to build a new city? *Key is to identify cooling service demands in a needs-driven manner, taking full account of what would be required to meet the Sustainable Development Goals.*
- **Making cold:** Harness unused or "waste" resources such as cold-water bodies, "wrong time" renewable energy (wind, solar), waste cold (LNG) and heat, or ambient heat sinks (ground source, sky cooling). *Key is to explore opportunities to harness free cooling and synergies between processes, waste resources and cooling needs that can further reduce the required cooling requirement.*
- **Storing cold:** Store energy thermally, in physical mass (think walls) or phase-change materials (ice) to make use of cyclical changes in ambient heat sinks and supply of (electric) energy at lower costs. *Key is to include e-vehicles and e-logistics.*
- **Moving cold:** Use new energy vectors and materials to move thermal energy, e.g. liquid air or nitrogen can be used for cooling and generate mechanical energy. *Key is to identify suitable new technologies.*
- **Using cold:** Reduce cold loads by lowering cooling demand (insulation), increasing equipment efficiency, and substituting refrigerants with high GWP. *Key is to highlight behaviour change and demand mitigation strategies likely to be useful while maintaining required service levels. Also, modal shifts can substitute for cooling solutions, with much lower energy use. Fast transportation of vaccines by airborne drones in rough terrain can deliver the same service (i.e. safe product delivery) without the need for portable cooling.*
- **Managing cold:** Make cooling systems smart for real-time monitoring of cooling needs and performance (sensors), load adjustments (controls) and integrated system management and storage (communication). Deliver cooling only where and when needed while optimizing system-wide impacts. *Key is to ensure the correct installation and maintenance of cooling units, in the absence of which inefficient energy use and refrigerant leakage rates above 25% are possible, and safety provisions may be missed.*
- **Financing cold:** Ensure access to cold while improve human decision making and modify behaviour through smarter financing options (pay-for-use), instant visibility of system status and consequences, integration of external costs/benefits (carbon pricing), markets for alternative energy vectors (e.g. waste heat) and other incentives. Key is to explore opportunities to right mechanisms to encourage behaviour changes around investments, consumptions etc.

System approach to cold



Summary

We aim to enable the accelerated roll-out of fit-for-market, financeable, clean and sustainable cooling solutions that are attractive to end-users, civil society, governments, policymakers, industry and the finance community to ensure impact, lasting legacy and scalability. Policy and financing choices vary by geography, desired economic, societal and environmental outcomes and different cooling needs. Successfully meeting the cooling demand via affordable, renewable energy, efficient solutions that deliver societal and economic impact to everyone (small and marginal groups) with minimal pollution and environmental impact, will be critically dependent on an integrated 'fit for market' suite of interventions.

The key merits of our proposed needs-driven approach and robust cooling action plan methodology as follows:

1) Ensure solutions can be tailored to a robust, data-driven set of national or community needs and policy, rather than approaching the problem with pre-ordained assumptions.
2) Understand local resources will enable countries to develop National Cooling Action plans which best mitigate demand and harness all available sources of waste, free and renewable energy to meet the multiple cooling service needs of a community.
3) Enable government teams and development agencies to understand how to aggregate policy and finance choices towards the desired societal, economic and environmental outcomes prioritizing the right new interventions, and allow for system-level and service aggregation approaches to be considered to deliver both energy and economic efficiencies.
4) Identify the needs for local capacity building to ensure successful outcomes to deployment interventions in terms of sustainable cold-chain infrastructure operation and maintenance, both of which are crucial to the ability to effectively delivery of clean and sustainable cooling.
5) Deep understanding on the impacts of business as usual on sustainable development goals and Nationally determined contribution and equally the environmental contributions of the Cooling Action Plans and establish a critical baseline for access to sustainable cooling by setting targets to address a country's cooling needs and track progress.

Clean Cooling is ultimate, about future-proofing society. Today, our urgent goal is to ensure basic needs are met for all people in a warming world while living within our natural resource limitations and mitigating future risks to our survival on the planet. However, equally, we need to improve the quality of life for all, while simultaneously delivering environmental growth in collaboration with the global and local ecosystems that provide the resources upon which we depend to survive and thrive.

Rising ambient temperatures and the increasing frequency and severity of heatwaves will demand more cooling for health, food, productivity, data and, increasingly, safe living. Thus, the provision of comprehensive Clean Cooling is a prerequisite for a sustainable and resilient future. The sooner we recognise this fully and understand the cooling loads required so we can invest accordingly in the step-change interventions to deliver access to environmentally and socially sustainable cooling for all who need that helps the global community adapt to and thrive in – but also mitigate the impacts and risks of – a warming world, the better the outcome for humans in the 21st Century.

Street vendor trying to keep fish cool in a busy street market

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