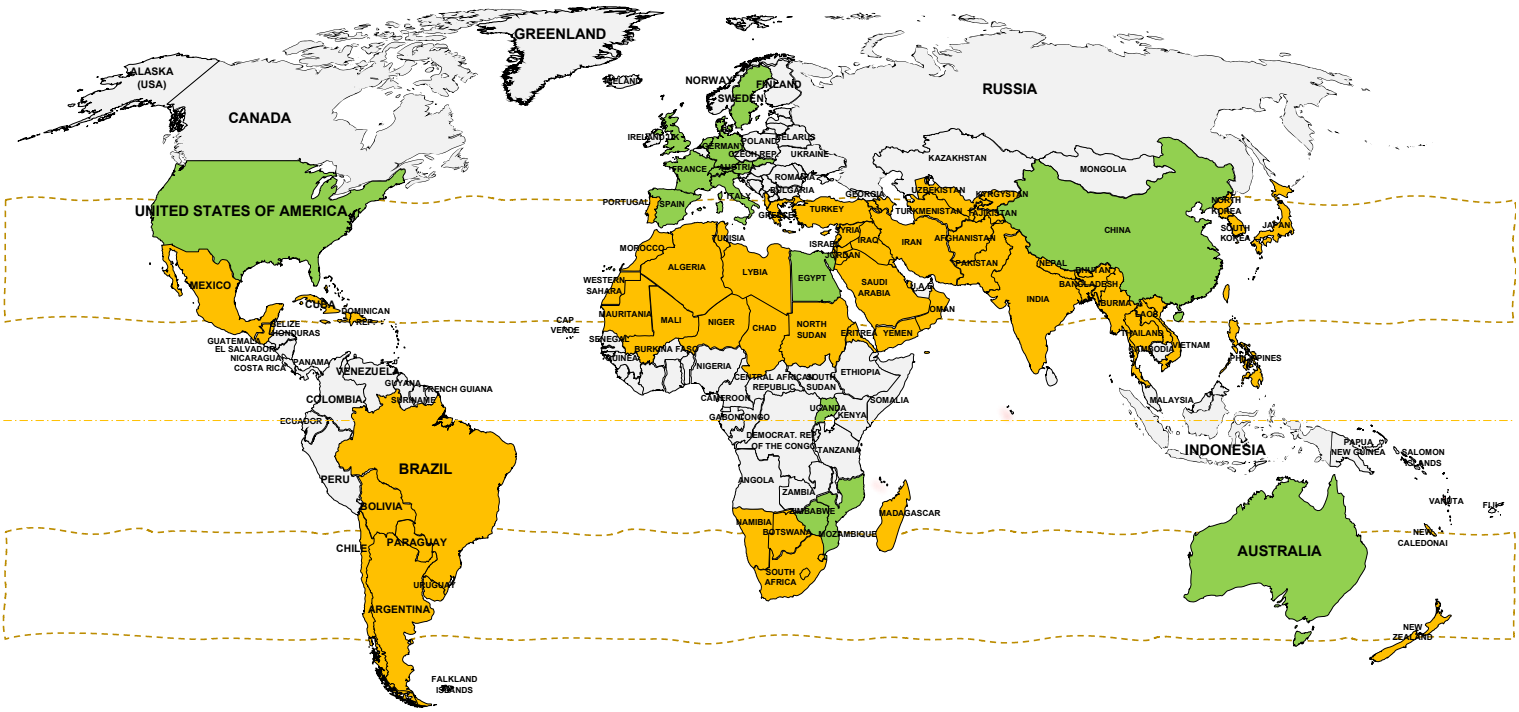
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Roadmaps for Solar Cooling in Sunbelt Countries



IEA SHC TASK 65 | SOLAR COOLING FOR THE SUNBELT REGIONS

Technology Collaboration Programme
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SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Roadmaps for Solar Cooling in Sunbelt Countries

This is a report from SHC Task 65: Solar Cooling for the Sunbelt Regions and work performed in Subtask D: Dissemination

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Cover photo credit: World map with Sunbelt regions (marked yellow) and the 18 countries of the participating Task 65 experts (marked green), source: Neyer Brainworks & JER

Solar Heating & Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64, 72)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46, 71)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
- SHC International Conference

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1 Executive Summary

The goal of the IEA SHC Task 65 “Solar Cooling for the Sunbelt regions” is to focus on innovations for affordable, safe, and reliable Solar Cooling systems for the Sunbelt regions worldwide. Countries located between the 20th and 40th degree latitudes in the Northern and Southern Hemispheres, placed in the Sunbelt, face increasing cooling needs on the one hand and higher solar irradiation on the other a compelling solution.

This document is the final report on activity D3 “Roadmaps for solar cooling in Sunbelt countries”. Activity D3 is dedicated to provide guidelines and recommendations on the development of roadmaps and policy recommendations to accelerate and spread the development of solar cooling technologies. A literature review provides information and compares exemplary roadmaps and documents on cooling demand and solar technologies, respectively. The review results identify promising methods and possibilities in roadmap and implementation plan formulation. Furthermore, existing roadmap manuals and analyses and Task 65 results are introduced to provide background information and to collect input for new roadmap and policy recommendations. The screening and review outcomes indicate that a linkage between the solar cooling technologies and their potential field of application on a national scale, directly targeting the most fruitful operation, is promising.

As a final result of Activity D3, this report provides an adapted and updated process recommendation on the roadmap development following a step-by-step approach. Additionally, list of policy recommendations is delivered as potential guidance for policy makers to promote solar cooling technologies on a national level.

2 Scope of Activity D3

The scope of activity D3 is to support the promotion of solar cooling technologies via guidelines on roadmap development and potential policy recommendations for decision maker. A first guideline on roadmap development was developed under IEA SHC Task 48 Activity D4 in 2015 (Preisler et al. 2015). These guidelines are reviewed and adapted according to latest development in the field of cooling demand and technology roadmaps.

The results of activity D3 published in this report serve as a guidance and inspiring handbook for policy makers to set up national roadmaps on solar cooling technology and for engagement of key stakeholders.

3 Introduction

The pathway of clean energy transition (CET) in general requires national commitment to the uptake of renewable energies, increase of energy efficiency and reduction of fossil fuel-driven energy consumption. Roadmaps and action plans are a useful tool to be first step of CET.

3.1 Roadmaps and Action Plans

Different activities are being conducted and followed on all over the globe. Countries and institutions are working on guidelines and roadmaps to pave the way for sustainable energy generation and efficient energy consumption.

National Cooling Action Plans (NCAPs) are an effective tool to define a country-specific roadmap. The NCAP methodology development was guided by the UNEP-led Cool Coalition (CC) (UNEP 2021). The methodology is based on seven steps (see Figure 4). A NCAP combines different fields, such as uptake of efficiency and the implementation of measures agreed on by signing the Paris Agreement and the Kigali Amendment under the Montreal Protocol. Thus, the phase-out of HCFC and the phase-down of HFC refrigerants are also taken into consideration (UNEP Energy 2024).

Actions Plans on Renewable and Clean Energy are being developed by countries all over the world and focus on the uptake of renewable energies, specifically solar, wind, hydro and biomass power generation. Solar is most often connected and sometimes even limited to solar PV. Those action plans advocate the electrification of industrial and transport sector as well as the agile management of electric grids for integration of volatile energy generators, such as solar PV and wind power plants. Action plans and roadmaps on renewable energies are often linked to strategies in individual fields.

3.2 Task 65 Report Outcomes

Task 65 covers in total four subtasks: Subtask A: Adaptation, Subtask B: Demonstration, Subtask C: Assessment & Tools, and Subtask D: Dissemination. The activities in the subtasks A to C deliver useful results and outcomes for guideline development. In the following, key results from Subtask 65 activities are presented and described in terms of their significance for the guideline development for solar cooling in Sunbelt regions.

Following reports were already published at the time of writing:

A1 – Climatic Conditions & Applications
The report on activity A1 – Climatic conditions & applications puts focus on the use of GIS software solutions as a tool to assess the potential of solar cooling systems and to geographically identify use cases. The performance of solar cooling systems is dependent on the location in terms of solar radiation yield (Gurtner et al. 2023).

- The use of GIS enables preliminary statements of pre-defined solar cooling systems and a fundamental comparison between locations taking solar radiation, climatic conditions, and water availability into account.
- Using this approach, solar cooling systems can be exploited the proven concepts have a promising position for installations in similar locations.

A4 – Building & Process Optimization

This report presents an overview on the relevance of building and process optimization and presents results from scientific publications in a literature study. Several ongoing and completed projects are introduced and results are depicted (Bonomolo and Strobel 2023).

- There are R&D projects running worldwide which focus on building energy efficiency and efficient space cooling technologies.
- Passive measures in the building envelope, such as insulation, shading elements or high reflective paint are presented
- Urban Heat Islands (UHI) are shortly presented, their role in the space cooling demand in urban areas is underlined and mitigation options are outlined.
- The quality and scope of results presented in scientific studies show great deviation with each other, reducing the level of direct comparison. Most publication in the field do focus on the cooling system level rather than the building operation and description.

B2 – Design Guidelines

This report presents numerous designs and system integration guidelines for solar cooling projects pointing out real-life data and installations. Data of 10 case studies were collected and compared as well as three unique installations presented in more detail (Saini and Weiss 2023).

- Particular opportunities for solar cooling installations are identified in industrial process applications.
- Application of solar PV driven compression chillers show lower levelized costs of cooling compared to solar thermal.
- Hybrid chiller systems consisting of a sorption and a compression unit indicate a significant reduction in electricity consumption when using the topping cycle of an adsorption chiller.

B3 – Lessons Learned

This report includes a survey among universities, energy solution providers, renewables energy research and promotion centres and manufacturers to gain reliable data and insights on the chances and obstacles of solar cooling (Weiss et al. 2023).

- The market transformation of solar cooling is a multidimensional process that required collaboration in various context. The engagement of different stakeholders is crucial for solar cooling uptake.
- Adoption of solar cooling is currently hindered by lack of awareness, shortage of experienced personnel, high initial costs, minimal supporting policy options and limited access to capital.
- Most crucial steps to boost solar cooling are awareness raising, increasing market acceptances and accelerating market penetrations.
- Development of a “Conversation Guide” and the application of GIS analyses are recommended tools.

C1 – Design Tools and Models

This report covers the design and modelling of tools to assess solar cooling systems on an economic and financial level. The main focus is the documentation of the tools and their specific application to provide measured data for validating the tools and the adaptation of selected ones for Sunbelt countries. Three approaches are used to evaluate tools used worldwide and this IEA SHC Task. First, a (i) generic literature research of 1,216 documents in Web of Science (WoS), (ii) interviews and questionnaires among the IEA SHC Task Expert, and (iii) interactive questionnaires during Task expert meetings (Daborer-Prado et al. 2023).

- Modelling and assessing the technical and economic behaviour of solar cooling plants is essential in all design phases up to implementation and optimization.
- Different tools are used, from sophisticated dynamic simulation models to simple spreadsheet calculations.
- Companies and their experts often develop their own for their specific components and systems.
- Generic publicly available models can be found for almost all applications, especially simulation tools.
- The configuration and data sheets for the entire tool depend on the approach and are often difficult to find.

Additionally, the report of Task 65 Activity B4 is finalized, but is not yet published at the time of writing. In the following, key results of the activity are listed:

B4 – Standardized Solar Cooling Kits

Task 65 Activity B4 focuses on the development and presentation of standardized solar cooling kits. These kits include different technologies, such as solar thermal, solar PV, absorption chiller and electric-driven cooling units. The results of this activity present a variety of different standardized cooling solutions, bringing simplified solar cooling system on the market.

- Four technology groups are identified: Absorption cooling, Adsorption cooling, Desiccant-evaporative cooling and vapour-compression cooling.
- Different commercially available solutions and model examples are presented for each of these four technology groups
- Heat rejection systems in dry climates present significant challenges.
- Use of medium-temperature solar systems to operate two-stage absorption chillers to increase competitiveness

More information on the results of IEA SHC Task 65, further the deliverables and materials/tools, are available on the website: https://www.task65.iea-shc.org

4 Overview on Existing Roadmaps and Plans

The screening and review process will provide an assessment and comparison of existing roadmaps and action plans. On the one hand, the information gathered in the review process will provide a better picture of action plans and roadmaps worldwide. On the other hand, the assessment and analysis of existing roadmaps using different indicators will outline principles and hints for the set-up of new solar cooling roadmaps for the Sunbelt region.

The report “Final Deliverable – Guidelines for Roadmaps on solar cooling”, published in 2015, derived from Activity D4 of IEA SHC Task 48, creates a first baseline for this report (Preisler et al. 2015). The report from Task 48 put focus on the role and importance of technology roadmaps. It furthermore already included a review process of a number of existing roadmaps focussing on solar thermal technologies which were used for an evaluation.

4.1 Screening of Existing Roadmaps on Cooling

The purpose of this review process is to update the methodology of Task 48 review and to take new and latest roadmaps and documents into account. This leads to a new review process of existing roadmaps, action plans and comprising documents on global scale. The methodology is described in the following four steps:

Table 1: Four steps of review process

	Search of documents holding roadmaps and actions plans. The literature search was performed mainly via online search and covers documents written in English and also in national language, such as German and French.
	Classification of documents in terms of focus topic. Roadmaps and action plans are most of the time focussing on one topic only. Two groups have been identified: solar roadmaps and cooling roadmaps. Besides, solar/ cooling roadmaps can also be embedded in larger roadmaps (energy efficiency/ renewable energy production)
	Identification and selection of indicators on solar technology, cooling technologies, cooling demand and future steps.
	Mapping and assessment of roadmaps and action plans in the previously identified indicators.

In total, 15 documents are found to be interesting and connected to this report and the review process. Eight documents cover cooling roadmaps and strategies and seven cover solar technologies and roadmaps.

Most documents are published by countries, whereas four reports derive from institutions, of which one has a political background (EU), two are from economic/ societal background and one report was published by an association. This selection from different backgrounds causes different perceptions and technological depths in the roadmaps, action plans and strategies.

Table 2: Overview of reports and documents screened in the review.

	No.	Stakeholder	Year	Title	Reference
Focus: Cooling demand	1	Bangladesh	2021	Bangladesh National Cooling Plan for the Implementation of the Montreal Protocol	(MOEF 2021)
	2	Cambodia	2022	Cambodia's National Cooling Action Plan	(MoE Cambodia 2022)
	3	Kenya	2023	National Cooling Action Plan for Kenya	(Papst et al. 2023)
	4	Rwanda	2019	Rwanda National Cooling Strategy	(Rwanda MoE 2019)
	5	Panama	2020	Panama Cooling Action Plan	(UNDP 2020)
	6	India	2019	India Cooling Action Plan	(MoEFCC 2019)
	7	Barbados	2022	Barbados National Cooling Strategy	(MENB et al. 2022)
	8	Lebanon	2021	Guidance for integrating efficient Cooling in National Policies in Lebanon	(UNDP 2021)
Focus: Solar Technology	9	Uzbekistan	2022	Solar Energy Policy in Uzbekistan: A Roadmap	(IEA 2022)
	10	UNEP	2014	Assessment on the Commercial Viability of Solar Cooling Technologies and Applications in the Arab Region	(Kohlenbach et al. 2014)
	11	SEIA	2013	Solar Heating & Cooling: Energy for a Secure Future	(SEIA 2013)
	12	EU	2014	Solar Heating and Cooling Technology Roadmap	(Ivancic et al. 2014)
	13	IEA	2012	Technology Roadmap Solar Heating and Cooling	(IEA 2012)
	14	Austria	2014	Roadmap "Solarwärme 2025"	(Fink and Preis 2014)
	15	France	2013	Feuille de route stratégique Solaire thermique	(ADEME 2013)

4.2 Indicators

The identified and reviewed roadmaps and action plans derive from different backgrounds and focus on different objectives. All reviewed documents are connected to either cooling, solar, or both topics. The selected indicators for the review cover the different thematic fields which are of importance for solar cooling technology roll-up in the countries of the Sunbelt region. In total, 26 indicators divided into following six categories have been selected: Cooling demand, Cooling by sector, Technologies, Environment, Spatial scale and Other. A similar structure of analysis can be found in the Inventory of International Cooling Programmes and Initiatives report (CCAC 2022, p. 3).

Table 3: List of selected indicators for roadmap and action plan screening.

No.	Name	Description
Cooling demand	Demand analysis	Current overview of cooling energy demand
	Demand analysis by sector	Current overview of cooling energy demand by sector
	Demand projection	Future projection of total cooling energy demand
	Demand projection by sector	Future projection of total cooling energy demand by sector
Cooling in sectors	Domestic refrigeration	Household applications such as refrigerators and freezers
	Commercial refrigeration	Application of refrigerators and freezers in supermarkets/ shops
	Industrial refrigeration	Application of cooling in industrial processes, especially in food and pharmaceutical industries
	Transport refrigeration	Cooling application for good refrigeration in transport, e.g., food cooling chain
	Domestic AC	Application for domestic air conditioning
	Commercial AC	Application for air conditioning in non-residential buildings, such as offices, malls, etc.
	Mobile AC	Air conditioning in mobile application, cars, busses, metro, etc.
	Other	Other application, e.g., cold storages
Technology	Solar thermal	Solar thermal collector application for renewable heat generation
	Solar PV	Solar photovoltaic module application for renewable power generation
	Absorption chiller	Use of thermally driven absorption chiller with liquid sorbent (e.g., LiBr solution)
	Adsorption chiller	Use of thermally driven absorption chiller with solid sorbent (e.g., zeolite/ silica gel)
	Compression chiller	Electric driven units using vapour compression process for cold generation
	Split units/ heat pumps	Conventional electric driven split units, including multi split
	Thermal energy storage	Thermal energy storage for both heat and cold in solar thermal systems
	Increase of energy efficiency	Relevance of energy efficiency and its increase
Environment	GHG emissions	GHG emissions of the cooling sector
	Potential GHG emission savings	Potential savings of GHG emissions by specific technologies or actions
Spatial Scale	National	Focus lies only one country
	Continental/ Regional	Focus on a group of countries
	Global	Report focussing worldwide
Other	Implementation plan	Specific list of actions to implement

4.3 Review Results

Before the review results are presented and discussed, the authors highlight that each screened document, roadmap and action plan is a unique report targeting individual aspects for each country/ region/ technology separately. The following results break down some topics of the reports in a simplified way.

The initial result, which was already indicated in the review methodology, is that cooling and solar action plans are most often elaborated separately. Solar solutions and technologies in general are often embedded in roadmaps targeting renewable energies, whereas cooling is seen as a separate field or embedded in larger roadmaps covering the energy consumption field.

The following tabular matrix presents what roadmap and report of which country/ institution addresses what kind of indicator field. For each indicator field, it is presented on what level the indicator field is taken into consideration. Following three options are taken into account for the review:

x	The indicator field is mentioned in the roadmap and is assessed/ given a role
(x)	The indicator field is mentioned once or twice, but not further treated
o	The indicator field is not mentioned

Table 4: Matrix of Review Results. This table indicate what topics are considered in the individual reports.

		Cooling demand				Cooling in sectors								Technology								Env.		Scale			
No.	Country/ Institution	Demand analysis	Demand analysis by sector	Demand projection	Demand projection by sector	Domestic refrigeration	Commercial refrigeration	Industrial refrigeration	Transport refrigeration	Domestic A/C	Commercial A/C	Mobile A/C	Other	Solar Thermal	Solar PV	Absorption chiller	Adsorption chiller	Compression chiller	Split units/ heat pumps	Thermal energy storage	Increase of efficiency	GHG emission	potential GHG emission savings	National	Continental/ Regional	Global	Implementation Plan
1	Bangladesh	x	x	x	x	x	x	x	x	(x)	(x)	x	x	o	o	x	o	x	x	x	x	x	x	x	o	o	x
2	Cambodia	x	x	x	x	x	(x)	x	x	x	x	x	x	o	(x)	x	x	x	x	x	x	x	x	x	o	o	x
3	Kenya	x	x	x	x	x	x	x	x	x	x	x	x	o	x	o	o	x	x	x	x	x	x	x	o	o	x
4	Rwanda	o	o	o	o	o	o	o	o	x	o	o	o	o	(x)	o	o	x	x	x	x	(x)	o	x	o	o	x
5	Panama	x	(x)	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	o	x	(x)	o	x	o	o	o
6	India	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x	x	x	x	(x)	o	x	o	o	x
7	Barbados	(x)	(x)	o	o	x	x	o	o	x	x	(x)	o	x	x	x	x	x	x	x	x	x	x	x	o	o	x
8	Lebanon	x	x	x	x	x	x	x	x	x	(x)	x	o	o	x	o	o	x	x	x	x	x	x	x	o	o	x
9	Usbekistan	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	o	o	o	(x)	x	x	x	o	o	x
10	UNEP	o	o	o	o	o	(x)	(x)	o	x	x	o	o	x	x	x	x	x	x	x	x	(x)	(x)	x	x	o	x
11	SEIA	o	o	o	o	o	o	x	o	x	x	o	o	x	x	x	o	x	(x)	x	(x)	x	(x)	x	o	o	o
12	EU	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	o	o	x	x	o	o	o	x	o	x
13	IEA	o	o	o	o	o	o	x	o	x	x	o	o	x	(x)	x	x	x	(x)	x	x	o	(x)	o	o	x	x
14	Austria	(x)	o	(x)	o	o	o	o	o	(x)	(x)	o	o	x	(x)	(x)	o	o	o	x	o	o	(x)	x	o	o	o
15	France	o	o	o	o	o	o	x	o	(x)	(x)	o	o	x	o	o	o	o	o	x	x	o	o	x	o	o	(x)

The matrix in Table 4 shows what topics are considered in the individual reports. The reports, as highlighted in chapter 4.1, target different topics, primarily the cooling demand or solar technologies. This difference can be spotted in the analysis of the reports. The first eight documents focussing on the cooling demand usually portray not only the cooling demand in general, but also the individual sectors, such as industry, space cooling and home refrigeration, and a future projection.

Figure 1 presents how often a topic is covered (green) or partly covered (yellow) in the 15 screened documents. The indicator category most often addressed is Technology, of which the increase of energy efficiency units is most numerous indicators.

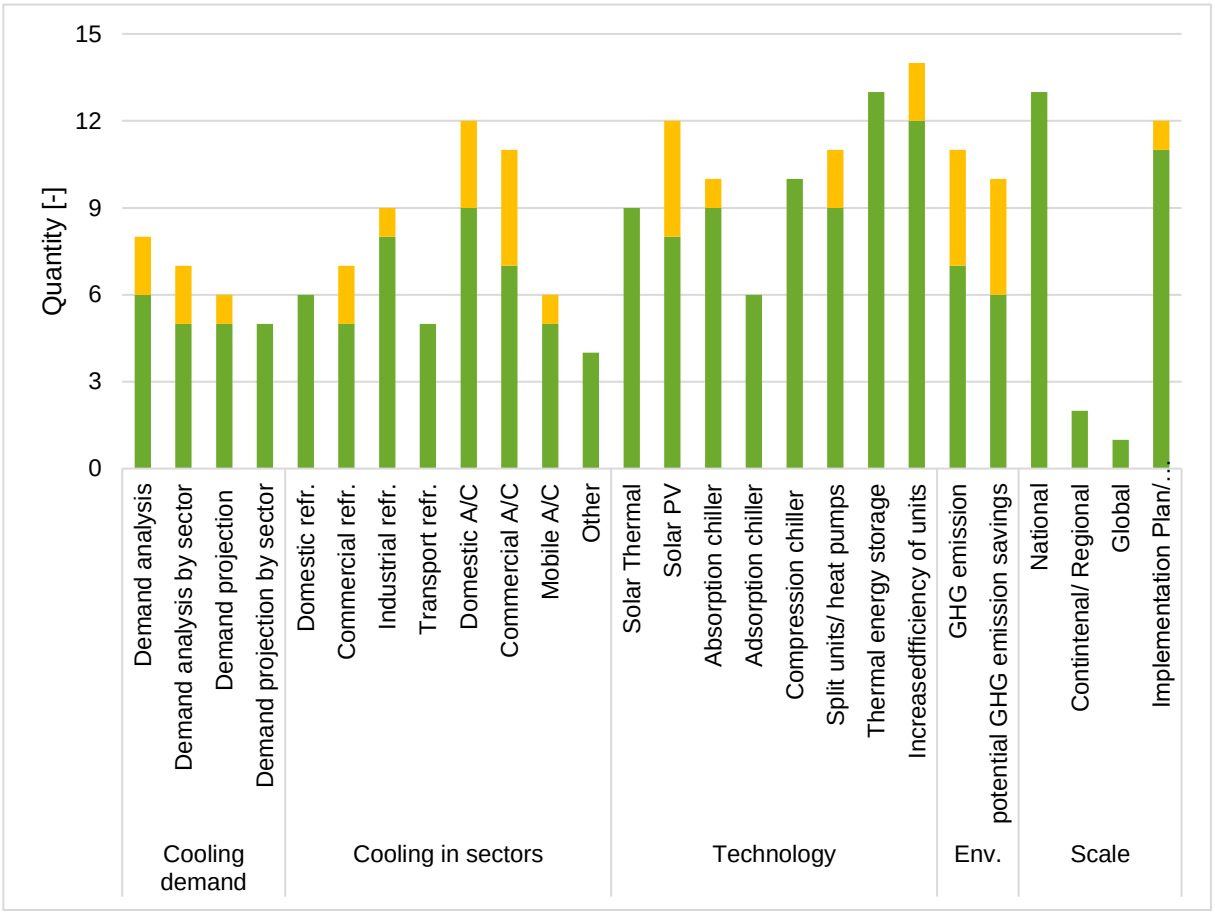

Figure 1: Frequencies of indicators in the 15 reviewed documents.

In the following, the review results in the different categories of the analysis are described in more detail. Some examples from the documents are presented, showing the level of detail and stating the differences and/ or similarities in them.

Cooling Demand

The National Cooling Action Plan for Kenya presents the cooling demand by sector, but uses not number of unit sales, market size or energy demand for comparison, but the proportion of emissions (Papst et al., p. 15). Accordingly, is the unitary air conditioning sector responsible for about 50% of GHG emissions in Kenya. The Rwanda National Cooling Strategy is the only cooling-focused document which does not provide information on the cooling demand, but offers information such as on the numbers of refrigerator sales by sectors (Hotel, Restaurant, Agribusiness, Food and beverage production, other commercial/ industry and other) (Rwanda MoE 2019, p. 14). The Barbados National Cooling Strategy on the other hand gives information on the division of electricity consumption in different fields and partly gives information on the relevance of cooling appliances in the

consumption. The Hotel sector for example consumes 15% of the national electricity production, of which 60% is dedicated for AC and refrigeration (MENB et al. 2022, pp. 34–35). The reports and documents focusing on cooling technologies do not present information on the cooling demand in total and in the different sectors.

Cooling in Sectors

Some reports put focus on the description of the state-of-art in the different sector, presenting the situation, needs, market and latest and future developments. The different cooling applications cover both space cooling as well as refrigeration application in domestic households or industrial processes. Most addressed is space cooling application in the residential sector. Transport refrigeration and transport AC are the least addressed sectors across the screened documents.

Technology

Across all screened documents the presentation of any technology, whether solar thermal, solar PV as well as cold providing energy appliances, thermal energy storage or the topic of energy efficiency measures is given. The level of detail and information however shows great deviation between the documents. Whereas most cooling-focused documents just mention the potential application of single technologies, the solar-focused documents do focus more on the future potential of different solar systems and describe system designs and component differences. However, solar-focused documents do focus primarily on solar heating and solar PV solutions in general, but also present solar cooling. Cooling focused documents more often refer to solar PV than solar thermal technologies. The documents on solar technologies more often name absorption chillers than adsorption chillers.

Environment and Scale

The environmental topics of GHG emissions and potential savings through energy efficiency measures and renewable energy integration are integrated in both documents focussing on cooling and on solar. The vast majority of reports target individual nations. Only the UNEP report on the Assessment on the Commercial Viability of Solar Cooling Technologies and Applications in the Arab Region (Kohlenbach et al. 2014) and the EU Solar Heating and Cooling Technology Roadmap (Ivancic et al. 2014) target a region or a combination of countries. Some documents on the cooling demand compare the cooling by sector in GHG emissions or present this information in addition to the energy demand, such as the Cambodia National Cooling Action Plan (MoE Cambodia 2022) or the report Guidance for integrating efficient cooling in national policies in Lebanon (UNDP 2021). The relevance of HFC refrigerants is also partly taken into account related to the HFC phase out. The reduction or growth of GHG emissions in the cooling sector is covered either by the increase of energy efficiency measures or the uptake of solar and other renewable energy sources (SEIA 2013, p. 25). The Kenyan National Cooling Action Plan depicts a saving of about 23 Mt CO_2-equivalent until 2050 if all recommended actions of that report will be realized.

Implementation Plan

A great result of the review is that most documents already present or propose a list of actions for implementations or recommendations. Those plans come in very different formats. The roadmap of solar energy policy in Uzbekistan, which assess the total potential of solar heating, cooling and power generation, presents a list of 19 actions. Each action is linked with an individual schedule in a timeframe from 2022 until 2030 (IEA 2022, p. 45). All actions are divided into three categories:

- Maximising the benefits of solar energy in the energy system
- Policy and regulatory frameworks for further solar energy deployment
- Securing power system flexibility

The Kenyan National Cooling Action Plan on the other hand has divided identified 16 actions into two fields of short-term and medium-term actions subdivided into three targets, see Table 5 below. This list is more detailed in the Kenyan Cooling Action Plan and assigns each action to be performed to a responsible agency, such as the Ministry of Education or the National Treasury and Planning (Papst et al. 2023, p. 66). Such an assignments of tasks given a schedule of performance is a great tool for all involved stakeholders and facilitates the future planning and progress of the roadmap.

Table 5: Summary of Kenya National Cooling Action Plan Objectives. Source: (Papst et al. 2023, p. 12)

Targets	Short-Term Actions	Medium-Term Actions
Accelerate market transition to high efficiency cooling appliances and equipment	1.1 Increase ambition of efficiency standards for ACs and refrigerators 1.2 Raise awareness on energy labels for cooling products 1.3 Strengthen compliance and enforcement 1.4Launch bulk and government procurement programs 1.5 Implement favourable fiscal	1.6 Expand efficiency standards to cover end-uses with growing energy demand
Transition the cooling sector away from high-GWP refrigerants	2.1 Ratify the Kigali Amendment 2.2 Raise awareness for the application of natural refrigerants	2.3 Ban high GWP-refrigerants in selected product groups 2.4 Establish formal qualification, certification, and registration scheme for techr1icians
Increased access to agricultural cold chain solutions	3.1 Create an enabling environment for the cold chain market 3.2 Expand fiscal benefits to cold storage systems 3.3 Raise awareness on the benefits of the cold chain	3.4 Support R&D for technical solutions adapted to local conditions 3.5 Promote access to innovative business models 3.6 Design finance models targeted at small-holder farms

4.4 Conclusion of Review

The documents and roadmaps reviewed target different topics and present accordingly more information in the specific fields. If there is a comparison between different sectors of cooling demand, in general it is a holistic overview, naming all sectors. Absorption chillers are more frequently named compared to adsorption chiller across all reviewed documents. Twelve of the 15 documents provide some kind of implementation or action plan, sometimes integrated into a schedule.

The final conclusion of this review is that future roadmaps on solar cooling technologies should take both the cooling demand sector and the technology development itself into consideration. Directly addressing the target field of application of a solar cooling technology facilitates its market uptake and the contributes to tailoring the roadmap, focussing on the national cooling needs and the capabilities of solar cooling.

5 Development and Adaption of Roadmaps

Defining a roadmap is a great help to collect relevant data and create a future projection for a technology on national scale on the one hand. On the other hand, a roadmap is first commitment of a country and its government towards a defined target. Thus experts, companies, manufacturers researchers and the public have assistance in their future decision making, based on the agreed roadmap. Additionally, a roadmap connected with scheduled actions is binding, thus creating trust. This chapter provides fundamentals on roadmap development and an adaption for solar cooling in Sunbelt countries.

Countries in the Sunbelt region are affected by a combination of drivers to increase the need for cooling. Those drivers are primarily economic growth, rising population and warmer climate. Urbanizing is another driver causing the urban heat island effect to come even more into action.

5.1 Fundamentals in Roadmap Development

A very helpful document when it comes to roadmaps is the Energy Technology Roadmap Guide from the IEA (IEA 2014). This guide gives a general framework for policy makers and experts to establish an energy technology roadmap for a specific technology. The plan is structured into four phases and divided in the two sectors of Expert *judgment and consensus* and *Data and analysis*.

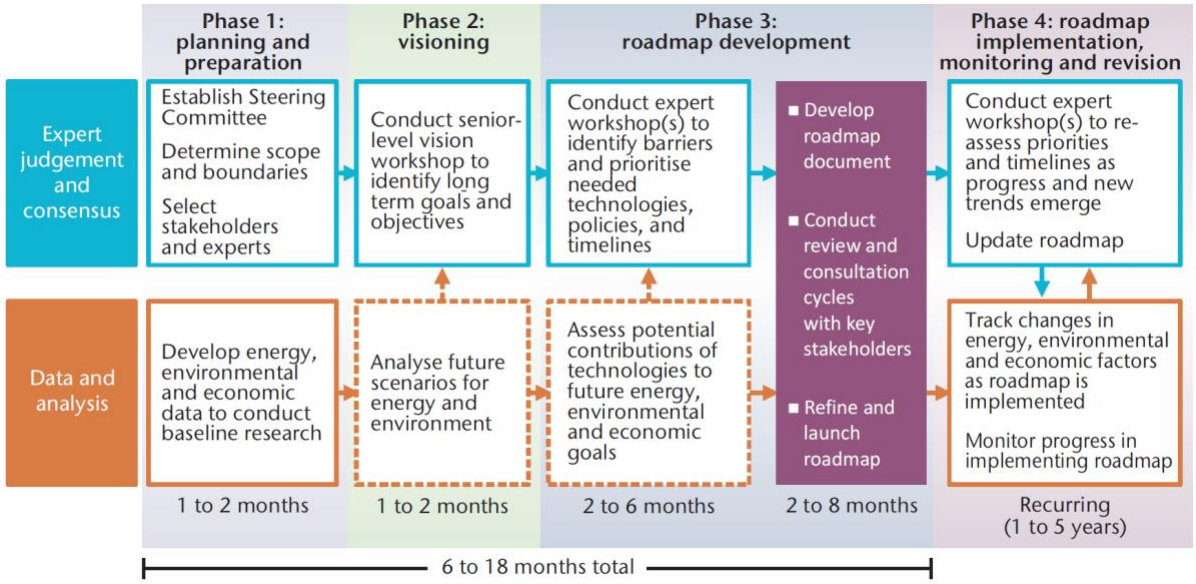

Figure 2: Methodology of Technology roadmap divided into 4 phases. Source: (IEA 2014, p. 6)

The SHC Task48 D4 activity group created a the framework on a solar cooling roadmap in the final report on Activity D4 (Preisler et al. 2015). This framework is structured in the four phases of the IEA Technology Roadmap Guide (see Figure 2). This framework offers a list of questions creating guidance when developing a roadmap. In the following, a number of key questions and key recommendations per phase is presented:

Phase 1	• Which technology areas or classes will the roadmap consider? Which energy sources or end-use sectors will be considered? • What is the current state of the technology under consideration (current installed base, potential energy savings, cost, efficiency, etc.)?
Phase 2	• What essential trends of the economy, society are key? • What vision timespan is foreseen a short, middle or long-term, e.g., 2020 2030 or 2050? • What specific target do you address (NZE building/ Economy/ …)?
Phase 3	• How can the objectives be reached? • Which frameworks have to be changed, which laws have to be introduced? • Which of these actions has to be done by whom? What cooperation is necessary?
Phase 4	• Plan a successful roadmap launch to build awareness and create momentum needed to stimulate action. • Designate the roadmap implementation body early in the process. • Monitor key energy, environmental and economic indicators to track progress.

Figure 3: Key questions and recommendations from Task 48 roadmap guidelines. Source: adapted from (Preisler et al. 2015)

Another guide when it comes to national cooling plans is given by K-CEP (Kigali Cooling Efficiency Programme) (K-CEP 2019). It provides a number of principles for both the policy mechanism as well as the cooling sector itself. K-CEP transformed into CCC (Clean Cooling Collaboration) in 2019. This three-staged process holds 7 steps to develop not a roadmap, but a national cooling action plan. The three stages cover the planning, assessment of cooling demand and finally the synthesis and NCAP creation.

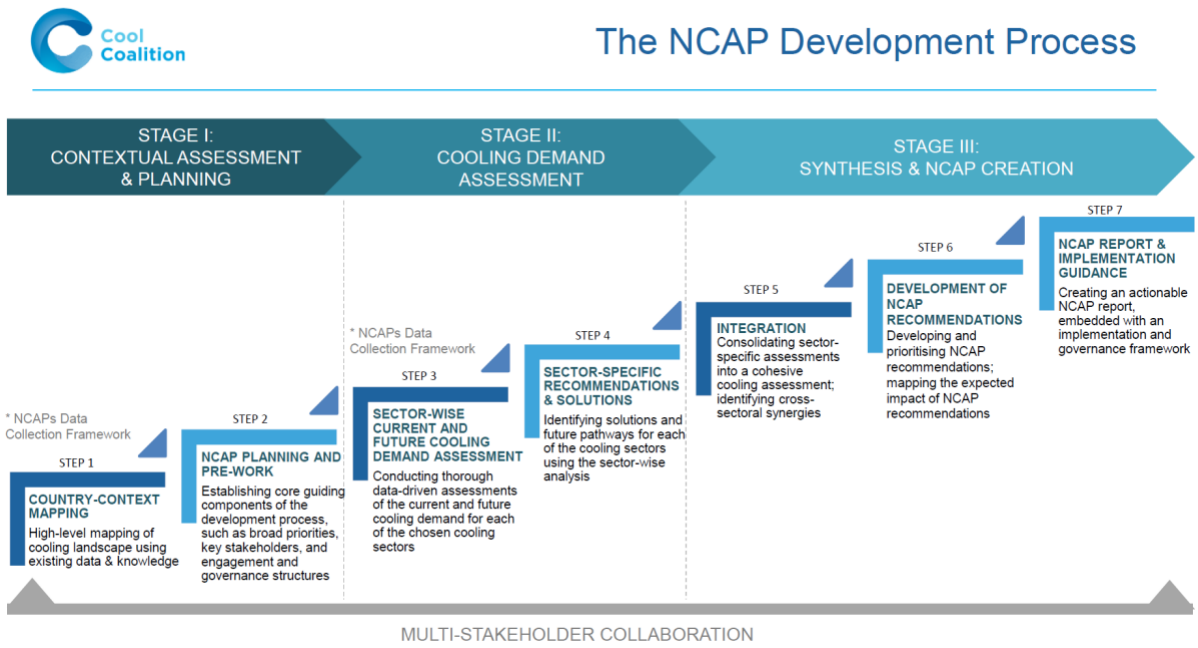

Figure 4: Methodology of NCAP Development Process. Source: (UNEP Energy 2024)

5.2 Adaptation for Solar Cooling

Solar cooling refers to various compositions of technology combinations. The general objective is to run cooling appliances with energy derived from solar radiation as primary energy source. However, systems may run on solar PV or solar thermal energy and cold can be generated via heat pumps or sorption chillers. All solar cooling systems have in common that they are locally fixed systems, not suitable for mobile use. The selection of cold providing technology (heat pump, adsorption chiller, adsorption chiller, …) is dependent on the type of cooling demand, especially on the required chilled water temperature. The type of cold providing technology on the other hand is associated with a specific solar energy generation type, not only in power or thermal energy, but also in solar thermal collector output temperature.

The following decision scheme presents the different opportunities of technology combination in the sector of solar cooling system. It gives a first impression and overview on the selective design of a solar cooling system and the selection of system components based on demand and configuration decisions.

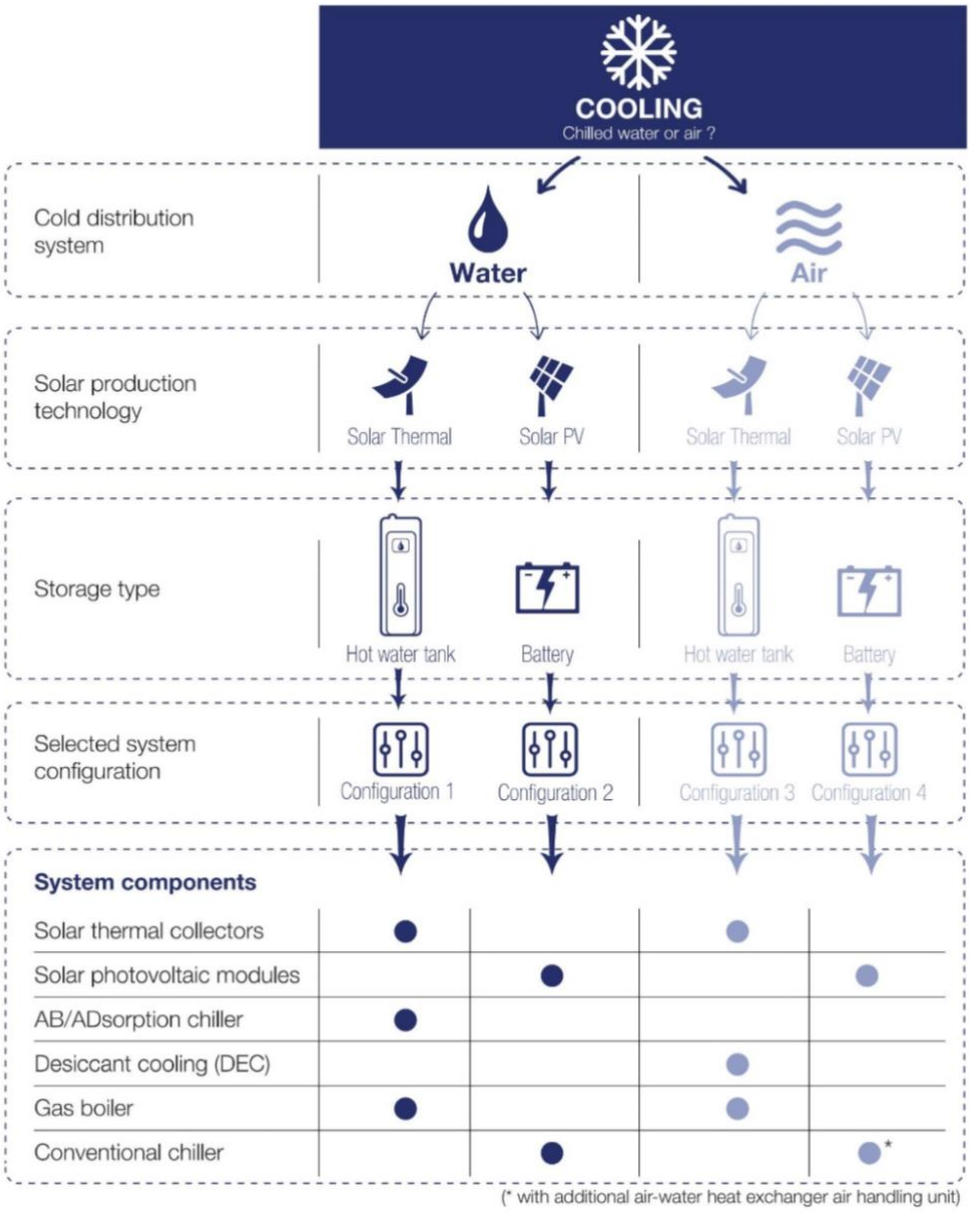

Figure 5: Decision scheme for solar cooling technology selection. Source: (Kohlenbach et al. 2014/ Solem Consulting)

The cooling and the solar sector are very diverse sectors linked to different use cases in the industry, in space cooling, in dehumidification and building quality and design when it comes to air conditioning. As the field of solar cooling is so wide, the development of a baseline data base is a challenging task.

Additionally, solar radiation is a power and heat generating energy source and only available in the daytime with seasonal variation. This causes either supply limitations or, if these have to be avoided, the necessity to directly plan batteries and storages within a system to balance energy generation and cooling demand. The solar yield is also dependant on the location of installation.

As identified in the IEA SHC Task 65 Activity B5 – Lessons learned (technical and non-technical) – the most effective approach for a wide solar cooling technology market adoption needs to be identified (Weiss et al. 2023). One potential way is to identify and link the solar cooling technology options directly with the different needs. Figure 6 below shows the application field of cold providing technologies for different use-cases. This overview is presented in the 2020 Cooling Emissions and Policy Synthesis Report by IEA and UNEP (IEA and UNEP 2020). A similar overview for solar-only driven cooling solutions would be an effective approach to facilitate the chances, limitations and application fields of solar cooling.

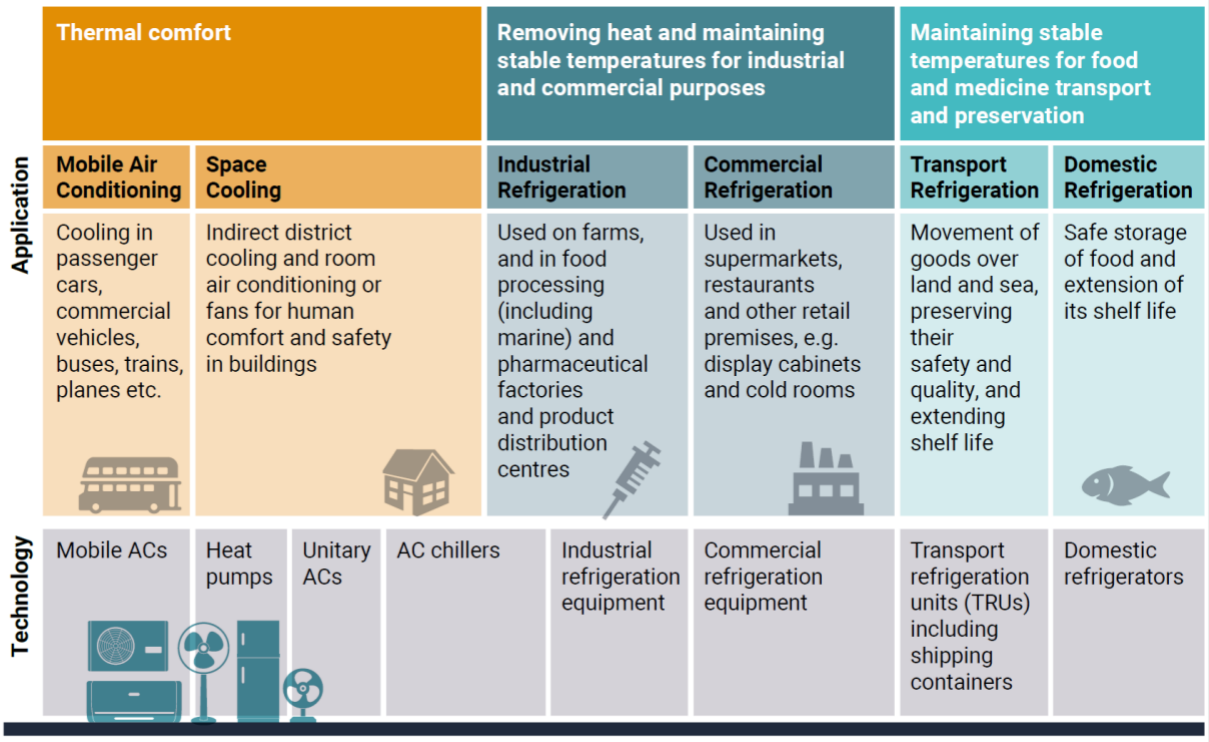

Figure 6: Linkage between cooling demand in use cases and application of cooling technologies. Source: (IEA and UNEP 2020, p. 15)

One field of technology/ application for solar cooling is missing in Figure 6: solar district cooling. The IRENA roadmap Renewable Energy in District Heating and Cooling from 2017 highlights the solar thermal potential for application in district cooling networks: *"As an example, solar district cooling can be achieved through solar thermal collectors to drive an absorption heat pump."* (IRENA 2017). This opportunity must not be neglected for future roadmap developments.

Thus, roadmap development of solar cooling solutions needs to get picture of the possibilities but also disadvantages of those. As identified in IEA SHC Task 65 Activity B5, the market transformation of solar cooling is a multidimensional process.

A team of experts developed a roadmap for solar thermal cooling technologies in Austria in 2012 (Preisler et al. 2012). They identified following fields of action:

Table 6: Overview fields of action to foster solar thermal cooling in Austria (Preisler et al. 2012)

Fields of Action for Solar Thermal Cooling		
Technology Development	**Market penetration**	**Promotion of innovation**
• Ab-/adsorption chillers • Heat rejection • DEC-Systems • Solar thermal system • Storages • System optimization	• Representation of interest • Demonstration plants • Dissemination activities	• R&D funding • Investment promotion • Evaluation promotion • Coupling funding • Quality dependent funding • Potential studies

5.3 Adaptation for Countries in the Sunbelt Region

Countries in the Sunbelt region have in common that the solar radiation is available with less fluctuation compared to countries in central Europe. The Sunbelt countries show a great cultural and economic deviation. More than 40% of the countries in the Sunbelt region have a GDP of less than 5,000 $/capita (World Bank 2024). Therefore, economically feasible and proven technologies are most promising. Furthermore, the dry climate is covering about 50% of land mass in the Sunbelt, followed by temperate climate, causing the Sunbelt countries to have a high cooling demand by climate already.

Especially for those countries who are experiencing economic development and financial growth, it is important to develop roadmaps and define a pathway at early stage, to direct the energy and economic development in the cooling sector in the right direction.

An enormous increase in the number of AC units sold is expected, considering the economic growth worldwide and in particular the increase in many Sunbelt countries combined with the hot climate. This development could be a chance for solar cooling solutions. The general individual developments in various sectors of a country (household, offices, agriculture, industrial cooling, etc.) lead to the fact that it is helpful to involve different ministries and department. This is what happened in the development of the Indian Cooling Action Plan (ICAP): five national ministries with additional councils, centres and departments collaborated. Figure 7 below presents the development framework of the ICAP.

Figure 7: Multi-stakeholder Development Framework of the Indian Cooling Action Plan. Source: adapted from (MoEFCC 2019, p. 7)

As solar cooling is still a niche market at the moment, the knowledge transfer to Sunbelt countries is an important aspect, as this technology is not as widespread as the use of split units for air conditioning or electric vapour compression chillers. The number of private companies and research institutions active in the field of solar cooling in Sunbelt countries is not as high as in the USA, Germany or India. Therefore, the integration of foreign experts and stakeholders seems promising in case there is a lack of national stakeholders for roadmap development.

6 Policy Recommendations and Roadmap Guideline

Policy measures are promising tools to launch the technical and economic progress of solar cooling in countries in the Sunbelt region. Those policy measures can be part of an action plan derived from the roadmap. The defined final policy recommendations are based on three aspects, on the learning of IEA SHC Task 65 activities and the published results (i), on the review of existing roadmaps (ii), and the input from previous assessment (iii), such as in IEA SHC Task 48 (Preisler et al. 2015). The list of recommendations serves as guidelines for roadmaps on solar cooling.

The roadmap and the policy recommendations are newly developed and build a separate baseline. They are based on input from:

- **Task 65 Activities** (Gurtner et al. 2023; Bonomolo and Strobel 2023; Weiss et al. 2023; Daborer-Prado et al. 2023)
- **Reviewed reports** (MOEF 2021; MoE Cambodia 2022; Papst et al. 2023; UNDP 2020; MoEFCC 2019; MENB et al. 2022; UNDP 2021; IEA 2022; Kohlenbach et al. 2014; SEIA 2013; Ivancic et al. 2014; IEA 2012; Fink and Preis 2014; ADEME 2013)
- **Additional documents** (K-CEP 2019; UNEP 2021; UNEP Energy 2024; Bhalla 2023; CCAC 2022)

6.1 Adapted Solar Cooling Roadmap Guideline

In the following, the adapted guideline for roadmap development for solar cooling in the Sunbelt region is presented.

1. Establishment of core working group/ steering committee

First step is to identify the national institutions, departments and experts to include in the development of the roadmap. This includes national stakeholders like ministries, but also international stakeholders which can bring expertise. Close collaboration between members of the core working group/ steering committee is essential.

2. Identification and organization of data and information

Data and information to define the current state of the art are important. Thus, potential data resources and information holder need to be identified and the content to be screened. If no sufficient data are available to form a baseline, those missing materials need to be collected.

3. Development of baseline data base

Based on the available and collected data, a database has to be developed to form a baseline. This baseline has the benefit to compare the state of the art with other countries and regions and is the fundament for further analysis. The baseline database holds information on energy consumption, market size and situation, the technological progress in the last decades and essential trends in economy and society, amongst others.

4. Identification of application fields and sectors

The baseline database holds information on the energy consumption and generation. This helps to identify and prioritize the most crucial fields of application to take actions in. This takes into account space cooling and process cooling in particular.

5. Identification of technologies

The identification of technologies to focus on in the roadmap is necessary to tailor later actions and measures to foster them. The solar cooling technologies should match with the identified fields of applications. Those technologies may be island-based PV air conditioning systems or solar thermal cooling systems for process cooling or space cooling, amongst others.

6. Involvement of stakeholders to involve

The realization of a technology roadmap requires the involvement of stakeholders from private sector, especially with engineering and economic background.

7. Definition of tools

Different tools and methodologies are available for the following definition of targets. Those tools must match with the available data, the strengthening of the roadmap pathway and the national scope. Tools can be GIS software, future projection models of energy mix in generation and consumption or system design software tools like TRNSYS.

8. Definition of targets & milestones

An essential aspect of a roadmap is the definition of targets, the vision timespan and the linkage to other roadmaps and targets. Targets do not only serve as an overall goal to follow, but also as an obligation to keep on track on the activities defined in the roadmap. This process is supported by the set-up of milestones. These milestones should be clustered in short-, medium- and long-term milestones, to prioritize activities in their schedule. Short-term milestone may take up to one year, for example awareness raising campaigns. Medium-term can take up to 5 to 10 years, for example business model promotion. Long-term milestones reach up to 20 years, for example the establishment of a national supply chain and grown market.

9. Roadmap report implementation

This step concludes the finalization of the phase of roadmap development. The roadmap report concludes all information and baseline information, underlines the fields of application and key technologies and provides an overview of final targets and milestones.

10. Awareness raising

Awareness raising is necessary to spread the activities and information gathered in the roadmap. The awareness raising includes also the general public to draw attention on the solar cooling technologies.

11. Monitoring activities

Monitoring is necessary to evaluate the progress of the roadmap and to identify the need for action. Those activities include data acquisition, market assessment and expert consultation. Progress is then compared to the measurable targets of the roadmap.

12. Roadmap revision

Solar cooling roadmaps should be considered as living processes. The monitoring activities are worth for both take policy actions but also for revision of the initial roadmap if the environment changes, whether from technological, socio-economic of market perspective. A promising measure is a follow-up analysis report on the initial roadmap in a cycle of 5 to 8 years.

6.2 Policy Recommendations

The guideline describes step-by-step the process of roadmap development on solar cooling solutions on a national level. Other than the activities in the guideline, national government have the power to directly and indirectly foster the uptake of solar cooling technologies in the country.

In the following, different possible policy recommendations for countries in the Sunbelt are presented. The list is suggestive only and in no particular order of priority.

I. Funding schemes for solar cooling system installation

Those funding schemes can be dedicated to different target groups (private homeowners, SME, industrial enterprises, …) and different technologies (solar PV + split unit, solar thermal cooling system, …). Based on the market assessment and the baseline data bank, the areas of most impact and/ or the most promising short- or long-term results can be targeted. The type of funding can vary from interest-free loans to financial subsidies without repayment obligation. Such measures have short- to medium-term impact. The topic of financing and also business models is also covered by Task 65, in Activity D2.

II. Taxation measures

Taxation measures to promote solar cooling technologies can go both ways. Either by lowering the tax burden on renewable solar cooling components or systems, or by slowly increasing the tax load on non-renewable and GHG-intensive technologies. Another option is to introduce a trading system of CO_2 emission certificates, following the example of the European Union.

III. Import trade measures

Those measures only affect countries and import activities not being affected by free-trade agreements. Reducing the financial burden of import taxes on solar cooling system components (PV cells, absorption chiller, …) will increase the economic attractiveness of solar cooling.

IV. Attract & support companies active in solar cooling systems

If there is a lack of solar cooling market players, market players need to be either attracted from external countries or the organisation and structure of domestic companies must be fostered. The support of those companies is essential for a wide market uptake of solar cooling. A concrete activity could be a simplified and an expedited visa process for foreign experts or financial funding connected to a minimum of fixed budget of investment in the country.

V. Promote training activities

If there is a lack of experts in the field of solar cooling, knowledge transfer and training activities should be supported. This includes activities in the chamber of crafts as well in higher education and train-the-trainer events. This promotion can be in the form of financial support of education bodies with long-term perspectives.

VI. Establish certification and licensing schemes

The establishment of certification and licensing schemes for installers and manufacturers secures the quality of cooling systems installations. Technicians benefit from their professional qualification and end-users can be sure of the quality of their products.

VII. Promote national solar cooling association

The creation of a national solar cooling association will (i) bring market players together, (ii) grows the political power of solar cooling as a technology and (iii) facilitates the communication between politics and market players. Additionally, this is the base of industrial codes coming from manufacturers and installers themselves.

VIII. Regulation and building codes

Stipulating the application of solar cooling technologies via regulation or buildings is one way to direct the market into the desired direction. However, regulation and building codes are characterized as measures with medium- to long-term results and must be balanced with the market situation and end-user facilities.

IX. R&D funding

To secure the national technology development and optimization in the field of solar cooling, the funding of R&D activities such as projects or higher education should be supported. This addresses both the set-up of R&D activities in the first place as well as supporting and expanding te existing capabilities.

X. Best practice funding

Another funding option is the funding of best practice solar cooling projects. There, the potential of integration in a real-life use case is demonstrated. This will underline the effectiveness of solar cooling and potentially dismiss mistrust towards this new technology.

XI. Awareness raising

Awareness raising is a measure that needs to be well structured, based on the application fields of interest for the country. Those activities can be focussed on different target groups (private households, SME, industrial companies, …) identifying the need of the target group and the advantage of solar cooling in that field. In addition, the information to disseminate should be adapted, for either experts or the general public. Examples of awareness raising activities could be advertising solar cooling funding schemes or the

organization of different fairs and conferences on solar cooling to inform end-users and experts/ installers respectively.

XII. Directives on HFC application

Countries are obliged to perform the HFC phase out following the Kigali and Montreal amendments. In this course, the benefit of refrigeration systems running on natural refrigerants is helpful for the phase-out. Some solar cooling technologies such as e.g. ab- and adsorption chillers or vapour-compression chillers are operated using natural refrigerants. Introducing HFC obligations can be an additional measure to other policy measures.

XIII. Recycling and circular economy approach

This policy recommendation has a broader and more general scope than other measures. On the one hand, a recycling obligation lowers the attractiveness of refrigeration systems running on HFC refrigerants mandatory appropriate treatment/ disposal of the refrigerant which is connected with additional costs. Additionaly to this aspect, a circular economy is most promising at an early stage when establishing the young solar cooling market. At this stage, the manufacturer and installers can already plan on the basis of a circular economy approach and adapt their work accordingly, such as material-seperated dismantling options.

7 Summary and Conclusion

Roadmaps are a good tool for advancing certain technologies or developments, such as solar cooling. This report gives an overview of existing initiatives, roadmaps and action plans on that field. A large number of countries and institutions have already drawn up roadmaps in the areas of solar energy and cooling demand. At the moment, the solar cooling technology is mentioned in the reviewed roadmaps, but solar and cooling is rather seen as separate aspects.

The review shows that there is a basic difference between the cooling demand roadmaps and the solar-focused documents. Cooling roadmaps and action plans focus on the national cooling energy demand or the related GHG emissions, whereas solar roadmaps do focus on solar heating, cooling and power generation, not putting much focus on the different cooling demands. Most reviewed documents have in common, that they finally present an overview of recommended actions or an implementation plan.

The guideline on solar cooling technologies is adapted to the need of countries in the Sunbelt region and includes learning from the Task 65. It covers 11 fields of action directly focussing on solar cooling, implemented in a general schedule. Finally, a list of policy measures for national decision makers offers a manual on actions to support solar cooling uptake from the government perspective. These policy recommendations cover both financial intensive measures (tax reduction/ direct funding) and organisational measures (building codes/ awareness raising). This list serves as a guidance for policy makers to identify and to institute the most suitable and promising options.

8 Abbreviations and Definition of Terms

Table 7: List of abbreviations and their description.

Abbreviation	Description
AC	Air Conditioning
ASEAN	Association of Southeast Asians Nations
CC	Cool Coalition
CCC	Clean Cooling Collaboration (formerly K-CEP)
CET	Clean Energy Transition
GHG	Greenhouse gases
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
K-CEP	Kigali Cooling Efficiency Programme
NCAP	National Cooling Action Plan
NCP	National Cooling Plan
NREAP	National Renewable Energy Action Plan
PV	Photovoltaic
RE	Renewable Energy
SAC	Solar Air Conditioning
SEforALL	Sustainable Energy for all
U4E	United for Efficiency

Table 8: List of terms and their definition.

Term	Definition	Source
Roadmap	A specialised type of strategic plan that outlines activities an organisation can undertake over specified time frames to achieve stated goals and outcomes.	(IEA 2014)
Roadmapping	The evolving process by which a roadmap is created, implemented, monitored and updated as necessary.	(IEA 2014)
National Cooling Plan	National strategy which integrates consideration of HCFC phase-out and HFC phasedown, energy efficiency and access to cooling.	(K-CEP 2019)
Implementation	The process of putting a roadmap into action, by carrying out projects and initiatives that address roadmap tasks and priorities, and by monitoring progress using a tracking system.'	(IEA 2014)
Setting a vision	The process of analysing future scenarios and identifying objectives.	(IEA 2014)
Stakeholder	Relevant individuals who have an interest in seeing the roadmap developed and implemented, such as representatives from industry, government, academia and nongovernmental organisations (NGOs).	(IEA 2014)
Solar Cooling	Technological systems using solar radiation as primary energy source to drive cooling/ refrigeration units. The main technologies are solar thermal cooling and solar PV cooling.	

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